The Nautilus Institute

for Security and Sustainability

FOUNDATIONS OF ENERGY SECURITY FOR THE DPRK:

1990-2009 ENERGY BALANCES, ENGAGEMENT OPTIONS, AND FUTURE PATHS FOR ENERGY AND ECONOMIC REDEVELOPMENT

REPORT PREPARED BY THE NAUTILUS INSTITUTE FOR SECURITY AND SUSTAINABILITY IN COLLABORATION WITH

THE KOREA ENERGY ECONOMICS INSTITUTE (KEEI)

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Executive Summary

The purpose of this report is to provide policy-makers and other interested parties with an overview of the demand for and supply of energy in the Democratic Peoples' Republic of Korea (DPRK) in six years during the last two decades:

- **1990**, just before much of the DPRK's economic and technical support from the Soviet Union was withdrawn;
- **1996**, possibly when the DPRK hit its lowest economic point in the 1990s;
- **2000**, a year that has been perceived by some observers as a period of modest economic "recovery" in the DPRK, and just before (October 2002) the nuclear confrontation re-erupted between the DPRK, the United States, and it neighbors in Northeast Asia over the DPRK's nuclear weapons development program;
- **2005**, when observers noted an upward trend in some aspects of the DPRK economy, as well as the most recent year for which any published estimates on the DPRK's energy sector and economy are available;
- **2008**, the last year in which the DPRK received heavy fuel oil from its negotiating partners in the Six-Party talks; and
- **2009**, the most recent year for which we have analyzed the DPRK's energy sector.

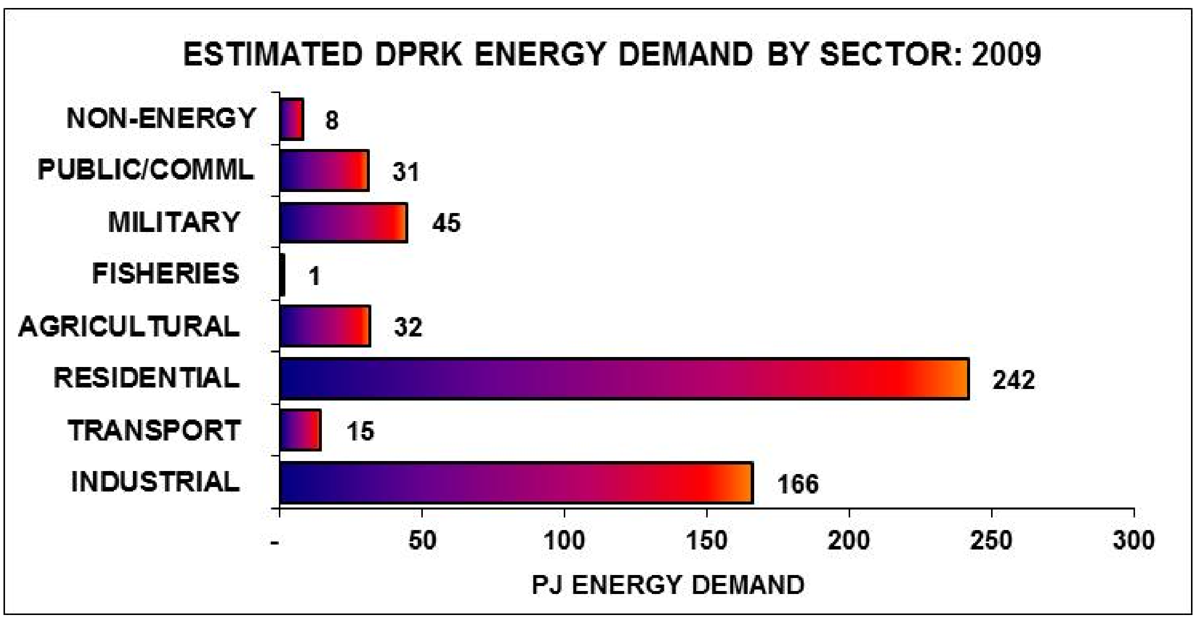
Building on previous energy balances prepared for 1990, 1996, 2000, and 2005, the authors assembled information from as many data sources as possible to try and update earlier work and to provide an estimate of year 2008 and 2009 energy supply and demand in the DPRK. Revised results of the 1990, and 1996 energy balances, and a detailed description of input parameters and assumptions used in the analytical process, are presented in Chapter 2 of the report that follows.

The estimates of year 2000 and on energy demand and supply presented here are typically somewhat lower than some estimates assembled by others, including international statistical resources and ROK estimates. The estimates described in Chapter 3 of this report include overall year 2000, 2005, 2008, and 2009 gross electricity generation of about 13.3, 16.5,17.2, and 15.8 terawatt-hours (TWh, or 15.8 billion kilowatt-hours) respectively, reflecting somewhat improved electricity sector performance in some recent years. For 2009, our estimates are that coal production was 540 million gigajoules (GJ), or about 18.5 million tonnes of coal equivalent of which a significant 17 percent (3.2 million tonnes of coal equivalent) were exported. Crude oil imports in 2009 were about 520,000 tonnes, and net refined products imports were 12 million GJ, or about 270,000 tonnes. The electricity and coal output, and oil imports, estimates for 2009 are on the order of 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, and in-country observers and forestry experts alike note the negative impact of increased wood harvesting for energy on the DPRK's forest resources and, in some areas, on soil fertility.

One major refinery continues to run in the DPRK as of 2009, and operated at a higher rate than in 2000 (and at a similar rate to operations in 2005 and 2008), but at a much lower level even than in 1996. A minor refinery also apparently operated periodically in 2000, and we assume that it continued to do so through 2009, though we have no direct recent evidence regarding this facility. Much of the electricity generation infrastructure in the DPRK continues to be in poor condition, though some rehabilitation of power plants has apparently taken place, thus our estimate is that thermal and hydroelectric power plant operable capacity (and output) are slightly higher than in 2000. Hydroelectric plants continue to be in somewhat better condition than thermal power plants, but remain at the mercy of water availability, and thus operate with relatively low capacity factors. Coal mines continue to be plagued with equipment and transport problems and, most importantly, by lack of electricity to operate mining machinery, lights, air supply, water pumps, and other crucial infrastructure, though selected coal mines have been upgraded in order to produce coal for export to China. The coal seams currently mined in many locations are becoming lower-yielding, or yield coal of lower quality, as the better deposits are mined and new seams are not opened up. In addition, many coal galleries are flooded—and may in some cases take years to pump out.

Industrial output is estimated to have declined, by 2009, to 11 to 60 percent of 1990 levels, varying substantially by subsector—export-oriented subsectors such as mining and metals show the greatest activity relative to 1990 levels. As a consequence of this decline, the share of overall energy demand contributed by the industrial sector is now second to that of the residential sector, as shown in figure ES-1, though residential demand continues to include a substantial amount of wood and other biomass estimated to be used as "substitute" fuels in the absence of sufficient or consistent supplies of coal and electricity.

Figure ES-1:



In Chapters 4 and 5 of this report, we briefly renew what is known about the DPRK's natural resource base, with Chapter 4 focusing on fossil fuels and renewable resources including forests, and Chapter 5 providing more detail on other minerals, including existing mining infrastucture and institutions in the DPRK, along with a summary of some of the key challenges facing the minerals sector. The resources described in these Chapters, plus the productive capacity of the North Korean people, provides the base on which future economic and energy development in the DPRK will be built, and must be considered in any plan for DPRK energy sector assistance. Chapter 4 also provides updated results of our brief analysis of the "energy efficiency" resource in the DPRK, in which we estimate the potential cost and resource savings from the application of several key energy efficiency options for the DPRK energy demand and supply sectors. Chapter 6 of this report presents brief sketches of several future pathways for the DPRK economy and energy sector, including a "Redevelopment" pathway, and describes some of the preconditions for and impacts on the energy sector of different paths—including the relative costs and benefits of different DPRK energy futures. Also described in Chapter 6 is 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.

Following on from the quantitative exploration of different DPRK energy futures in Chapter 6, in Chapter 7 we address the implications of a possible collapse of the DPRK's government. Although we continue to emphasize that in our view, even as the DPRK transitions to a new young leader, such a collapse is **not** likely, considering the possible implications of such a collapse provides insights into which policies by the international community are likely to be helpful in any kind of DPRK transition, whether abrupt or gradual and managed.

Chapter 8 provides suggestions on 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. Also discussed, in response to the DPRK's recent announcement of its construction and operation of a uranium enrichment facility and its plans to construct a small light water nuclear reactor, are possibilities for international cooperation with the DPRK on peaceful activities in the nuclear energy arena.

This document is intended to provide a best estimate, given available data, of an internally-consistent energy supply/demand balance for the DPRK for the most recent year that our analysis covers, 2009, as well as balances for previous years prepared with similar methodologies. In so doing, we have tried to assemble what is known, and assess what is not known, about the DPRK energy sector. As with previous reports, this analysis 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.

As this report is being finalized, discussions with regard to reviving the Six-Party Talks on the DPRK's nuclear weapons program, or of starting similar talks under a different organization, are continuing, albeit with little progress likely given the transition to new leadership in the DPRK and the elections due in 2012 in most (possibly all) of the other Six-Party Talks nations. Ultimately, however, the Parties will need to return to the bargaining table, and at that point, as in past negotiations, provision of energy security will continue to be a critical element of a successful and robust resolution to the nuclear confrontation between the DPRK and the international community.

Acknowledgements

The authors acknowledge the financial support of the United States Department of Energy and the Korea Energy Economics Institute (KEEI) for the preparation of this report, as well as the support of Korea Foundation, the Ploughshares Foundation, the MacArthur Foundation, the Iara Lee and George Gund III Foundation, and the New Land Foundation, which have funded earlier, recent, and current Nautilus research efforts related to North Korea, and the Korean Institute for Energy Research, which is funding work related to this study. We would also gratefully acknowledge the many colleagues who have provided their time and invaluable insights to assist us and guide us in the preparation of this analysis, including the participants in the 2006 and 2008 DPRK Energy Experts Working Group (EEWG) Meeting and the 2010 Energy and Minerals Experts Working Group Meeting. Some of those colleagues' names and work are cited in the pages that follow, but there are many who are not cited but who have made key contributions nonetheless. We are particularly indebted to the Preventive Defense Project for their support of the 2006 DPRK EEWG Meeting, which was held at Stanford University: see http://nautilus.org/projects/by-name/dprk-energy/2006-meeting/, and to KEEI for co-sponsoring the 2010 Meeting; see http://nautilus.org/projects/by-name/dprk-energy/2010-meeting/.

We would also like to acknowledge the input of Nautilus colleagues Ms. Lea Prince, Dr. Jungmin Kang, and Ms. Eun Kyung Park, who helped to assemble data used in this and earlier versions of this report, Mr. Tim Savage, who has provided materials for and was involved in the preparation of earlier versions of this report, and Mr. Scott Bruce, who has also provided relevant news articles and ably administered the project as a whole, and the DPRK Energy and Minerals Experts Working Group Meetings in particular. Thanks also to Mr. Roger Cavazos, for his careful review of this report. Finally, special thanks go to our KEEI colleagues for their continuing support and friendship through more than 17 years of collaboration.

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ATTACHMENT 1:

WORKPAPERS, BACKGROUND DATA, AND DETAILED RESULTS: ESTIMATED/PROJECTED ENERGY SUPPLY/DEMAND BALANCES FOR THE DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA (DPRK) AND RELATED ENERGY SECTOR AND POLLUTANT EMISSIONS ANALYSES

ATTACHMENT 2:

WORKPAPERS AND DETAILED RESULTS: ESTIMATES AND PROJECTIONS OF ANNUAL FUEL USE BY THE MILITARY SECTOR IN DPRK—UPDATE THROUGH THE YEAR 2009

1. Introduction and Background: The DPRK Energy Sector

1.1. Purpose and Goal of Report

During the decade of the 1990s, and continuing into the second decade 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, provocations, and posturing, economic collapse, transboundary air pollution, food shortages, floods, droughts, tidal waves, and, most recently the death of North Korean leader Kim Jong Il and the passing of the DPRK leadership mantle to the third generation of the Kim dynasty in Kim Jong Un—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, and have played and will play (and are playing, as of September 2012) a central role in the resolution of the ongoing confrontation between the DPRK and much of the international community over the DPRK nuclear weapons program. It is unclear as of this writing whether the Six-Party Talks process for addressing DPRK nuclear weapons and related issues, a process that have been moribund for some years, will be revitalized or will be replaced in the near or more distant future with a similar process, in all likelihood involving many or all of the same actors (and perhaps others). What is clear, however, is that energy sector issues will continue to be a key to the resolution of the crisis, as underscored by the formation of a Working Group under the Six-Party Talks that was (and nominally, still is) devoted to the issue of energy and economic assistance to 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 the various forms of energy used in the DPRK in six years during the last two decades:

- **1990**, the 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 year that has been perceived by some observers as a period of modest economic "recovery" in the DPRK, as well as a marker of the period before the start, in late 2002, of a period of renewed political conflict between the DPRK, the United States, and it neighbors in Northeast Asia over the DPRK's nuclear weapons development program; and
- **2005**, also a year in which observers have again noted an upward trend in some aspects of the DPRK economy, as well as the most recent year for which any published estimates on the DPRK's energy sector and economy are available.
- **2008**, the last year in which the DPRK received heavy fuel oil from its negotiating partners in the Six-Party talks; and
- **2009**, the most recent year for which we have analyzed the DPRK's energy sector.

Requirements for fuels to provide people with energy services—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, 2000, 2005, 2008, and 2009 for the whole of the DPRK economy on a sector-by-sector basis. This method allows a review of the energy situation in a broader context, and illuminates some of the key issues, options, and uncertainties that must be included in the consideration of energy—including electricity, coal, oil, and biomass fuels—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.

The 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 are in many cases based on earlier work, revised to take into account new information and new insights from colleagues with knowledge of and experience in DPRK energy sector issues. Some of the new information and insights used in this update were gleaned from the papers and discussions presented at the "DPRK Energy Experts Working Group Meeting", held June 26th and 27th in Palo Alto, California, USA, a second meeting of the same name held in Beijing, China, in March of 2008, and a "DPRK Energy and Minerals Experts Working Group Meeting" held also in Beijing, in September of 2010. See http://nautilus.org/projects/by-name/dprk-energy/ for information on and papers and presentations from these Meetings.

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[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 People's Republic of Korea (DPRK), Nautilus 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 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). The two most recent versions of Nautilus' DPRK energy sector analyses, and the starting points for the preparation of this document (and the analysis that underlies it), were D. Von Hippel, P. Hayes, and T. Savage, March, 2003, The DPRK Energy Sector: Estimated Year 2000 Energy Balance and Suggested Approaches to Sectoral Redevelopment, available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DPRK_Energy_2000.pdf with its companion attachments volume available as http://nautilus.org/wp-content/uploads/2012/09/DPRK_2000-ATTACHMENTS_revised.pdf and D. von Hippel and P. Hayes, June, 2007 Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths, available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/07042DPRKEnergyBalance4.pdf, with its companion attachments volume available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/07042DPRKEnergyAttachments.pdf. A large number of more recent (post-2000) Nautilus DPRK-related publications are referenced later in this report.

The discussions and text provided here are in many cases modified versions of discussions in earlier reports, but, particularly for this report, estimates of energy sector activity in earlier years (1990, 1996, 2000, and 2005) have been revised as information from colleagues and the literature have changed our understanding of both the present and the history of the DPRK energy sector. The goal of this work is to provide, to the extent that time allows, quantitative estimates of six "snapshots" of the evolution of the DPRK energy situation over the past decades. 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 Russia and China (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, prominently 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 two decades since 1990, 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, with years of modest improvement interspersed with years in which economic conditions worsen.

The DPRK is a nation of, depending on the source of the information, somewhat under 20 million to over 24 million people (as of 2010), with approximately 60 percent (though possibly less, in recent years[2]) 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 in fact probably decreased, overall, in the decade of the 1990s, with perhaps some modest growth in population since[3]. DPRK population centers, as well as the bulk of industry

[2] Anecdotal reports have suggested movement of population from some urban areas to the countryside, in part to help provide labor to bring in crops, and in part for improved access to food. Official statistics, however (see next footnote) do not reflect a significant urban-rural movement.
[3] Census data from the DPRK are notoriously unreliable, when available. An official DPRK census for the year 2008 (DPR Korea National Population Census, 2008, Central Bureau of Statistics, Pyongyang, 2009, available as

and agriculture, are concentrated in the coastal plains on both the east and particularly west coasts of the peninsula. The interior of the peninsula is generally rugged and mountainous. Political/infrastructure and topographic maps of the DPRK are provided as Figures 1.1 and 1.2.

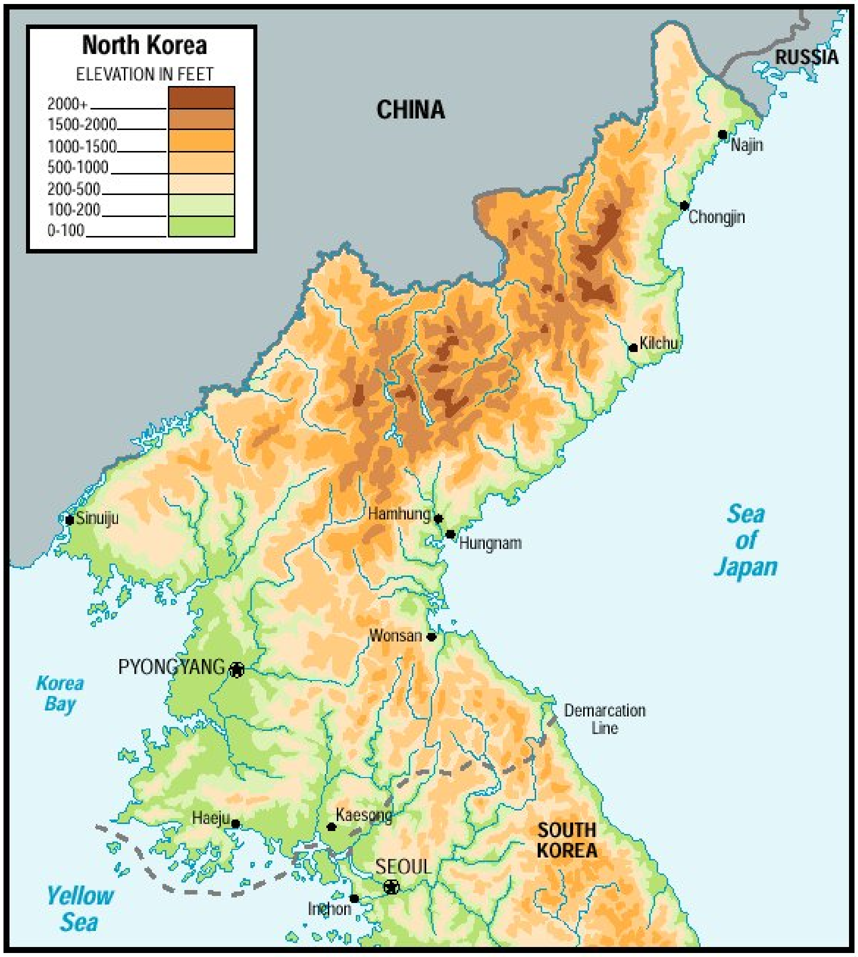
http://unstats.un.org/unsd/demographic/sources/census/2010_PHC/North_Korea/Final%20national%20census%20report.pdf) was completed under United Nations auspices in 2009, and was the first such official data made available in many years. Though comprehensive and generally accepted by researchers working on DPRK issues (in part due to a lack of better alternatives), its estimate of a total DPRK population of over 24 million in 2008 seems overstated to many, including the authors, though we have provisionally used this value and other data from the 2008 census in preparing the energy balances described in this report.

Figure 1-1: Political Map of the DPRK[2]

Map No. 4163 UNITED NATIONS
March 2001

Department of Public Information
Cartographic Section

Figure 1-2: Topographic Map of the DPRK[3]



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 death in July of 1994. 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[4]. The mantle of leadership then passed to the son of Kim Il Sung, Kim Jong Il. Upon Kim Jong Il's death on December 17, 2011[4], leadership of the nation has been passed to a third generation of the Kim family, 27- (or 28, sources differ)-year-old Kim Jong Un, supported by senior Kim family members and close advisors[5].

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[4] See, for example, BBC News Asia, "North Korean leader Kim Jong-il dies 'of heart attack'", dated December 19, 2011, and available as http://www.bbc.co.uk/news/world-asia-16239693.

[5] See, for example, Ruediger Frank (2011), The Party as the Kingmaker: The Death of Kim Jong Il and its Consequences for North Korea, Nautilus Institute NAPSNet Policy Forum, available as http://www.nautilus.org/publications/essays/napsnet/forum/Kingmaker_Ruediger.

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 accounted for about 90 percent of all economic activity in the early 1990s[5]. 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 related 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 and in markets for many DPRK-made goods.
- 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); in recent years, the DPRK government has undertaken various monetary actions with impacts on the exchange rate, including a major devaluation of the Won versus the dollar in 2006 (from 0.45 to about .006 USD per Won[6]), and a controversial "currency reform" in late 2009[6]. "Black market" exchange rates between the dollar (and other hard currencies, such as the Euro) and the Won have typically been much higher (more Won per dollar) than the official rates. Estimates of per capita GNP in 1990 ranged 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[7]. Per capita GDP has remained, at least by ROK estimates, in the range of $1000 per capita in recent years[8]. The (U.S.) CIA World Factbook lists the DPRK's 2009 GDP per capita at $1800, expressed on a purchasing power parity (PPP) basis in 2010 dollars[7].

[6] See, for example, S. Haggard and M. Noland (2010), The Winter of Their Discontent: Pyongyang Attacks the Market, Peterson Institute for International Economics Policy Brief Number PB 10-1, dated January 2010, and available as http://www.piie.com/publications/pb/pb10-01.pdf.

[7] 1990 GDP estimates for DPRK using a "purchasing power parity" measure of production and value are closer to $2000 per capita.

[8] ERINA, quoting the Bank of Korea (ROK) lists $989 (USD) estimated per capita GDP for the DPRK in 1996, $757 in 2000, and $914 in 2004 (Page 50, Chapter 5 of Northeast Asia Economic Databook 2005, dated approximately December, 2005, available as http://www.erina.or.jp/En/Lib/datab/2005pdf/05-De.pdf). The DailyNK (2012) quotes a ROK source as estimating per capita GNI (gross national income) for the DPRK in 2010 as $1074 (Park Seong Guk, DailyNK, dated 18 January 2012, and available as http://www.dailynk.com/english/read.php?cataId=nk00100&num=8696). Factoring in inflation, the GDP/GNI per capita estimates for 2004 and 2010 are nearly the same.

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 had limited trade with other Asian nations, as well as, on and off, 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[8].

1.2.2. Changes in the DPRK since 1990

The economic, if not social and political, landscape in the DPRK 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[9]. 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[10]. This economic decline has been both a result and a cause of substantial changes in energy demand and supply in North Korea over the decade of the 1990s, largely continuing to this day. Observers of the DPRK economy have suggested that at least a modest improvement took place in the years around 2000—ROK sources, for example, estimated that the DPRK economy grew approximately 6 percent in 1999, and another 1.3 percent in 2000[11]. A more recent estimate by the Bank of Korea showed the DPRK economy (as measured by GDP) growing at 0.4 percent in 2000, and by amounts varying from 1.2 to 3.8 percent annually from 2001 through 2005, followed by a period of slow decline (-0.5 to -1.2 percent/yr) in all years from 2006 through 2010 except 2008, when growth of 3.1 percent was estimated, meaning essentially zero overall growth in the DPRK economy from 2006 through 2010[12]. Other observers, however, tended to argue that most of any economic upturn in the DPRK economy in the years 2000 through 2005 appears to have been driven by food and other aid from abroad, inputs that have diminished over the last few years[9].

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[13], 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 have been a sign of reduced output in the DPRK coal industry, particularly as coal imports to North Korea from China remained near the same level (in dollar terms) from at least 1982 through the early 1990s[14].

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[9] For example N. Eberstadt (2001), If North Korea Were Really "Reforming", How Could We Tell—And What Would We Be Able To See? 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…".

- In recent years, however, the exports of coal and other raw mineral products (largely iron and steel scrap and metals ores) to China have increased dramatically, with coal exports to China reaching 2.8 million tonnes in 2005 and 4.6 million tonnes by 2010[15] [10]. This is one manifestation of a recent increase in investment in the DPRK by Chinese businesses, particularly in the raw materials sectors, but also, to some degree, in manufacturing[11].

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[12].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 years between 1995 and 2000, 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[16] by the mid-1990s. The DPRK's trade deficit as of 2000 stood at $US 856.88 million[17], remained at near one billion dollars through 2004[13], and was over one billion dollars in 2009 and 2010[18].

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[10] Figure for 2010 DPRK coal exports to China from United Nations Comtrade database, http://comtrade.un.org/db/dqBasicQuery.aspx, accessed 8/2012. Reported coal imports into China from the DPRK in 2011 were an even higher 11.2 million tonnes, more than double the 2010 value.

[11] Issues related to Chinese investment in the DPRK, and changes in DPRK policies that have made investment possible, are addressed in the Nautilus Institute Policy Forum Online 06-70A, August 23rd, 2006, "DPRK's Reform and Sino-DPRK Economic Cooperation" , by Li Dunqiu (http://nautilus.org/napsnet/napsnet-policy-forum/dprks-reform-and-sino-dprk-economic-cooperation/). See also Professor Li's presentation as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Li.ppt. Professor Li describes two "waves" of recent Chinese investment in the DPRK, with a first wave of investment led by private companies and businessmen, mainly from China's northeast provinces, and the second wave described as "mostly represented by large state-owned enterprises, in areas like heavy industry, energy, mineral [resources] and transportation".

[12] As of 1995 the DPRK's trade deficit was estimated at $879 million (United States Department of Energy's 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.)

[13] As estimated by ERINA (Economic Research Institute for Northeast Asia) in Chapter 5 of Northeast Asia Economic Databook 2005, dated approximately December, 2005. ERINA's estimates are based on data from the Korea Trade-Investment Promotion Agency (KOTRA) for trade between the DPRK and nations other than the DRPK, plus figures on trade between the Koreas from the ROK Ministry of Unification. Avalable as http://www.erina.or.jp/En/Lib/datab/2005pdf/05-De.pdf. Page 53.

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[14]. An additional blow to North Korean agricultural production was dealt 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 was factored in—were a food shortage severe enough to spur the DPRK government to take the unusual step of publicly requesting food aid from the international community. Additional floods and tidal waves in several areas of the country caused damage to agricultural areas in 2006, and left tens of thousands of residential homeless. This cycle of misery caused by flooding returned to the DPRK in the summers of 2007, 2010, and, most recently, 2011[15].

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[14] 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.

[15] See, for example, Cankor (2011), "DPRK Flood Damage Reports by KCNA", dated 8 August 2011, and available as http://vtncankor.wordpress.com/2011/08/08/dprk-flood-damage-reports-by-kcna/; and United States Central Intelligence Agency (2010), North Korea: Assessing the Impact of Flooding on Agricultural Output (U//FOUO), dated 15 December 2010, and available as http://www.fas.org/irp/cia/product/nk-flood.pdf.

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 starved in the latter half of the 1990s, and possibly in recent years as well, and that hundreds of thousands more (at least) have been and continue to be malnourished and gravely at risk. Given drops in the amount of food aid being donated to the DPRK, the World Food Programme (WFP) warned in 2002 that it was facing a shortage of 611,000 tonnes of food in 2002.[19] The United States announced in 2002 that it would donate 100,000 tonnes to help alleviate this shortage[20], and made other contributions in subsequent years. The WFP reports that significant food shortages in the DPRK continue (as of 2006/2007), and continued to appeal to the international community for additional donations, though its program in the DPRK was revised in 2006 toward a more "developmental" focus at the request of the DPRK government[16] [17]. As of 2011, the DPRK, based on assessments by the World Food Program and the United Nations Food and Agriculture Organization, remained short of food due to poor harvests and limited ability to secure food imports[18].

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[19]. 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, as did flooding in more recent years. 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.

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[16] The WFP (in "Where we work - Korea (DPR), Food Security: Overview", available as http://www.wfp.org/country_brief/indexcountry.asp?country=408) notes "The 2006 deficit is forecast by the UN Food and Agriculture Organization, WFP's sister agency, at some 800,000 metric tons (tonnes) – about 15 per cent of needs. Many of the country's 23 million people struggle to feed themselves on a diet critically deficient in protein, fats and micronutrients. Food is scarcest during the "lean season", the five-month period prior to the autumn rice and maize harvests when stocks of the previous year's crops rapidly run down."

[17] As of March, 2007, the WFP reported a DPRK food gap of "of 1 million tons, or about 20 percent of its needs", and noted that it could only fill a fraction of the DPRK's needs due to a "huge" drop in donations over the past two years (Reuters, "NORTH KOREA DESPERATE FOR AID AMID NUCLEAR WOES: U.N.", 2007-03-28, as summarized in Napsnet (Northeast Asia Peace and Security Network) Daily Report, 3/28/2007).

[18] See, for example, CHOE SANG-HUN (2011), "North Korea's Children in Need of Food Aid, Agencies Warn", New York Times, dated November 25, 2011, and available as http://www.nytimes.com/2011/11/26/world/asia/north-koreas-children-in-need-of-food-aid-agencies-warn.html?_r=1.

[19] Another way in which the food shortage likely has affected the economy is that scrap metal, some taken from industrial facilities, apparently has been (we do not know to what extent the practice continues) 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 have been 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 Russia, China, and the countries of the former East Bloc, although, as noted above, direct assistance and concessional trade from these countries (except, arguably, China) has been substantially suspended in recent years. Recent years has seen increasing investment by China in the DPRK, with investments focused on minerals extraction and similar industries. Relations with Japan, the United States, and the Republic of Korea remain tenuous, with the last decade and more 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 the early years of the 21st century, aid workers had reported growing access to areas of the country outside the capital, although still well below the desired level. In the years since 2005, however, these organizations have in many instances 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. China has also been a significant donor of food aid to the DPRK[20].
- *Talks relating to the "Agreed Framework"* (see section 1.4, below). In these talks 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, was proceeding until about 2002 (see below). As of April 2007, the Agreed Framework has unraveled completely, although both parties continued to argue that the other party was obliged to fulfill its past commitments under the Framework. At the first session of the Six-Party Energy Working Group on February 17th 2007 in Beijing, the parties began to discuss the energy dimension of a new framework based on the Six-Party September 2005 Joint Principles and the February 13th Six-Party Agreement, under which the DPRK would abandon its nuclear weapons programs in return for energy and other assistance[21]. The Six-Party Talks process, although it concluded some significant agreements, has similarly unraveled in recent years. As of early 2012, informal discussions continue on the resumption of the Six-Party Talks, but it remains unclear that the process will be revived, and what form it might take if it is revived.
- *Bilateral US-DPRK talks* that were underway during the Clinton administration have been largely stalled since George W. Bush assumed the presidency. At a visit by U.S. Assistant

[20] See, for example, the Dong-A Ilbo, "Scale of yearly Chinese unconditional aid to N.Korea unveiled", June 24, 2012, available as http://english.donga.com/srv/service.php3?biid=2012062508548.

[21] See P. Hayes, The Beijing Deal is not the Agreed Framework, Nautilus Institute Policy Forum Online 07-014A: February 14th, 2007, available at: http://www.nautilus.org/wp-content/uploads/2012/04/Beijing-Deal-is-Not-Agreed-Framework-NKR-2007.pdf

Secretary of State James A. Kelly to the DPRK in October of 2002, the United States delegation confronted the DPRK with evidence that suggested that the DPRK was pursuing a program to enrich uranium for use in nuclear weapons. This event started a period in which the provisions of the Agreed Framework were in large part, and by degrees, scuttled by both the United States and the DPRK sides, leading to the DPRK's assembly and, in late 2006 and again in May of 2009, testing of nuclear explosive devices[21]. The DPRK's motivations for improving relations with the United States include the desire 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, as well as receiving security guarantees from the United States.

- During the period from late 2002 through early 2007, a set of negotiations known as the *Six-Party Talks* between the DPRK, its neighbors (China, Japan, the ROK, and Russia), and the United States have taken place. These negotiations have been marked by periods of action and agreement interspersed with periods of relative estrangement of the parties. In February of 2007, a tentative agreement was reached between the parties, the details of which were to have been developed by the parties in a series of "working group" meetings[22].
- *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. The Kaesong (or Gaeseong) industrial park project is ongoing, with several factories set up and working in the park; a power line from the ROK to Kaesong started operation in 2005[23]. Work on the rail interconnection progressed, but a test run of the system was canceled by the DPRK in 2006[24]. Other cooperation projects between the Koreas have included meetings of relatives separated by the division of the Korean peninsula, the organization of tours to the Mount Kumgang area of the DPRK (a project that has been on hold in recent years), and periodic food, fertilizer, medical, and other humanitarian aid provision from the ROK to the DPRK[22].
- *Bilateral Japan-DPRK talks* have usually broken down over allegations that the DPRK kidnapped some 11 Japanese citizens, a charge that the DPRK denies. 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 had hoped that 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 countries had not been held since 2008, however, before a reported January 2012 meeting in China between representatives of the two countries to discuss "terms for restarting intergovernmental negotiations"[23].

[22] For example, The Telegraph, "North and South Korea talks: timeline of Pyongyang's nuclear ambitions", dated 8 February, 2011 (and available as http://www.telegraph.co.uk/news/worldnews/asia/northkorea/8310219/North-and-South-Korea-talks-timeline-of-Pyongyangs-nuclear-ambitions.html) provides a summary listing of events related to DPRK negotiations with the ROK and other parties from 2003 to early 2011, when military talks between the ROK and DPRK "to explore the possibility of re-starting negotiations were to begin.
[23] See, for example, The Japan Times Online (2012), Japan, North hold secret talks in China", dated http://www.japantimes.co.jp/text/nn20120110a5.html; and Taipei Times (2012), "North Korea, Japan hold talks: media", dated 11 January 2012, and available as http://www.taipeitimes.com/News/world/archives/2012/01/11/2003522971.

- *Talks between the DPRK and EU nations* had, as of 2002, 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, but the implementation of that role, which looked very promising as late as September of 2002, has been largely on hold since then.

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 substantial, and even possibly absolute, 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 as the economy in the Russian Far East becomes more robust.

1.3. Summary of the Overall Energy Situation in the DPRK

Overall energy use per capita in the DPRK as of 1990 was 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[24] use in the DPRK in 1990 was approximately 70 GJ per capita, approximately three 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. Much more detailed reviews/estimates of energy demand and supply in the DPRK in 1990, 1996, 2000, 2005, 2008, and 2009 are provided in later chapters of 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, though more recently, reportedly, in urban and peri-urban areas as well) 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 fuels supplies in the DPRK than they do in industrialized countries, due primarily to the

[24] 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.

minimal development of the commercial sector in North Korea. Wood and 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 (and visibly, to visitors to the country) 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 (and some observers report that some public-sector and residential buildings have not received heat at all in recent years) 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. (This is a further argument, as elaborated later in this report, for making every effort to improve the efficiency of energy use in all sectors of the DPRK economy as restraints on energy supplies are reduced.)

- *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. Recent years have seen limited attempts by the DPRK government to reform markets for energy products, some private markets exist for local products like firewood, and some commercial fuels have in recent years reportedly been traded "unofficially" (on the black market), but for the most part, energy commodity markets in the DPRK essentially do not exist[25]. 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, even when and if such technologies are made available.

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

[25] In his paper and presentation "Changes In The North Korean Economy And Implications For The Energy Sector: Is North Korea Really Short of Energy?", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, William B. Brown discusses the state of DPRK energy markets, and notes that by one measure of electricity cost, the ratio of the price of rice to the price of a kilowatt-hour of electricity, power was one hundred times as expensive in the United States in 2006 than it was in the DPRK. See http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Brown.ppt and

area. There is little, if any, coal cleaning (washing and sifting of coal to remove impurities such as sulfur and ash) in the DPRK. There have been reports of some operating oil wells in North Korea, with production starting around 2000, but these reports are far from fully substantiated. Modest oil resources reportedly have been located offshore in DPRK waters, and have been the subject of reported agreements between the DPRK and, variously, other countries and foreign companies. 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 from 2000 through 2012), 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, simple, 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 end use in the DPRK in 1990 was about 1,500 kWh per capita. By comparison, overall 1990 electricity demand in South Korea was about 2,200 kWh per capita[25]. Per capita electricity consumption in the DPRK has declined very substantially since, due largely to reduced availability of power, though also as a results of reduced economic activity. 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 as of 1990 was 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[26]. 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. Since 1990, the ratios of hydro to "thermal" power production have varied from year to year, for reasons described in the Chapters that follow.

The DPRK has the coal resources necessary to expand thermal power generation, but it is 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 sub region, North Korea probably has a significant wind power resource, as yet untapped (and largely unmapped), but it is far from equally distributed throughout the nation, with average winds in many of the most populous onshore areas (including the western coastal plains) being relatively light. 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

[26] 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.

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[27].

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 of 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[28].

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 (as of 1990) were classified as forests, and about 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[29, 26], observers have noted a host of environmental problems in DPRK. Among these problems are:

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[27] That is, for the most part, even as of 2006, power is reportedly simply provided to consumers without metering, so "sales records" as such do not exist.

[28] Additional discussion of the environmental situation in the DPRK can be found, for example, 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; and in P. Hayes (2009), "Unbearable legacies: The Politics of Environmental Degradation in North Korea", Global Asia, Volume 4, Number 2, dated June 2009, and available as http://globalasia.org/Current_Issues/V4N2_2009/Peter_Hayes.html.

[29] 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".

- 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[30];
- Indoor air pollution from domestic combustion of coal and biomass fuels;
- Pollution of surface- and groundwater from agricultural practices (fertilizer and pesticide application, irrigation) and from insufficient sewage treatment systems;
- 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 addition, DPRK environmental laws, while in principle stringent and well-intended, lack the specificity needed to be easily implemented or enforced. 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 EU, the United Nations, or others).

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

The floods of 1995 and 1996, 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 was lacking for the excavation machinery and other equipment needed to rehabilitate paddy land and restore irrigation systems[27]. It seems likely (though as yet only conjecture) that the sediments deposited by the 1997 and subsequent 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 otherwise 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[31] are also likely to have a long-term impact on forests and on other vegetation. Lack of agricultural products has reportedly sent North Koreans to foraging intensively for edible and semi-edible wild plants.

[30] This problem has been notably reduced in recent years with the considerable reduction in industrial activity and overall energy use in the DPRK.
[31] There is some evidence that the food shortages of more recent years are in large part a result of structural problems in the DPRK agricultural sector that date back to 1990 or before.

There have been reports from the late 1990s through the present day (2012) of people eating preparations made from bark stripped from trees, though visitors to the DPRK suggest that bark use for food was not common in the mid-2000s, at least. Stripping of bark from trees is 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. References to consumption of "grass porridge" or "grass meal" as a food of last resort also have appeared frequently in anecdotal reports of life in the DPRK over the past decade and more[32]. 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 the middle year of the decade from 2000 to 2010, the DPRK's agricultural situation showed some signs of improvement. The World Food Programme and the Food and Agriculture Organization reported that the DPRK produced 3.54 million metric tonnes 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 tonnes of rice (milled basis), 1.4 million tonnes of corn, and 100,000 tonnes of wheat. That left the DPRK with an estimated food deficit for 2001-2002 of around 1.47 million metric tonnes, down from 2.2 million tonnes a year earlier[28]. 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. Improved harvests in recent years have reduced the DPRK's food deficit, and food donations from ROK increased for a time[33], but WFP/FAO estimates (see above) still projected a substantial DPRK food deficit in 2006, continuing through.

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[34]" 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 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[35].

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[32] See, for example, Good Friends: Research Institute For North Korean Society (2011), "North Korea Today No. 411", dated July 13, 2011, and available as http://goodfriendsusa.blogspot.com/2011/07/north-korea-today-no-411-july-13-2011.html. Though such anecdotal reports are certainly not systematic surveys, and may to some degree reflect the bias of the reporting organization, they may offer an indication of ongoing problems, if not a definitive statement of their extent or severity nationwide.

[33] ROK food donations to the DPRK in 2006 reportedly declined substantially from previous years.

[34] 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.

[35] 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.

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[36], and at least one fairly new large diesel-type generator was reported installed in an industrial setting around 2000. 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 in the years since 1990, though there have been reports of some modest energy technology imports recently) has resulted in an energy sector that is notably inefficient.

The North Korean workforce is literate, disciplined, and hard-working; these attributes were 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[29]) 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 15 percent) of the potentially economically-active males is in the armed forces of the DPRK[37]. The duration of mandatory military service for men is reportedly up to ten years. Although soldiers

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[36] Diesel generators were reportedly often incorporated into industrial plants built with USSR assistance in order to provide back-up power. It is likely that some newer generators have also come into use in recent years, particularly in, for example, military installations which reportedly build in more redundancy than other facilities, and in buildings and industrial plants serving organizations and markets from outside the DPRK.

[37] This rough estimate assumes a standing army of about 1 million men and a total of about 7.5 million men in the 18 to 65 age group, the latter from the DPRK's official 2008 Census. Estimates of the size of the army vary. Wikipedia, in its listing of the sizes of the world's armies ("List of countries by number of troops", available as http://en.wikipedia.org/wiki/List_of_countries_by_number_of_troops), puts the DPRK military at 1.1 million troops, which at 48.8 troops per 1000 people in the country, gives the DPRK more soldiers per capita than any other country by a factor of two, with the runner-up being Israel. At 1.1 million troops, the DPRK military is among the top five largest armies. Recent estimates based on the 2008 DPRK Census have suggested that the armed forces might be slightly smaller. The Hankyorreh ("[North Korea Census 2008] Korean People's Army estimated to number 700 thousand troops", dated 19 March, 2010, and available as http://english.hani.co.kr/arti/english_edition/e_northkorea/411106.html) suggests "..while a precise determination is impossible, it can be estimated that the scale of the Korean People's Army is 702,372 troops plus some additional, unspecified number. This differs markedly from South Korean Ministry of National Defense estimates, which put the size of North Korea's regular army at 1.19 million people as of December 2008. In view of the fact that 27 percent of enlisted men in the South Korean military as of 2008 were non-commissioned and commissioned officers with addresses outside their bases, analysts say there are grounds for viewing the Defense Ministry's estimates on the scale of the North Korean army as inflated."

often 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 five to seven—depending on the estimate—million reservists in undergoing military training) undoubtedly acts as a drain on the overall DPRK economy[38].

In the years since about mid-2002, the DPRK's government has initiated several economic reforms leading to currency devaluation, wage, and (for some commodities) price reforms, and the limited recognition (and later, suppression) of private markets. These reforms have at times to some degree improved the availability of some commodities, but have also resulted in economic dislocation, as prices for commodities such as rice and other cereals have risen to the point where a worker's official monthly salary will buy only a few kilograms of basic foodstuffs, and as the general food distribution system, which formerly provided much of the food needs of residents, has ceased to operate in many areas of the country. DPRK delegations to meetings outside the DPRK have expressed the desire to obtain training on market creation and operation, and noted the government's commitment to proceeding with economic reforms, but much remains to be done in these areas.

The process of DPRK economic reform, according to observers, is complex and not in a single direction, as internal struggles between DPRK officials who want to reform the economy, and those that want to maintain state control of markets, result in liberalization of some markets at times, but moves toward tighter control of other markets at other times. Overall, the direction of change during the middle years of the 2000s was toward market liberalization, but not all changes in DPRK economic policy implemented in recent years have been in that direction—some have been quite the opposite.

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 was to be supplied with two pressurized-water-type light-water nuclear reactors for electricity generation (referred to as PWRs or LWRs) in exchange for abandoning its existing graphite-moderated nuclear research reactors and taking further steps to comply with nuclear safeguards. Work at the reactor site (at Kumho, near the Sea of Japan/East Sea of Korea port city of Sinpo in the DPRK) began in August of 1997[30]. Under the agreement, until the reactors were completed the Korean Peninsula Energy Development Organization (KEDO) had 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) thereafter totaled the agreed annual amount until December 2002, when deliveries were suspended[31]. The oil provided by KEDO was 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 was from the Korean Peninsula

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

Energy Development Organization (KEDO), formed in the mid-1990s, which obtained 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[39]. Following the erosion of relations between the United States and the DPRK in late 2002, and the DPRK's subsequent withdrawal, in January 2003, from the international Treaty on the Non-Proliferation of Nuclear Weapons (NPT), and its related re-starting of previously frozen nuclear facilities, KEDO suspended construction on the PWR project. The project was formally terminated in mid-2006, and KEDO was disbanded.

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[32], energy efficiency measures are not, or at least, to date, have not been, politically substitutable for the PWR transfer[40]. The PWR transfer—or some similar arrangement—has been considered 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. A possible (as of 2012) revival of the Six-Party talks (or a similar process) may offer a way of achieving an end to the DPRK's nuclear weapons program without the (eventual) construction of a PWR in the DPRK, but it is not yet clear whether other combinations of energy assistance will be considered by the DPRK leadership to be an adequate substitute for the modern nuclear power reactors promised under previous agreements. The DPRK's announced and apparently ongoing construction of their own, small, domestic LWR, and its recently (2010) revealed uranium enrichment facility, have further complicated nuclear discussions with other parties, but may offer additional opportunities as well[41].

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 revised 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.

[39] 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).

[40] 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://nautilus.org/wp-content/uploads/2011/12/ModernizingAF.pdf.

[41] See, for example, Siegfried S. Hecker (2010), A Return Trip to North Korea's Yongbyon Nuclear Complex. NAPSNet Special Report, dated November 22, 2010, and available http://nautilus.org/napsnet/napsnet-special-reports/a-return-trip-to-north-koreas-yongbyon-nuclear-complex/; Peter Hayes (2010), DPRK Enriched Uranium Highlights Need for New US DPRK Policy, dated November 22, 2010, and available as http://nautilus.org/napsnet/napsnet-policy-forum/dprk-enriched-uranium-highlights-need-for-new-us-dprk-policy/; and D. von Hippel and P. Hayes (2010), Engaging The DPRK Enrichment and Small LWR Program: What Would It Take?, NAPSNet Special Report, dated December 23, 2010, and available as http://www.nautilus.org/publications/essays/napsnet/reports/vonHippelHayesLWR.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 years 2000, 2005, 2008, and 2009. Estimates for the years 2000 and 2005, like those for 1990 and 1996, are as revised from previous analyses based on input from colleagues and from new sources of information. Estimates for the years 2008 and 2009 are also based on our research, and include information from colleagues attending the June, 2006 and March, 2008 DPRK Energy Experts Working Group Meetings, as well as the September 2010 DPRK Energy and Minerals Experts Working Group Meeting and many other sources.
- In **Chapter 4** of this report, we briefly renew what is known about the DPRK's natural resource base, focusing on fossil fuels and renewable resources including forests. Chapter 4 also provides updated results of our brief analysis of the "energy efficiency" resource in the DPRK, in which we presernt our revised estimates of the potential cost and resource savings from the application of several key energy efficiency options for the DPRK energy demand and supply sectors.
- **Chapter 5** extends the description of the DPRK's resource endowment and related infrastructure by providing detail on what is known about the status of the non-energy minerals sector, including existing mining infrastucture and institutions in the DPRK, along with a summary of some of the key challenges facing the minerals sector. The resource picture described in Chapters 4 and 5, plus the capacity of the North Korean people, constitutes a key feature of the base on which future economic and energy development in the DPRK will be built, and must be considered in any plan for DPRK energy sector assistance.
- In **Chapter 6** of this report, we present a brief sketch of our work-in-progress in revising analysis 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 6 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.
- Following on from the quantitative exploration of different DPRK energy futures in Chapter 6, in **Chapter 7** we address the implications of a possible collapse of the DPRK's government Although we continue to emphasize that in our view, even as the DPRK transitions to a new young leader, such a collapse is **not** likely, considering the possible implications of such a collapse provides insights into which policies by the international community are likely to be helpful in any kind of DPRK transition, whether abrupt or gradual and managed.
- In **Chapter 8** of this report, we conclude by providing 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. As such, Chapter 8 provides suggestions on 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. Also discussed, in response to the DPRK's recent announcement of its construction and operation of a uranium enrichment facility and its plans to construct a small light water nuclear reactor, are possibilities for international cooperation with the DPRK on peaceful activities in the nuclear energy arena.

- **Attachments** to this report present detailed results of the estimates of DPRK supply and demand in 1990, 1996, 2000, 2005, 2008, and 2009, and present details on the data, assumptions, and analytical approach used in preparing those energy balance estimates. The attachments volume also presents details of our estimates of the potential costs and savings associated with the implementation of energy efficiency and related measures in the DPRK, of our estimates of key pollutant emissions (acid gases and greenhouse gases) in the DPRK in each of the years for which energy balances have been estimated, other analyses related to DPRK energy infrastructure.

2. Estimated 1990 and 1996 Supply/Demand Energy Balances

As a backdrop to the cooperation strategies and other recommendations discussed in Chapter 8 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, including electricity generation, transmission, and distribution, 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 pose 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. The approach used to prepare the 1996 energy balances, that is, to update the 1990 balance based on reported or inferred changes in the energy sector between 1990 and 1996, is the same general approach used to prepare energy balances for subsequent years (2000, 2005, 2008, and 2009), as presented in Chapter 3. This Chapter therefore describes the basic approach to preparing energy balances in subsequent years, thus the data and results presented in Chapter 3 are incremental to the data and results presented here, focusing on changes between the years covered.

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, implementation of renewable energy sources, or, in the case of the DPRK substantial energy sector redevelopment, 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 the W. Alton Jones Foundation, which culminated in a 1995 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[42]" for the DPRK for 2000 and 2005. Our 2002/2003 report, The DPRK Energy Sector: Estimated Year 2000 Energy Balance and Suggested Approaches to Sectoral Redevelopment, prepared with funding from and in collaboration with the Korea Energy Economics Institute, updated our analysis to a 2000 "base year", and our 2007 report, Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths, provided a further update to a 2005 base year.

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 (or were similar at some time in the relatively recent past). This process included collection of energy sector intensity data from the international literature[43] 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

[42] Nautilus typically uses the term "scenario" to refer to fictional, typically qualitative narrative "snapshots" of what the future might hold based on uncertainty in key parameters (see, for example, A Korean Krakatoa? Scenarios for the Peaceful Resolution of the North Korean Nuclear Crisis, Nautilus Institute, dated August 2003, and available, as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DPRKscenarios20033.pdf), 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 would be referred to as energy paths, but at the time we referred to them as "scenarios". In this report, which focuses on quantitative results in looking at future possibilities for the DPRK energy sector, we tend to use the terms "path" and "scenario" interchangeably.
[43] In particular, the Energy Analysis Program at Lawrence Berkeley Laboratory, Berkeley, California, USA.

was available, so analogous and "placeholder" data from other countries, usually China or the former Soviet Union, were often used.

The detailed inputs to and results of our 1995 work are presented in the 1995 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, 2005, 2008, and 2009 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[44]. 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[45]. In addition, the North Korean government is loath to provide data to outsiders[46]. 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 "fit" 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. Moreover, as the balance is built up from many independent observations, estimates, and assumptions, we feel that the probability is reduced that any one off-base assumption or erroneous piece of data has considerably altered the overall accuracy of the assessment.

It should be noted that other estimates of DPRK energy supply demand balances have been developed over the years, and we have consulted those estimates available to us, and in some cases, collaborated with other researchers developing balances. Notable among other estimates of DPRK energy balances are those developed by our colleagues at the Korea Energy

[44] 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.

[45] 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 had 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 or industrial 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. It should be noted that some observers, however, feel that the trend toward exaggeration of statistics in the DPRK has changed somewhat in recent years (for example, since 2000), and that the few official DPRK statistics that are made available to outsiders are, in fact, now relatively reliable.

[46] This applies especially to those from outside DPRK, but probably applies to the internal sharing of information, for example, between government organizations, as well. Many countries, however, share this trait to varying degrees.

Economics Institute (KEEI), as described in a presentation to the 2006 DPRK Energy Experts Working Group Meeting by Dr. Kyung-Sool Kim of KEEI[33]. The International Energy Agency (IEA) also maintains some energy statistics, including an estimated energy balance, for the DPRK[47].

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 footnotes, bibliography, and/or attachments volume 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.
   - Official statistics provided by the DPRK government.
   - Historical documents on energy use in the ROK.
   - News reports from around the world related to the DPRK's economy and/or energy system.
   - Other documentation from the authors' files, and personal conversations and correspondence with others interested and conversant 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[48] 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.

[47] The IEA's most recent (2009) energy balance for the DPRK, for example, is available as http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=KP
[48] In particular, the Energy Analysis Program at Lawrence Berkeley Laboratory, Berkeley, California, USA.

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 was (as of 1994/95) sufficiently recent to pertain to current conditions, but sufficiently far in the past that we could expect to find relatively complete energy and economic statistics. Second, 1990 represented a watershed year for the DPRK economy, in that after 1990[49] 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.

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)", an updated version of which is printed out 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 Attachments for additional information, details on data and assumptions used, 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[34]. A version of this analysis updated to 2009 is presented briefly in Chapter 4 of this Report.

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.

[49] Some observers, in fact, argue that 1989 was the peak year for the DPRK economy and energy sector, and that spending on public works (for example, venues for the 13th World Festival for Youth and Students, held in Pyongyang in July of that year—see, for example, "Photos Highlight 50-Year State History-On Occasion of Golden Jubilee of DPRK", at http://www1.korea-np.co.jp/pk/058th_issue/dprk50thann/98090201.htm) helped to begin the downward slide of the DPRK economy, which accelerated when the Soviet Union/Russia began withdrawing economic support for the DPRK. It has been argued that the DPRK's spending in hosting the Youth Festival reduced needed investment in other key sectors (including the energy sector), contributing substantially to an economic decline that started in 1990. See "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.

- 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 by the DPRK, and reportedly exported to North Korea by the DPRK's trading partners, 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 in 1996 by KEDO.

In updating our 1990 energy balance to 1996, as well as in subsequent research, 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 industrial goods all played roles.
- A reduction in transport generally, and a reduction in the use of oil products in the transport and agricultural sectors, with biomass and human and/or animal labor 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[50]. 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 cases we were able to use historical energy intensities from the Soviet Union as provided by a colleague in Russia[51].

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.

[50] 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 rates 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 (until recently, and even now limited to only selected classes of goods), 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).

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

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 selected subsectors are provided below.

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	Fuel Use Intensity (tce/Unit)*	Electricity Use Intensity (kWh/Unit)*
Iron and Steel	te crude steel	1.85	805
Cement	te clinker	0.235	110
---Fraction of input fuel as coal		90%	
Fertilizers--Ammonium	te NH_3	1.71	5,760
---Additional Heavy Oil and Naptha used as Feedstock		0.55	
Fertilizers--Superphosphate	te P_2O_5	9.71	16,258
Other Chemicals--Carbide	te Ca Carbide	0.82	4,571
Other Chemicals--Caustic Soda	te	0.96	2,413
Pulp and Paper**	te pulp	0.89	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	2.39	
Textiles--Printing and Dyeing	running meter	4.39E-04	
Textiles--Vinalon fiber	te	6.032	5,400

* 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. Fuel is coal except as noted.

** Assumes that half of non-electric fuel use for paper production is provided by mill wastes and other wood by-products (but fuel use intensity shown includes both use of wood and coal).

*** 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, before application of the "Intensity Inflator" described in Table 2-1)[35]. By way of comparison, intensities in "key, medium and small plants" in China as of 1987[36] were somewhat higher (890 kWh/tonne).

For the *Cement* industry, after reviewing available estimates, we have concluded that the official output figures (13.9 million tonnes) from the National Report of DPRK to UNCED (dated 1992), may be somewhat overstated, and thus use a somewhat lower estimate of output (11 million tonnes) for 1990. This is generally consistent with the report by dprkguidebook.org that "[t]he country's overall cement industry is made of a total of 30 plants and has a total capacity of about 12 Mt/yr."[37] We use a DPRK-specific coal-use intensity that is slightly higher than energy intensities for Chinese plants[38], 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[52]. 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[39]. 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[53]. We have assumed that essentially most of the nitrogen fertilizer is based on ammonia produced via the DPRK-specific industrial process outlined (by a DPRK official)[40] 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[54]. 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. Also categorized as non-energy use are inputs of heavy oil and of naptha (a light hydrocarbon product) to fertilizer manufacture, as a recent source indicates that key DPRK fertilizer factories make use of these feedstocks[41]. Another major facility for production of both fertilizer and chemicals/plastics is the Namhŭng Youth Chemical Complex, located near Anju, in South P'yŏng'an Province. This complex, reportedly built in 1976 with Japanese, French, and West German equipment, has a total capacity of 550,000 tonnes/yr (all outputs), including 400,000 tonnes of Urea and 20,000 tonnes of synthetic fibers and resins (Orlon, polyethylene, and others). It uses electricity from the nearby Ch'ŏngch'ŏn River Thermoelectric Power Plant. The plant is reported to have added equipment

[52] 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.
[53] We have thus assumed that the DPRK produced about 500,000 tonnes (as N) of nitrogenous fertilizers).
[54] The electricity intensity of urea manufacture in China, for example, appears to be two orders of magnitude less than that for ammonia.

in 2000 to produce sodium carbonate, and "…has a French-built polyethylene production facility that uses intermediates of propylene and butane. There is also equipment imported from Japan that is used to produce ethylene, ethylene oxide, and ethylene glycol.[55]" Figure 2-1 provides a photo of another major fertilizer complex, at Hungnam

Figure 2-1: Photo of Hungnam Fertilizer Complex, South Hamgyong Province[56]

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

[55] From the Nuclear Threat Initiative (NTI, 2011), "Namhŭng Youth Chemical Complex", prepared for NTI by the James Martin Center for Nonproliferation Studies at the Monterey Institute of International Studies, available as http://www.nti.org/facilities/609/.

[56] Photo from dprkguidebook.org (date not provided, but probably 2006 or 2007), "Main Industrial Sectors & Business Opportunities", available as http://dprkguidebook.org/contents_3.htm.

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).

It has been reported (by DPRK officials[42]) 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[43] were coupled with coal and electric energy intensities from Chinese data, and include a working assumption that 50 percent of the (non-electric) fuel energy needed required to produce pulp and paper is provided 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 of the metals found or produced in the DPRK. 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 have been 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[44]. For magnesite, we used a reported estimate for the intensity of heavy fuel oil use in DPRK magnesite refining[57], 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

[57] 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.

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[45].

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 in the DPRK in 1990 were similar to per-capita production in China in the same year. 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[58].

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 15, 13, and 15 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	35%
Cement	40%
---- fraction of heat from heavy oil	10%
Fertilizers	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	33%
Non-Specified Industry--diesel oil	20%
Non-Specified Industry--heavy oil	30%

[58] 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).

For the steel and cement subsectors, we assumed production in 1996 of 2.1 and 4.4 million tonnes, respectively, or somewhat lower than 1992 production estimates from ROK sources[46]. We assume that fertilizer production decreased to less than 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 30 percent of 1990 levels. Production in most other industrial subsectors is also 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[59]. 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, and factoring in the probable lower average efficiency of DPRK industrial equipment in 1996 relative to 1990, due to greater difficulties in obtaining spare parts and other maintenance supplies.

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 1,200 average passenger kilometers traveled per year in 1990 in motorized transport by the roughly two-thirds of the population that is "economically active". This translates to about 800 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[47]).

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 (as estimated by the Korea Foreign Trade Association[48]), but had to guess at an average transport distance of 75 kilometers. Another assumption was that about 24 percent of the freight transport occurred in diesel trucks, somewhat under 5 percent (probably mostly in rural locations) in trucks fitted with biomass gasifiers, 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[49]; and 2) the probability that a great deal of freight as of 1990 was 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

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[59] 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 years earlier (Chosun Ilbo, "POSSIBILITY OF COUP IN DPRK: HONG KONG MAGAZINE", 06/19/97).

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 8,500 km per year (fairly low for an auto in an industrialized 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 public passenger transport is by road[50], and that 50 percent of this (bus) transport is in diesel vehicles. We adapted energy intensity estimates 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[51]. For freight transport, we began with an estimate of 169 million tonnes of freight carried by rail[52], but were forced again to make a guess as to the average distance (300 km for electric rail, 250 km for diesel rail) 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 motorized public passenger transport not provided in road vehicles was assumed to take place in trains (or trams), 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[53]. 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[54], 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[60], 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-engine 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[55], which we assume were used about 750 hours per year. For both the jets and non-jets, the

[60] 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.

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 flew into and out of the DPRK as of 1990 provided all of their own fuel. Thus, the DPRK made 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 possible use of fuels in this group. For 1990, we have used placeholder values of 1.0 million and 0.6 million GJ of petroleum products and electricity, respectively, in this category.

Our estimates of energy use in the transport sector in 1990 currently includes no coal consumption, although coal may have been used to a limited extent as a fuel on some isolated railways, in older ships, and/or in trucks powered by gasifiers. 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[56]. We assume that these vehicles convert biomass (or biomass charcoal) to "producer gas" (a gas produced by pyrolysis—a process of partial combustion—of biomass or other fuels) for use in internal combustion engines[61], although it is possible that some vehicles are steam-driven. We assume that the overall efficiencies of biomass-fueled trucks are on average about 50 percent of the efficiency of their gasoline-driven analogs.

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 7.6 percent of road freight in 1996, up from an assumed 4.6 percent in 1990, and the fraction of freight carried in diesel trucks was assumed to decrease modestly, to about 20 percent of the total. Energy intensities for all gasoline- and diesel-fueled trucks, and buses were assumed to be 10 percent higher than in 1990, reflecting poorer fuel economy caused mostly by poorer maintenance (due to lack of parts and lubricants, for example) and a generally aging stock of vehicles. The energy intensity for cars was assumed to be 5 percent higher than in 1990.

- Electric Rail, Water Freight—down to 40 of 1990 values in 1996. Diesel rail freight also declines to 40 percent of 1990 values.

- Road, Rail Passenger (except civilian auto)—down to about 44 percent (though nearly 60 percent for travel in gasoline buses, reflecting the assumption that more smaller buses, for example, minibuses and vans, were in use in 1996) of 1990 values 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 so much in other

[61] A photo of a gasifier-powered truck appears at the end of this Chapter.

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 22 million people in the DPRK as of 1990 (excluding the 1.2 million persons in active units of the military) lived in urban areas[57], and that the average number of persons per household in both urban and rural households was 4.65 in 1990[62].

For the *Urban* subsector, we assumed, based on the observations of recent visitors to the DPRK (including the authors), that the average urban household lives in a multi-story building in an apartment of approximately 50 square meters[63]. We further assumed that the vast majority of these buildings are at least nominally heated using coal-fired boilers supplying hot water or steam to the apartments in the building, although some buildings use district heating systems that use steam provided from power plants, central district heating boilers (often, as in Pyongyang, co-located with power plants), and industrial cogeneration. Based on a series of very rough estimates (see Attachment 1) we estimate that somewhat under 9 percent of urban households used district heat (from both dedicated central district heat boilers and central combined heat and power systems as of 1990. For urban households using coal-fired heating systems, meaning either boilers in their buildings supplying heat to all (or many) apartments, or coal stoves in individual dwelling units, for 1990 we applied an average figure of 30 kg coal equivalent/m^2 from Chinese data, increased by 20 percent to take into account the colder (on average) climate in the DPRK, to derive an average household use of 2.2 tonnes of coal per year, or about 53 GJ/household-yr. We further assumed an average electricity use of about 770 kWh per household (HH)-year in 1990. This is about 2.4 times the average household use of electricity in South Korea in 1975[58], 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 in 1990 petroleum-based cooking fuels (liquefied petroleum gas, or LPG, and kerosene) were used exclusively in Pyongyang, but were not used extensively elsewhere[59]. Usage of these fuels per household was assumed to be about 9.3 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 16 percent of urban households used charcoal for cooking, mostly for specialty foods, at a rate of 150 kg/HH-yr. This assumption produces a charcoal demand consistent with the charcoal production we estimate (see section 2.3.4). All other urban cooking is assumed to be provided by coal or (much

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[62] 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, based on the authors' own observations in the Western DPRK village of Unhari in 1998.

[63] 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.

more rarely) electricity, with cooking use of those fuels subsumed in the overall coal and electricity use figures cited earlier.

For *Rural* 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 in 1990 50 percent of rural households used coal for heating and cooking, 2 percent used 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 growth averaging a small 0.08 percent annually through 2000[64].
- The fraction of the population living in urban areas increases slightly, to about 60.3 percent in 1996. 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, at least through 1996, were slightly more than balanced by rural to urban migration, greater net population growth in urban areas than in rural areas or other demographic shifts.
- Through a combination of austerity and fuel unavailability, that residential end-uses of coal declined to 75 and 60 percent of 1990 values in the urban and rural subsectors, respectively, while the fraction of households using coal for heating and cooking declined to about 82 percent in urban areas and 38 percent in rural areas, offset in part by increased use of biomass fuels. Urban use of electricity and heat per household is estimated to have declined to 57.5 percent of 1990 levels in 1996, with rural electricity use declining to about 45 percent of 1990 levels (due to relatively lower availability of electricity in rural areas). Rural biomass use per household is assumed to decrease by about 10 percent relative to 1990, as the greater number of households using biomass fuels due to reduced availability of coal is more than offset by a combination of the impacts of tighter supplies of firewood and reduced levels of cooking and heating in households. The use of charcoal is assumed to decline to 75 percent of 1990 levels, and the use of kerosene and LPG in urban and rural homes decrease to about

[64] 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 listed 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-1990 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 KEEI as the year 2000 population. This implies a very modest net total increase 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, offsetting the impacts of a national government program to increase the population.

47 and 50 percent, respectively, of their 1990 levels as a result (primarily) of reduced fuel availability[65]. The fraction of homes using these fuels is assumed to have declined slightly from 1990 levels as well.

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[60]. 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 in 1990, we applied a Chinese figure for annual fuel consumption of 41 liters of diesel oil per hectare (ha) farmed[61] 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[62]; 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 tractor-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, even as of 1990.

Electricity use in field machinery was estimated using a Chinese value of 126 kWh/ha-yr[63]. 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[64]) 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 were doubtless somewhat (though probably not vastly) different in China than in the DPRK, as were agricultural practices and agricultural yields, both of which would affect the energy used in processing crops.

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* (about 438,000 tonnes, and 360,000 horsepower[65]), 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 horsepower-hour.

[65] We assume that availability of LPG and kerosene for cooking would be more limited in rural areas than in urban areas, hence the smaller percentage of rural households that are assumed to use oil fuels. 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, particularly in rural areas, in the evening hours.

We assumed that 85 percent of the DPRK fishing fleet was in service, and that those ships spent an average of 200 days at sea, were underway an average of 12 hours per day, and operated at an average of 50 percent of full power when underway. 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 prepared estimates based on a report as to the number of fishing collectives and the number and size (on average) of motorized boats used by each collective[66]. We assumed the same average of 200 days per year, 12 hours per day of operation assumed for larger ships, but assumed that only 75 percent of boats were in operation in 1990, and that average power use was 25 percent of full power.

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 used.

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

We assumed no significant change in the area cropped between 1990 and 1996, but that the electricity use in field operations 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 first half of the 1990s. For coal, electricity, and biomass used in crop processing, we assumed that these would decrease with the amount of crops harvested, with cereal crop harvest estimates as the metric to calculate a ratio of output in 1996 versus 1990. We also assumed that per-unit crop use of these fuels would be 90 percent of 1990 levels, due to fuel shortages, lack of spare parts for key equipment, and other factors. In the fisheries sector, we assume that 1996 fishing effort (as reflected in fuels use in fishing) was approximately 30 percent of 1990 effort, and that the mechanized processing of fisheries products was 45 percent of 1990 levels, consistent with reports of a recent sizable reduction in marine products output[66].

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 (which we define to include institutional buildings such as nurseries, schools, and hospitals) in the DPRK. To provide a "ballpark" (approximate) 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[67]. We then applied coal use intensities (from the same source) to this total. To estimate electricity use, we derived an annual electricity use intensity of 33 kWh/m^2, derived from Chinese data (but about 10 percent higher to account for cooler average temperatures), 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

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

7 million GJ/yr for other uses of electricity in the public/commercial sector. We assumed that 15 percent of public/commercial floorspace in 1990 was heated using district heating systems, and that public and commercial sector buildings used wood and biomass fuels in 1990 in an amount equal to 5 percent of their use of coal (on an energy-content basis). We assumed that oil use in the public/commercial sector was modest in 1990, at 0.3 percent of coal use, with 90 percent of oil use in the sector in 1990 being kerosene, and the rest LPG. Our estimate of energy use in the public and commercial sector in the DPRK might be improved by collecting and applying intensity figures representative of Soviet-style construction.

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 have remained constant at 1990 levels through 1996, but that coal consumption per unit floor space decreased to 75 percent of 1996 levels, and electricity use per unit floor space (and for other sectoral electricity use) declined to 55 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. In addition, and consistent with the reports of observers of the DPRK, we have assumed a level of wood/biomass use in the sector equal to10 percent of coal use in 1996. Wood/biomass use in the public and commercial sector in the DPRK in 1996 was likely to be concentrated in more rural areas, and in areas of the country where supplies of coal and electricity were curtailed. Oil use is assumed to increase somewhat with the reported increase in private sector activities, to a level equal to 0.5 percent of coal use, with oil use split evenly between kerosene and LPG use.

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 estimates 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, landing on seashores, 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[68], and on the equipment stocks in each type of unit[69], 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[70] that described the various equipment types (size, range, fuel capacity, weight, and 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, ongoing maintenance, or just age and decay) at any given time, and that the Army conducts maneuvers approximately 1,000 hours per year, but that heavy armaments (tanks, armored vehicles, amphibious vehicles, and self-propelled guns and missiles) are used in training only 100 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 (about 90 percent). These and other trucks nominally in military use often, based on our own observations and that of many others, are used for both civilian (goods and human transport) and military purposes, often simultaneously.

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[67] and information on the early-1980s stocks of particular aircraft[71] 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[72], and from other[73]. 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

[67] As supplied in US Defense Intelligence Agency (1990?), North Korea, The Foundations for Military Strength, US Defense Intelligence Agency, Washington, DC, USA, available in part as http://www.fas.org/irp/dia/product/knfms/knfms_toc.html.

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, interpreted to mean that average fuel consumption was about 80 percent of fuel consumption implied by consideration of the fuel capacity, range, and maximum airspeed of the different aircraft as reported in the literature[68].

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[74] 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 (numbering about 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[69] [75], 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[76]. 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 (many of the latter may be dual-use vessels). 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

[68] This is admittedly a rough approximation, as published aircraft ranges may not be quoted at maximum airspeed, and the relationship between airspeed and fuel consumption is not linear (see, for example, page 252 in Warren F. Phillips (2004), Mechanics of Flight, published by John Wiley and Sons).
[69] 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.

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 to replace equipment reaching the end of its nominal lifetime. A Chinese figure of 250 kg coal equivalent per tonne of steel[77], 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[78]. 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 on the order of 1.2 million people do not exist without a substantial stock of military buildings. As in other sectors, however, 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 10 million GJ annually 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 had an electricity demand in 1990 of approximately 5 MW, as there is no electricity production by the DPRK's 25 MW thermal (though referred to as "5 MW electric") research reactor at Yongbyon (prior to its shut-down as part of the Agreed Framework). An additional 9.6 million GJ/year placeholder allotment was assumed for other uses of coal in the military, along with an additional 100,000 GJ/year for other uses of petroleum products.

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 was a 13 to 20 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 33 percent decline in aircraft use[70], and about a 30 percent decline in the use of the most actively used 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 70 percent of 1990 levels by 1996. Changes assumed in energy use by military buildings with included a 45 percent decline in electricity use for military activities relative to 1990 levels, along with a 5 percent decrease in the use of coal and wood fuels to meet end-uses typically served by coal, and a 5 percent decrease in the use of oil products. The decline in military electricity use was assumed to be partially the result of changes in the DPRK's nuclear program

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[70] 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.

under the terms of the Agreed Framework[71]. Wood use in the military was assumed to be negligible in 1990, when coal supplies were generally available, but we assume that wood use in the military by 1996 represented 10 percent of the total coal and wood used, as some military units, particularly in rural areas, found the need to supplement inadequate coal supplies with wood and biomass for heating and cooking.

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 entries here for 1990 are placeholder values of 5.9 million GJ of petroleum products consumption, of which 1.7 million GJ is diesel oil, and the rest kerosene, plus an estimated 0.47 million GJ of heat from the Yongbyon reactor, placed in the "hydro/nuclear" balance category[72]. No non-specified sector energy uses were included in the 1996 energy balance[73].

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 and oil 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 about 25 percent of its 1990 level in 1996, that non-energy petroleum products use declined to about 25 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 follows:

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

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[71] 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."

[72] Calculated based on thermal output for the Yongbyon reactor of 25 MW, and a 1990 capacity factor of 60 percent (see "Yongbyon 5-MW(e) Reactor" from http://www.globalsecurity.org/wmd/world/dprk/yongbyon-5.htm for estimates of Yongbyon capacity factor).

[73] The Yongbyon reactor's heat output for 1996 is taken to be zero, as the reactor was shut down under the terms of the Agreed Framework.

- *Hydroelectric power* from a number of hydroelectric plants (see Section 2.4.1).

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 in 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[74], 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[75].

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 were as high as 85 million tonnes of coal (for 1989), although estimates by the ROK's National Unification Board (NUB[79]) suggested 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 the NUB apparently assumes an average energy content that is on the order of that used for high-quality anthracite coal[80, 76].

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[81]. We have taken the figure of 4500 kcal/kg as the 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 for 1990, though some observers suggest otherwise.

Imports and exports of coal and coke to and from the DPRK were of modest scale in 1990, relative to domestic demand. 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[82]. The DPRK also exported 1.17 million tonnes of anthracite to China[83] and about 530,000

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[74] "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.

[75] 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.

[76] It is possible 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).

tonnes to Japan[77] in 1990, so DPRK was a net importer of both coal and coke in that year, 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 about 53 percent of their 1990 levels by 1996[78], and that coal imports (based on China Customs statistics) were at 18 percent of 1993 levels in 1996. DPRK coal exports to China were recorded at 22 percent of their level in 1993, but overall DPRK coal exports to China and Japan were about 75 percent of 1993 levels, and 27 percent of 1990 levels.

2.3.3. Petroleum

There are reportedly oil and gas reserves in offshore areas of North Korea[79], but the country lacks the technologies to effectively explore and develop these resources alone. In recent years (see Chapters 3 and 4), the DPRK has entered into agreements to develop its oil resources, and has by at least one report produced some crude oil from an onshore well. As of 1990, however, all of the petroleum products used in DPRK were either derived from imported crude oil refined in DPRK, or were imported refined products. Crude oil imports as of the first half of the 1990s 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[80]; and
- *The open market*, for example, through Hong Kong or Singapore.

The Korean Foreign Trade Association[84] lists total crude oil imports of 2.43 Mte (million tonnes) from the first three sources in 1990, while Choi[85] cites a total of 2.8 Mte crude oil imports from all sources. Some sources suggest that the 2.8 Mte estimate is too high, so we have used a figure of 2.6 Mte total crude oil imports 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[86].

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 essentially ceased, and shipments from the Middle

[77] Derived from Japan customs statistics, available as http://www.customs.go.jp/toukei/info/index_e.htm, and http://www.customs.go.jp/toukei/download/index_d012_e.htm (the latter last visited 4/2010).

[78] This includes coke imported from China (as reported in China Customs Statistics, as compiled by Nathanial Aden, 2006. For related analysis, see also N. Aden, North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Dr. Aden's paper is available as http://nautilus.org/napsnet/napsnet-special-reports/dprk-prc-trade-aden/), plus an assumed 10 percent additional to account for small-volume imports from Russia and other countries.

[79] 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.

[80] Some sources indicate that in recent years exports of oil from the Former Soviet Union to the 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).

East have virtually stopped as well. Data from Choi[87] 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 had come via pipeline from China. Chinese customs statistics for 1996 show oil shipments into North Korea at about 940,000 tonnes per year, rate similar to that which had prevailed for most of the 1990s[88] [81]. According to the Korean Energy Economics Institute[89], the DPRK received 80,000 tonnes of crude oil from Libya in 1995, but no shipments have been reported in 1996. Table 2-3 presents crude oil import figures provided by KEEI for 1989 through 1995, plus our crude oil imports figures from China 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	940
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	940

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

* China Customs Statistics from 1996.

In addition to the refined products produced at the Chinese-built refinery from Chinese crude oil received in 1996[82], China 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 based on China Customs Statistics, totaled about 68,000 tonnes. This figure is on the order of 80 percent of the amount of official exports of refined products from China to the DPRK in 1993[90]. 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 on the west coast of 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[91]. 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.

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[81] China Customs Statistics data as compiled by Nathanial Aden in 2006, 2008, and 2010. See, for example, N. Aden (2006), North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Mr. Aden's 2006 paper is available as http://nautilus.org/napsnet/napsnet-special-reports/dprk-prc-trade-aden/.

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

2.3.4. Wood and biomass

Approximately 9 million hectares (ha) of North Korea was covered with forests as of 1990. 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, left the forest stocks of DPRK in generally poor condition. A significant reforestation effort, totaling some 2.5 million hectares of plantations by 1993, was reported to be taking place[92], and is mentioned periodically in North Korean news reports. A total of 3 million hectares were classified as "productive forests".

Various figures have been given for the level of domestic wood production in the DPRK, ranging from about 4 million[93] to approximately 16 million cubic meters of wood. We have used a value, 6 million m^3, somewhat below the range provided in official DPRK estimates[94] that sets wood used for firewood at 8 - 10 million m^3. Official DPRK estimates set 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[83]. Based on our assessment of the DPRK forest resource base (see Chapter 4), we use somewhat lower estimates for 1990 in some of these categories—930,000 m^3 wood for charcoal production, and1 million m^3 wood for construction—but use 650 thousand m^3 for the total wood used as industrial fuelwood and for pulp and paper production.

In addition to its domestic production, the DPRK also imports wood from the Russian Far East. Teams of workers from the DPRK are (or at least routinely were) sent to harvest wood in Russia and the DPRK retained 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 1.5 million m^3 of roundwood (logs) are imported annually from Russia[84]. 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[95] reports that a total of 3.1 million tonnes of crop residue (straw and bran) was used in agriculture in 1990. In addition to this figure we have assumed a total of 2.54 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 (revised relative to previous versions of this report) is plausible, given the areas and reported

[83] 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.

[84] A document in the authors' files lists imports of 2.5 million cubic meters from Russia [TP1, p. 4], but other sources list these imports at 230 kcu.m./yr, and also list the number of DPRK workers sent to Russian forests at 16-20,000 annually. An abstract from a 1990s report on the Russian Far East forestry sector (CINTRAFOR Working Paper Abstract, "The Forest Sector in the Russian Far East: Status and Near-Term Development", by Ekaterina Gataulina and Thomas R. Waggener, 1998, available as http://www.cintrafor.org/research_tab/links/WP/WP63.htm) suggests that the average productivity of Russian forest workers as of 1994 was "360 m3 per worker (roundwood equivalent)", presumably per annum. This suggests, if the productivity of DPRK work crews were similar, that the DPRK crews might harvest up to about 7 million cubic meters per year, assuming the same rate of production (and the same access to harvesting equipment--which may well not be a given) as Russian crews. If, as has been reported, DPRK harvesting crews brought home approximately a quarter or a third of their harvest (the rest remaining in Russia), annual imports of wood back to the DPRK would be in the range from 1.4 to 2.4 million tonnes. We assume that 1990 imports of wood to the DPRK from the RFE were at the lower end of this range.

yields of crops in the DPRK, it is may still be somewhat high, indicating that our estimate for 1990 wood/biomass fuel demand in the rural residential subsector (see below) may remain 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;
- *District Heat Production*;
- *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 (pending receipt of information on coke production in the DPRK); *Other Transformation*, for future inclusion of major 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 (nominally) 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 took place in the 62 major power plants in the 1990s; 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[96]. 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, and district heat production, in 1990

Our estimate of electricity generation starts with the assumption that gross generation in North Korea in 1990 totaled 46 TWh of electricity[97]. This estimate is somewhat closer to official

DPRK estimates (60 TWh and higher) and UN estimates (55.5 TWh[98]) than to estimates by ROK sources (27.7 TWh[99]), Russian sources (35 TWh[100]), and more informal estimates of 31-32 TWh[101], 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 (about 54 percent) of all electricity generation occurred in thermal plants in 1990[102]. 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 in 1990. 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)[103]. 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 as of 1990 (and reportedly largely still is, as of 2012) dispatched literally by phone and telex, and outages on the grid are frequent. As records of power consumption at the end-user are not at all common in DPRK, however, there is probably limited opportunity to determine the true extent of transmission and distribution losses[85].

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.

There is also an unknown but substantial amount of district heating in the DPRK, some of which reportedly uses steam generated in fossil-fueled power plants (this in addition to steam and hot water provided by the 11,000 small- to mid-sized boilers used in buildings and industries in the DPRK) and by stand-alone district heat boilers located in major power plants along with boilers for electricity generation[86]. Our rough estimate, based on numerous assumptions (see “District Heat” section of Attachment 1) is that as of 1990 somewhat under 11 million GJ of total heat for district heating was generated, of which about 75 percent was from power plants, with the remainder from heat-only district heating plants. We assumed average heat losses of 15 percent between the district heating or combined heat and power plants and heat consumers. If district heating from power plants proves more extensive that we have estimated, 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.

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[85] 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.

[86] A document in the authors’ files, citing a DPRK source [NKES-01], indicates that the Pyongyang power plant has two district heating boilers rated (each, we presume) at 210 tonnes of steam/hr, or 100 Gcal/hr. Based on a very rough calculation, two boilers of this size could supply space heat and hot water for tens of thousands of households (perhaps 50,000 to 100,000).

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[87], we have assumed that the total installed and potentially usable[88] 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 as of the early 1990s. 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 fully complete the picture.

Table 2-4: Major Thermal Generating Facilities in the DPRK[89]

#	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**		

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 were made. Figure 2-2 provides a photo of the control room at the Pukchang ("Bukchang", in the table above) Thermal Power Plant, the DPRK's largest.

[87] 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.

[88] 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.

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

Figure 2-2: Control Room at Pukchang Thermal Power Plant[90]

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 by the early 1990s, 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 coal-fired 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 present 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. See Chapter 3 for estimated updates on the capacities and status of power production facilities as of 2000 and 2005.

[90] Photo from dprkguidebook.org (date not provided, but probably 2006 or 2007), "Main Industrial Sectors & Business Opportunities", available as http://dprkguidebook.org/contents_3.htm.

Table 2-5: Thermal (fossil-fueled) Generating Facilities Reported to be Under Construction or "Planned for Construction" in the DPRK[91]

#	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 generation using gross generation efficiencies in 1990 of 29.5 percent for oil-fired plants[92] 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 is comparable to Chinese electricity generation efficiencies for thermal plants of late-1970s vintage[104, 93].

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[105], and are relatively high compared to typical thermal power plants. For coal-fired plants, we assumed an additional "emergency loss" rate in 1990 of 5 percent (accounted for in the "own use" row of the energy balances), which is a bold extrapolation from experience at the Pyongyang power station[106], 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 in coal-fired plants.

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

[91] 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 actually appear twice on this list.

[92] 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.

[93] 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.

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 about 4,000 MW, over 85 percent of the total hydro 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[94]. Figure 2-3 presents a photo of one of the "cascades" of the Kangae (also referred to as "Kanggye") hydro power plant, showing a series of turbine-generator units floating on the surface of the river. It is unclear what fraction of the capacity of the Kangae cascade the units in the photo represent.

Figure 2-3: Photo of Kangae Hydro Power Plant[95]

[94] 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.

[95] From document in the authors' files [OS-4-19-2012, page 37].

Table 2-6: Major Hydroelectric Generating Facilities in the DPRK[96]

#	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) had progressed as of 1996. The only exception was the Kumgang Mountain plant, a first phase of which (reportedly about 125 MW) was opened in 1996. We were 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 about 2000, 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. In about 2000, 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 fell by about 3250 MW from 1990

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

values by 1996 as a result of flood damage[97] offset slightly by additions to capacity[98]. We have further assumed, based on conversations with those familiar with the situation, that 1996 power production for China from Chinese-controlled plants 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. Note that the electricity produced by these plants for China is not included in our energy balances as "exports" from the DPRK to China, since those plants are in fact owned and controlled by China.

Table 2-7: Major Hydroelectric Generating Facilities Reported to be Under Construction or "Planned for Construction" in the DPRK[99]

#	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[107]. 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[100]. 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[108], and is also similar to values for Chinese plants.

[97] Several sources that 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.

[98] 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.

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

[100] 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.

2.4.1.4. *Status of the Transmission and Distribution Network*

The unified electrical grid in the DPRK apparently dates back to 1958[109]. The DPRK T&D system must nominally manage a fairly complex grid of 62 power plants, 58 substations, 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 2-4a, and a similar map from another source with power station and other titles in English is provided as Figure 2-4b. 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[110]:

- 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[111].

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[112], 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[101]. 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.

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

Figure 2-4a: Overall Map of the DPRK Electric Power Grid

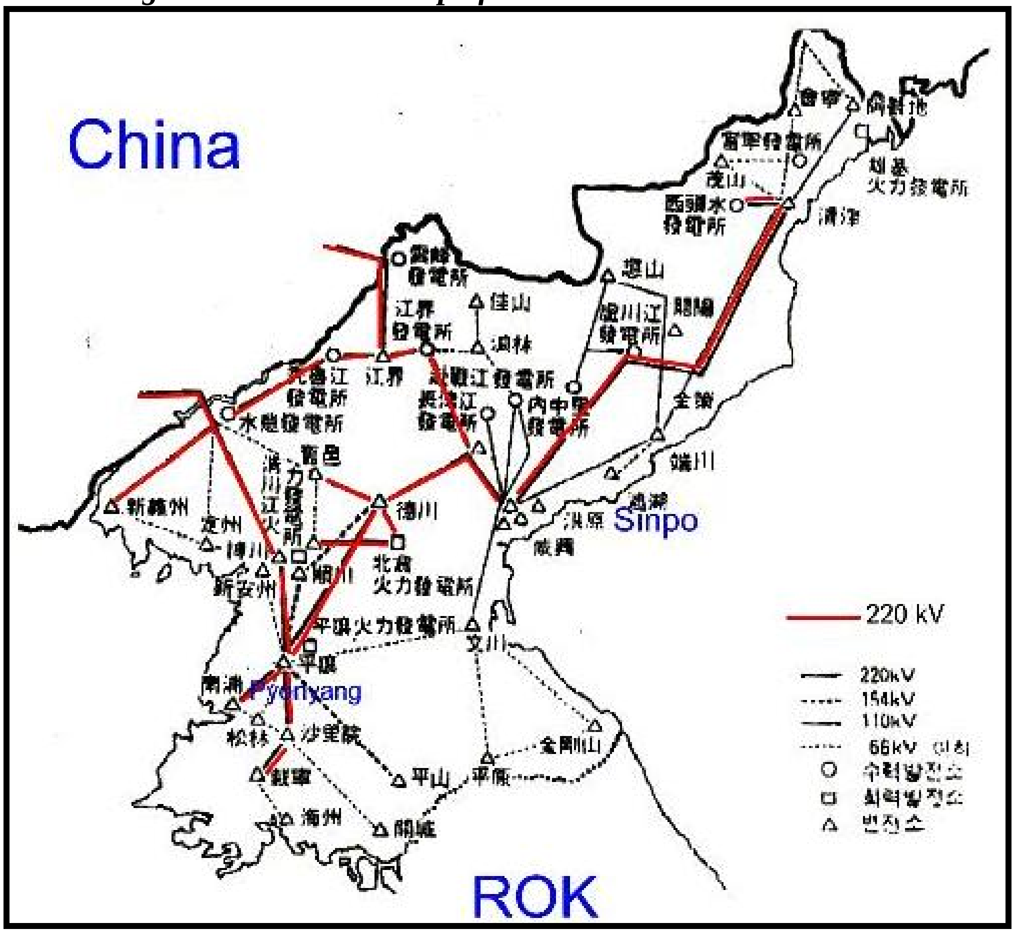
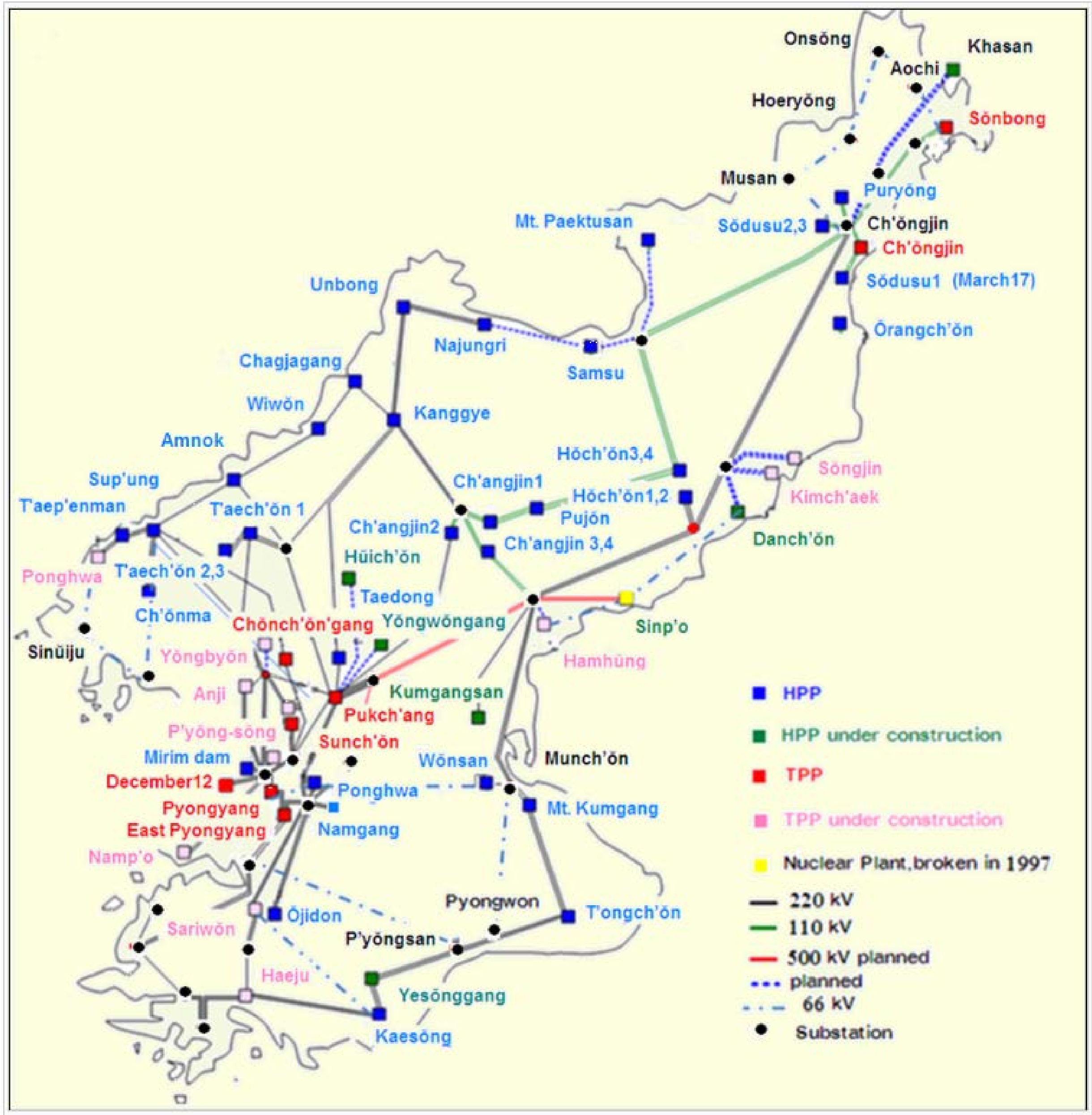


Figure 2-4b: Map of the DPRK Electric Power Grid[102]



There were, as of about 1990, reportedly 58 substations on the DPRK grid at the highest transmission voltage levels[103]. We have capacity information about only four of these[104], and names for a number of others. These data are provided in Table 2-8. A substation in the

[102] From document in the authors' files [OS-2-27-2012, page 38]. The legend entry "Nuclear Plant, broken in 1997" likely refers to the groundbreaking for the KEDO nuclear reactors at Kumho/Sinpo, and dates this map to sometime after 1997.

[103] More recent estimates provided by experts suggest that there may be somewhat under 80 transmission substations in the DPRK designed to operate with nominally 220 kV inputs, with perhaps another 200 transmission substations operating at the 66 kV/11 kV levels, 2500 11 kV distribution substations, and about 15,000 transformers to distribute power to consumers.

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

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[113]. 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)[114] in mid-1990s dollars. Estimates of transmission lines in South Korea were 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, were about $10 million for 154 kV units, and $36 million for 345 kV substations as of the late 1990s[105]. Costs for transmission lines vary considerably with the capacity and voltage of the line, the topography to be covered, and other variables. In addition, costs for transmission lines and substations may have increased, particularly in recent years, faster than inflation, due to the increase in commodities prices (especially metals) that preceded the recent global recession. As a rough total estimate based on the figures above, 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—in 1995 dollars—for the costs of replacing the entire DPRK electricity grid[106]. In 2011 dollars, this estimate would be above $4.5 billion, which we would suggest is definitely a lower bound for possible costs, especially as it does not include either the costs of either distribution lines or transformers (lower-voltage lines and transformers within cities and towns, and connecting buildings and other loads to the grid) or any power plant refurbishment. 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[107], there may be environmental issues and costs associated with substation replacement.

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[105] 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. Costs shown here should be considered to be in approximately mid-1990s USD.

[106] 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. As noted, 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 for even relatively simple meters.

[107] Possibly including, for example, costs and risks associated with disposal of PCBs, or (polychlorinated biphenyls), which are likely present in older substations and transformers as insulating oils.

Table 2-8: Partial Listing of High-voltage Substations on the DPRK Electrical Grid[115]

#	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 nominally 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.

Table 2-9: Listing of Regional Control Centers on the DPRK Electrical Grid[116]

#	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, for 1990, we used the official estimate that 10 percent of net generation is lost in electricity transmission, and an additional 6 percent in distribution[117]. These estimates are in aggregate similar to Chinese values of the same period for such losses[108], and comport with

[108] Note, however, that transmission and distribution data in Chinese energy statistics often only include losses on transmission and major distribution systems, with losses from smaller distribution systems counted as a part of end-use consumption by

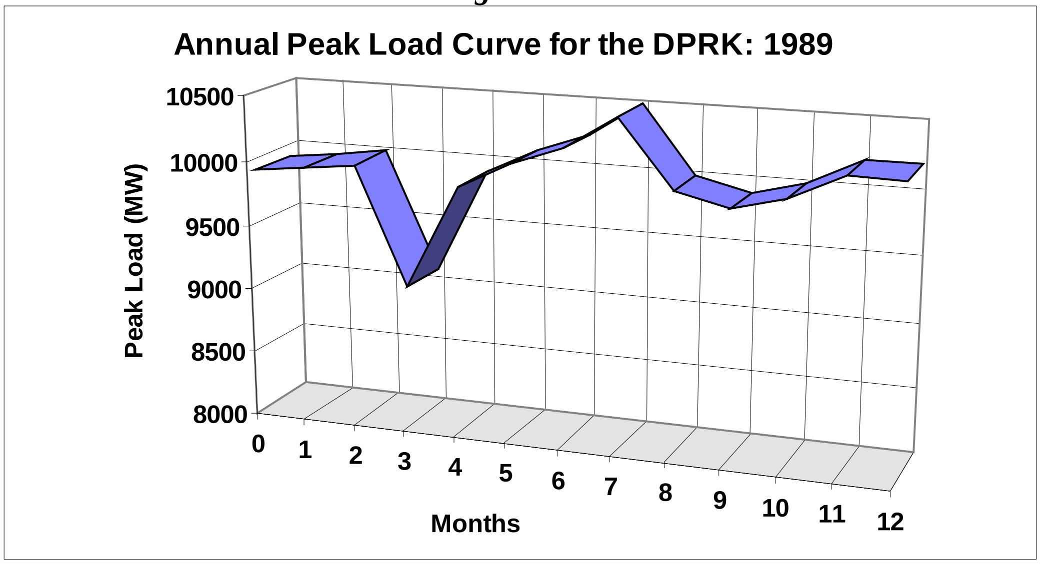
independent reports of loss rates (as noted above), but may still be optimistic for the DPRK. As records of power consumption at the end-user are apparently not common in DPRK, there is probably limited opportunity to determine the true extent of transmission and distribution losses.

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 2-5. 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 shows peak power demand in the DPRK to be (or at least, to have been) 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, given that most heating in the DPRK is non-electric, and given that there was (and continues to be) relatively little air conditioning 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, as it could also be related to demand related to the youth festival and/or to an all-out push to have all power generation facilities operating during that period. Why demand should be lower in March, we do not know, unless what is being reported in Figure 2-5 is actually peak power supplied, which could be lower in March due to lack of availability of hydroelectric resources.

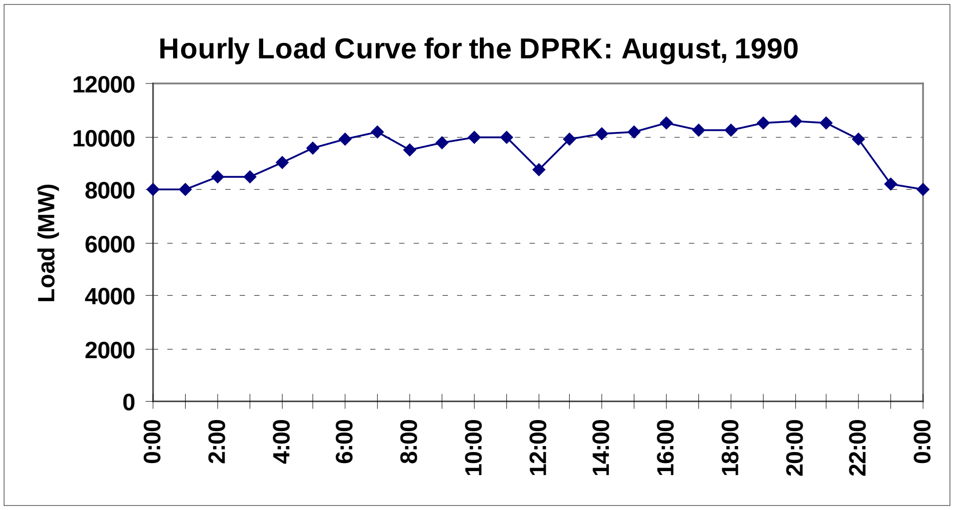
industry, residences, and others. As a consequence, published statistics for T&D losses in China will typically be much smaller, closer to 5-8 percent of generation.

Figure 2-5:



The variation of peak load over time during a weekday in August, 1990 is provided in Figure 2-6. 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 2-6, 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). The timing of these peaks is fairly typical of grids with a substantial number of residential consumers, though grids in most countries will typically show a much higher morning and evening peaks relative to baseload than is indicated in Figure 2-6. 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. It is worth keeping in mind that this is just one "snapshot" of a daily load pattern, and may or may not be representative of conditions in general as they were in 1990, though it is all we have to use at present.

Figure 2-6:



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[109]. 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[118]. 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/closed conditions of circuit breaker or switch positions. The only exceptions to this lack of access, as of 1990, were links to three power plants, but even these links were reportedly "slow and outdated". (See below for information on the status of projects to update the dispatching system.)

As of the mid-1990s, 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. There is no indication that this system has changed substantially since, beyond the installation of the a few upgrades in a limited area by the United Nations Development Programme (see below).

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

[109] A now-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.

what technical or operating problems (among those noted above and below) are central in preventing operation of the unified grid, but identifying and solving those central problems will likely be one (but not the only) requirement if a large power plant (such as the KEDO reactors, now no longer under construction) or a large power transfer to the DPRK (such as the 2 GW power transfer proposed by the ROK in mid-2005) 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 (based on reports as of 1990)[110] [111].

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[119]. 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[112] it is virtually certain 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 (short of wholesale refurbishment/replacement of the DPRK grid to ROK standards) 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

---

[110] 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.

[111] Our own power measurements in the DPRK in 1998 and 2000, in fact, showed a much wider range of frequency variation—with frequencies dropping at times to the 45 Hz range.

[112] 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 colonial period (and possibly of US influence in the ROK). 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).

would be required was estimated to be on the order of US $125 million per GW of capacity[113] in the late 1990s, or on the order of 5 percent of the costs of the PWRs that were to have been transferred to the DPRK 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:

- Should the first step in assistance be to interconnect the two grids, so that power can be sold (for example) from reactors built on the Sinpo site (where the KEDO-provided PWRs were to have been, and where their substantial foundations and other infrastructure remain), to the ROK (or so that the ROK can supply power to the North); 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[114]?
- Would it be less expensive and technically less risky (again, assuming that the power from any PWRs located in the DPRK is to be substantially sold to the ROK) to simply connect the reactors 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. In this case, it would almost certainly be necessary to build a new transmission line from the reactor site to the ROK border.
- Might it be more effective to rebuild the DPRK grid piecemeal, by developing new (or substantially refurbished) "mini-grids", perhaps at the county level, each supported by their own local generation, and designed to augment local economic redevelopment?

Status of Projects to Upgrade T&D System

In the early-to-mid-1990s, a project carried out by the United Nations Development Programme (entitled "Electric Power Management System") was undertaken in the DPRK. The overall intent of this pilot project was 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.

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[113] Order-of-magnitude cost estimate obtained in conversation (1997) with G. Jutte of Siemens Power Transmission and Distribution, Limited. Indications at that time were that per-unit costs for these systems were declining. 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/additional hardware).

[114] 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.

As of 1996, a personal computer-based local area network (LAN), complete with LAN software and software for modeling the T&D system, had been installed at EPPDCC, and operators had received some training in the use of the facilities. Microwave links with the eight remote power plants and substations had been established and activated, and the remote stations had 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. Jae-Young Yoon[120] reported on the outcome of the project as follows:

> "Some important new systems have been added with help from the international community. A supervisory control and data acquisition (SCADA) computer system, used for the monitoring and distribution of electricity, was supplied from China by the United Nations Development Programme (UNDP) in the 1990s and has been operating in the power plants of Supung, Jangjingang, Pyongyang, and Puckchang [listed as "Bukchang" in Table 2-4] as well as in the substations of Chungjin, Pyongyang #2, Pyongyang #3, and Wonjin.
>
> "These new systems still have to interface with aging, made-in-the-DPRK parts. While the SCADA system has a relatively modern electricity control mechanism, the protective relaying systems (which are necessary to identify problems in the system and keep them from spreading) are domestically made in the DPRK and are of unknown quality; in addition, it is unclear how well they have been maintained. This may limit the ability of the DPRK to effectively use the SCADA system to protect its power system."

As of our last information (approximately 1996), the DPRK and UNDP (in some combination) were preparing a pre-feasibility study to extend the system installed to the entire grid, but to our knowledge no substantial activity of this type has occurred.

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
- The average 1996 capacity factor of coal-fired power stations was approximately 70 percent of the value we assume for 1990, or about 58 percent overall.
- Effective hydroelectric capacity from existing facilities fell by about 3,250 MW from 1990 values (to 1,250 MW) by 1996 as a result of flood damage[115] offset by some additions to capacity[116]. Electricity production from the Chinese-controlled generator units in joint China/DPRK dams along the border rivers shared by the two countries decreased to 28 percent of their 1990 levels.

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[115] Several sources that 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.

[116] See discussion in Chapter 2.

- The average capacity factor of hydroelectric generating stations was at about 90 percent of the level in 1990, or about 49 percent overall (but effective capacity is much lower).
- Thermal plants fueled exclusively with heavy fuel oil were assumed to have a 1996 capacity factor 71 percent of that in 1990, or about 52 percent overall.
- We assumed that coal-fired plants used 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 were assumed to have been 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 have declined due to lack of spare parts and general degradation of boiler and combustion air pre-heat 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[117] and 4.5 million tonnes[118]. Capacities in this range would be adequate to process the volume of crude oil that is reported to have been imported in the years before 1990 (see, for example, Table 2-3, 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[121][119]) Chinese-designed refinery in the northwest DPRK. This refinery, named the Ponghwa Oil Refinery, was reportedly built in the late 1950s. It is designed to take Chinese crude oils (such as Daqing or Liaohe[122]). We assumed that the product slate of this refinery is the same as that of refineries of similar design in China, with product fractions (on a weight percentage of input basis) of 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[123]. The DPRK's other major refinery, the Sungri Oil Refinery is located in the town of Unggi, on the East Coast close to the Russian border and near Sonbong, has a reported capacity of 42,000 bpd (about 2.1 million tonnes/yr—though other sources suggest capacity of 2.5 million tonnes/yr), with a reported fluid cracking facility of 7,300 bpd[120, 124]. The refinery was built in around 1968 by the Soviet Union, and expanded in 1970. 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. Sources suggest that inputs from the Soviet Union arrived by train, with imports also received by ship from Saudi Arabia, Indonesia, Malaysia, and Iran. A page from a Japan-based North Korean organization lists the storage capacity of the plant at 2 million tonnes (it is unclear whether this is tonnes of oil products, of crude oil, or both—but is most likely for crude oil and oil products combined)[121]. A separate source reports much lower

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[117] United Nations estimate, as cited in Jang, Young Sik (1994), North Korean Energy Economics. Korea Development Institute.
[118] It is not clear whether these figures are given per tonne of crude oil input or per tonne of product output, though the difference between the two measures is unlikely to be more than 10 percent.
[119] Other sources (document in the authors' files [OS-2-27-2012, page 45]) suggest that the current capacity of this refinery is 2.5 million tonnes/year.
[120] Some information about this refinery, and plans for its expansion, was at one time available on the UNIDO (UN Industrial Development Organization) World-wide Web site at http://www.unido.org, though it is unclear if that information remains available.
[121] Web page http://www1.korea-np.co.jp/pk/095th_issue/99051905.htm, dated 1999, by "The People's Korea", and titled "Rajin-Sonbong Region".

storage capacity of 30,000 tonnes of crude oil, 40,000 tonnes of diesel, 30,000 tonnes of heavy oil, 20,000 tonnes of gasoline, and 5,000 tonnes of lubricants[122]. A "panorama" of the "Sungri Chemical Plant Oil Refinery, Sonbong" from the "The People's Korea" (source as above) is provided below as Figure 2-7.

Figure 2-7: Photo of Sungri Chemical Plant Oil Refinery

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 1996[123], if any, was minimal relative to the larger refineries, 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[125]. 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 major refined petroleum 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

[122] Document in authors' files [OS-2-27-2012, page 44]. This source also lists the Sonbong port that serves the refinery as having two underwater pipelines from the end of the wharf to a loading buoy for crude oil (3500 m), plus (apparently) one each for loading and unloading gasoline, diesel and fuel oil, with a crude oil (presumably) pipeline transit capacity of 2-3 million tons/year. The port is described as having docking capacity for two 6,000 ton, one 15,000 ton, one 30,000 ton, and one 250,000 ton tankers, plus storage tanks for crude oil in the following sizes: 9 tanks of 20,000 m^3, 10 tanks of 22,000 m^3 and one tank 400,000 m^3.

[123] An estimate for the operation of one of these refineries in the years 2000 and beyond is provided in Chapter 3 of this report.

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[126]. 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 data on imports of crude oil to define the refine refinery inputs, together with 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 time since then. 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 near or in fact under the ocean, which presents extreme mining difficulties due to the need to constantly remove seawater from the mines, requiring constant pumping and, thus (typically) reliable supplies of electricity. Coal production in some mines in the DPRK is (or was, as of about 1990) reportedly almost completely mechanized, but mechanization is apparently limited in other mines[127]. We applied Chinese figures from the 1980s for coal and electricity use during coal mining[128] to estimate the own use of these fuels during coal production in DPRK[124]. These estimates could be either low or high. The difficulties with water intrusion (for example) would argue that a large amount of energy would be expended for pumping, and thus these estimates would be understated[125]. On the other hand, the probable higher degree of mechanization in at least the larger Chinese mines would argue that "own-use" of energy would be lower in coal mines the DPRK than in mines in China.

Coal washing is apparently not practiced in the DPRK, although it would be beneficial for many coal combustion applications. Coal briquetting to produce household fuel is practiced widely (based on our observations) but on a small scale--many briquettes are produced in hand presses. No quantitative data were available to us to describe how this preparation process works on average nationwide[129], but our own 1998 and 2000 surveys as a part of the Unhari Wind Energy Project characterized the briquettes, at least in one village where we worked, as being on average 3 to 4 parts coal per part clay binder, and with a mass of the final, dried briquette of about 2.5 kg each[126]. Though this information is derived from a single locale, we would not be surprised if briquetting practices are very similar throughout the DPRK.

For 1996, we assumed that coal and biomass production could meet demand (as estimated based on the demand-sector parameters described earlier in this chapter), although coal

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[124] 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.

[125] 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.

[126] See, for example, page 24 of Rural Energy Survey in Unhari Village, The Democratic People's Republic of Korea (DPRK): Methods, Results, and Implications, David F. von Hippel, Peter Hayes, James H. Williams, Chris Greacen, Mick Sagrillo, and Timothy Savage, Nautilus Institute Report, dated May 20, 2001, available as http://www.nautilus.org/about/staff/peter-hayes/Unhari_Survey.pdf.

production capacity probably decreased somewhat by 1996 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 by themselves have not had a major effect on coal production.

We heard a report in the late 1990s that the quality of coal produced in the DPRK has fallen significantly since 1990, 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 that was mined in the DPRK in 1996 could have been less than the 4500 kcal/kg that we used as an average value for 1990, but not as low as 1000 kcal/kg, We certainly wouldn't rule out the possibility, however, that even our fairly low value for overall 1996 coal production (in TJ) is too high. If indeed the average energy content of coal mined in the late 1990s was 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[127]. 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 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" [130]. 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 0.65 million cubic meters at 1.5 cubic meters per tonne[131], we assume an efficiency of 30 percent to yield a charcoal output of approximately 2.1 million GJ

[127] 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.

(gigajoules) in 1990. An efficiency of 30 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 balances 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 these balances, and the balances for 2000, 2005, 2008, and 2009, presented later in this report, can be used as starting points for additional analysis and planning regarding the DPRK energy economy, including being adapted as bases for estimates of energy efficiency potential (that is, in a more thorough and detailed manner than the estimate we have prepared and presented in Chapter 4 of this report).

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 and some tables and graphs) 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	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	1,326	111	27	78	162	-	-	-	1,703
Domestic Production	1,301	-		78	150				1,529
Imports	68	111	27		12				218
Exports	44							-	44
Stock Changes									
ENERGY TRANSF.	(384)	(111)	95	(77)	(10)	3	9	132	(342)
Electricity Generation	(301)		(16)	(77)			8	166	(220)
Petroleum Refining		(111)	111					(1)	(1)
Coal Prod./Prep.	(63)							(9)	(72)
Charcoal Production					(10)	3			(7)
District Heat Production	(3)		(0)				3		(1)
Own Use								(12)	(12)
Losses	(16)						(2)	(12)	(29)
FUELS FOR FINAL CONS.	942	-	122	1	152	3	9	132	1,361
ENERGY DEMAND	948	-	109	-	152	3	9	120	1,342
INDUSTRIAL	672	-	28	-	6	-	-	70	776
TRANSPORT	-	-	38	-	2	-	-	11	51
RESIDENTIAL	189	-	7	-	86	3	6	11	302
AGRICULTURAL	10	-	5	-	45	-	-	3	62
FISHERIES	1	-	3	-	-	-	-	1	5
MILITARY	30	-	16	-	-	-	-	14	60
PUBLIC/COMML	33	-	0	-	2	-	3	11	48
NON-SPECIFIED			6	-					6
NON-ENERGY	14		6		12				31
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	HEAT	ELECTRICITY	TOTAL
ENERGY SUPPLY	1,325,571	110,742	26,622	78,075	161,944	-	-	-	1,702,954
Domestic Production	1,301,288	-		78,075	149,944				1,529,306
Imports	68,392	110,742	26,622		12,000				217,755
Exports	44,108							-	44,108
Inputs to International Marine Bunkers									-
Stock Changes									-
ENERGY TRANSFORMATION	(377,571)	(110,742)	82,762	(78,075)	(9,920)	2,976	9,251	120,464	(360,855)
Electricity Generation	(294,926)		(21,947)	(76,641)			7,884	165,600	(220,030)
Petroleum Refining		(110,742)	110,742					(593)	(593)
Coal Production/Preparation	(63,092)							(8,544)	(71,636)
Charcoal Production					(9,920)	2,976			(6,944)
Coke Production									-
District Heat Production	(3,417)		(73)	(1,433)			2,916		(2,008)
Other Transformation									-
Own Use			(5,960)					(12,408)	(18,368)
Losses	(16,136)						(1,549)	(23,592)	(41,277)
FUELS FOR FINAL CONSUMPTION	948,000	-	109,384	-	152,024	2,976	9,251	120,464	1,342,099
ENERGY DEMAND	948,006	-	109,384	-	152,021	2,973	9,251	120,467	1,342,103
INDUSTRIAL SECTOR	671,661	-	28,483	-	5,626	-	-	70,242	776,013
Iron and Steel	324,615							17,388	342,003
Cement	68,139		7,571					4,356	80,065
Fertilizers	23,994		4,573					18,891	47,458
Other Chemicals	11,203							6,616	17,819
Pulp and Paper	4,026				4,026			932	8,985
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	124,600		3,740		1,600			14,850	144,790
TRANSPORT SECTOR	-	-	37,896	-	1,672	-	-	11,470	51,039
Road			32,571		1,672				34,243
Rail	-		1,949					10,870	12,819
Water	-		1,253						1,253
Air			1,123						1,123
Non-Specified			1,000					600	1,600
RESIDENTIAL SECTOR	189,274	-	6,600	-	86,140	2,973	6,134	10,718	301,840
Urban	129,155		6,256			1,814	6,134	7,420	150,780
Rural	60,119		344		86,140	1,159		3,298	151,060
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	1,132	-	3,137	-	-	-	-	524	4,794
Large Ships	-		2,681						2,681
Collectives/Processing/Other	1,132		456					524	2,112
MILITARY SECTOR	29,825	-	16,444	-	-	-	-	14,008	60,277
Trucks and other Transport			6,585						6,585
Armaments			263						263
Air Force			2,648						2,648
Naval Forces			6,847						6,847
Military Manufacturing	887							48	935
Buildings and Other	28,938		100					13,960	42,998
PUBLIC/COMMERCIAL SECTORS	32,646		98		1,632		2,644	10,932	47,952
NON-SPECIFIED/OTHER SECTORS			5,950				473		6,423
NON-ENERGY USE	13,718		5,771		12,000				31,488
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	5,275	12,962	6,224	2,160	-		137,364
Domestic Production	-							-
Imports	110,742	5,275	12,962	6,224	2,160			137,364
Exports								-
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(110,742)	25,332	19,357	16,583	8,849	11,560	1,080	(27,980)
Electricity Generation				(21,947)				(21,947)
Petroleum Refining	(110,742)	25,332	19,357	38,603	8,849	17,521	1,080	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(73)				(73)
Other Transformation								-
Own Use						(5,960)		(5,960)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	30,607	32,319	22,807	11,009	11,560	1,080	109,384
ENERGY DEMAND	-	30,606	32,317	22,807	11,008	11,566	1,080	109,384
INDUSTRIAL SECTOR	-	-	3,050	21,775	-	3,658	-	28,483
Iron and Steel								-
Cement				7,571				7,571
Fertilizers				915		3,658		4,573
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				12,600				12,600
Textiles								-
Building Materials								
Non-specified Industry			3,050	690				3,740
TRANSPORT SECTOR	-	23,220	12,926	627	399	-	724	37,896
Road		23,220	9,351					32,571
Rail			1,949					1,949
Water			627	627				1,253
Air					399		724	1,123
Non-Specified			1,000					1,000
RESIDENTIAL SECTOR	-	-	-	-	4,473	2,127	-	6,600
Urban					4,129	2,127		6,256
Rural					344			344
AGRICULTURAL SECTOR	-	-	5,005	-	-	-	-	5,005
Field Operations			2,619					2,619
Processing/Other			2,386					2,386
FISHERIES SECTOR	-	-	2,777	360	-	-	-	3,137
Large Ships			2,547	134				2,681
Collectives/Processing/Other			230	226				456
MILITARY SECTOR	-	7,386	6,859	45	1,798	-	356	16,444
Trucks and other Transport		6,476	109					6,585
Armaments		45	218					263
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					88	10		98
NON-SPECIFIED/OTHER SECTORS		-	1,700		4,250			5,950
NON-ENERGY USE						5,771		5,771

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	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	684	40	32	19	167	-	-	-	943
Domestic Production	685	-	-	19	155	-		-	859
Imports	12	40	39	-	12	-		-	103
Exports	12	-	0	-	0	-		-	12
Stock Changes	-	-	6	-	-	-		-	6
ENERGY TRANSF.	(251)	(40)	12	(19)	(8)	2	5	51	(248)
Electricity Generation	(208)	-	(25)	(19)	-	-	5	82	(166)
Petroleum Refining	-	(40)	40	-	-	-		(0)	(0)
Coal Prod./Prep.	(33)	-	-	-	-	-		(4)	(37)
Charcoal Production	-	-	-	-	(8)	2		-	(6)
District Heat Production	(2)		(0)				2		(1)
Own Use	-	-	(2)	-	-	-		(10)	(12)
Losses	(8)	-	-	-	-	-	(1)	(17)	(26)
FUELS FOR FINAL CONS.	433	-	44	-	159	2	5	51	695
ENERGY DEMAND	433	-	44	-	159	2	5	51	695
INDUSTRIAL	251	-	9	-	2	-	-	24	285
TRANSPORT	-	-	17	-	1	-	-	5	22
RESIDENTIAL	122	-	2	-	118	2	4	6	253
AGRICULTURAL	5	-	2	-	24	-	-	2	32
FISHERIES	1	-	1	-	-	-	-	0	2
MILITARY	25	-	13	-	5	-	-	8	52
PUBLIC/COMML	26	-	0	-	3	-	2	6	37
NON-SPECIFIED			-	-					-
NON-ENERGY	3		1		7				12
									-
Elect. Gen. (Gr. TWhe)*	16.61	-	0.91	5.32	-	-		-	22.84

**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	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	684,227	39,874	32,211	19,160	167,345	-	-	-	942,817
Domestic Production	684,608	-		19,160	155,348				859,116
Imports	11,614	39,874	39,100		12,000				102,588
Exports	11,994		443		4			-	12,441
Inputs to International Marine Bunkers									-
Stock Changes			6,446						6,446
ENERGY TRANSFORMATION	(251,361)	(39,874)	11,979	(19,160)	(7,916)	2,375	5,128	50,757	(248,074)
Electricity Generation	(207,738)		(25,467)	(19,160)			4,543	82,238	(165,584)
Petroleum Refining		(39,874)	39,874					(213)	(213)
Coal Production/Preparation	(32,773)							(4,438)	(37,211)
Charcoal Production					(7,916)	2,375			(5,541)
Coke Production									-
District Heat Production	(2,468)		(163)				1,710		(921)
Other Transformation									-
Own Use			(2,266)					(10,186)	(12,452)
Losses	(8,382)						(1,126)	(16,644)	(26,151)
FUELS FOR FINAL CONSUMPTION	432,866	-	44,190	-	159,429	2,375	5,128	50,757	694,744
ENERGY DEMAND	432,867	-	44,190	-	159,428	2,374	5,128	50,757	694,743
INDUSTRIAL SECTOR	250,538	-	8,685	-	1,909	-	-	24,001	285,133
Iron and Steel	124,977							6,694	131,671
Cement	29,981		3,331					1,917	35,229
Fertilizers	6,515		1,129					5,130	12,774
Other Chemicals	3,697		-					2,183	5,880
Pulp and Paper	1,329				1,329			308	2,965
Other Metals	7,828							1,362	9,189
Other Minerals	832		3,326					131	4,289
Textiles	9,697							824	10,521
Building Materials	20,453							62	20,516
Non-specified Industry	45,230		899		581			5,391	52,100
TRANSPORT SECTOR	-	-	16,525	-	829	-	-	4,804	22,157
Road			14,345		829				15,174
Rail	-		779					4,804	5,583
Water	-		501						501
Air			899						899
Non-Specified			-					-	-
RESIDENTIAL SECTOR	121,735	-	1,785	-	117,606	2,374	3,572	6,145	253,219
Urban	92,747		1,649		15,135	1,455	3,572	4,562	119,120
Rural	28,988		136		102,471	919		1,583	134,098
AGRICULTURAL SECTOR	5,155	-	1,502	-	23,767	-	-	1,697	32,121
Field Operations			786					816	1,602
Processing/Other	5,155		716		23,767			880	30,518
FISHERIES SECTOR	509	-	998	-	-	-	-	236	1,743
Large Ships	-		804						804
Collectives/Processing/Other	509		193					236	939
MILITARY SECTOR	25,363	-	13,123	-	5,498	-	-	7,711	51,695
Trucks and other Transport			5,734						5,734
Armaments			211						211
Air Force			1,886						1,886
Naval Forces			5,198						5,198
Military Manufacturing	621		-					33	654
Buildings and Other	24,742		95		5,498			7,678	38,013
PUBLIC/COMMERCIAL SECTORS	26,180		131		2,618		1,555	6,163	36,646
NON-SPECIFIED/OTHER SECTORS			-				-		-
NON-ENERGY USE	3,386		1,442		7,200				12,028
Electricity Gen. (Gross TWhe)*	16.61		0.91	5.32					22.84

**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	39,874	8,545	5,185	18,388	518	(426)	-	72,085
Domestic Production	-							-
Imports	39,874	8,545	5,185	24,834	518	17		78,974
Exports						443		443
Inputs to International Marine Bunkers								-
Stock Changes		-	-	6,446				6,446
ENERGY TRANSFORMATION	(39,874)	8,183	8,090	(10,852)	1,618	4,070	871	(27,895)
Electricity Generation				(25,450)		(17)		(25,467)
Petroleum Refining	(39,874)	8,183	8,090	14,760	1,618	6,352	871	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(163)				(163)
Other Transformation								-
Own Use						(2,266)		(2,266)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	16,728	13,275	7,536	2,136	3,644	871	44,190
ENERGY DEMAND	-	16,728	13,276	7,536	2,137	3,643	871	44,190
INDUSTRIAL SECTOR	-	-	671	7,111	-	903	-	8,685
Iron and Steel								-
Cement				3,331				3,331
Fertilizers				226		903		1,129
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				3,326				3,326
Textiles								-
Building Materials								
Non-specified Industry			671	228				899
TRANSPORT SECTOR	-	10,376	4,999	251	320	-	579	16,525
Road		10,376	3,969					14,345
Rail			779					779
Water			251	251				501
Air					320		579	899
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	553	1,232	-	1,785
Urban					430	1,218		1,649
Rural					123	14		136
AGRICULTURAL SECTOR	-	-	1,502	-	-	-	-	1,502
Field Operations			786					786
Processing/Other			716					716
FISHERIES SECTOR	-	-	856	142	-	-	-	998
Large Ships			764	40				804
Collectives/Processing/Other			92	102				193
MILITARY SECTOR	-	6,352	5,248	32	1,199	-	292	13,123
Trucks and other Transport		5,639	95					5,734
Armaments		36	174					211
Air Force		395			1,199		292	1,886
Naval Forces		281	4,884	32				5,198
Military Manufacturing								-
Buildings and Other			95					95
PUBLIC/COMMERCIAL SECTORS					65	65		131
NON-SPECIFIED/OTHER SECTORS			-		-			-
NON-ENERGY USE						1,442		1,442

Total Energy Use

Our balance shows a total of 1703 PJ of primary (not end-use) energy used by DPRK in 1990, or about 77 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[128]. By 1996, this total had decreased to 943 PJ, or about 43 GJ per person, of which over one-sixth was biomass.

2.5.2. Energy supply, including exports and imports

Coal made up approximately 78 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 just under 10 percent. By 1996, coal was less than 73 percent of supplies, and biomass contributed 18 percent. Hydroelectricity (counted at 3600 GJ per GWh electricity generated) accounted for about 4.6 percent and 2.8 percent of the national energy supply in 1990 and 1996, respectively, with imported crude oil and refined products supplying the remaining approximately 8 percent in 1990 and 7 percent in 1996. Imports—by energy content, about 51 percent crude oil, 31 percent coal and coke, 6 percent wood, and 12 percent refined petroleum products in 1990—made up only about 13 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 44 petajoules per year in 1990, and 12 PJ in 1996), but no electricity exports, since electricity generated at border dams from generators owned by China, and not appearing as imports to China in China Customs Statistics, are not counted as exports in this version of our energy balances.. Figures 2-8a and b show the fuel shares of the total DPRK energy supply for 1990 and 1996, while Figures 2-9a and b shows the components of exports, imports, and domestic production by fuel type and for all fuels.

[128] 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 2-8a:

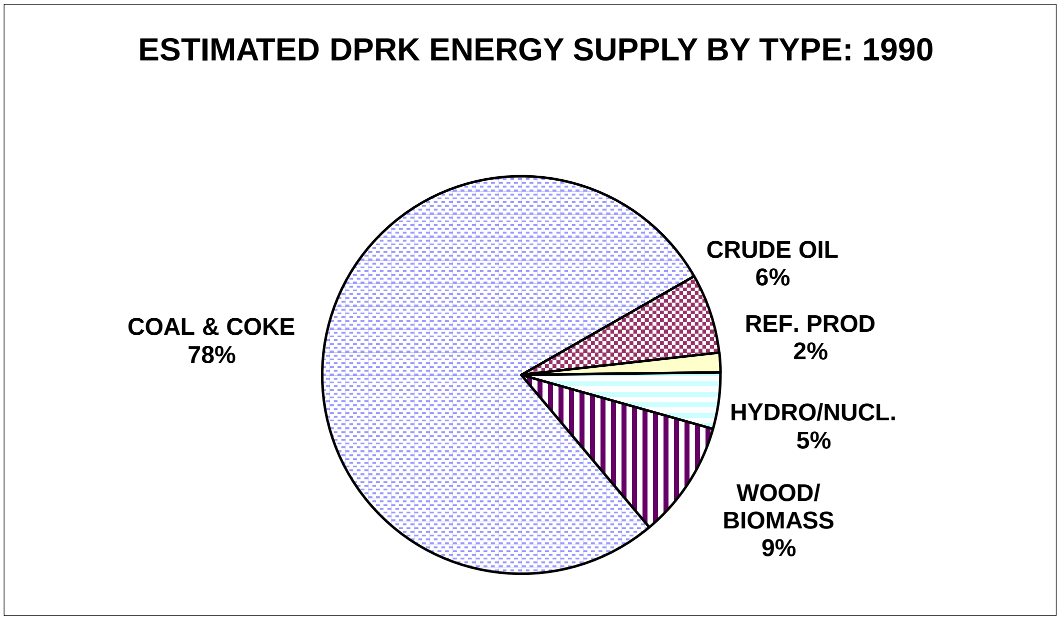


Figure 2-8b:

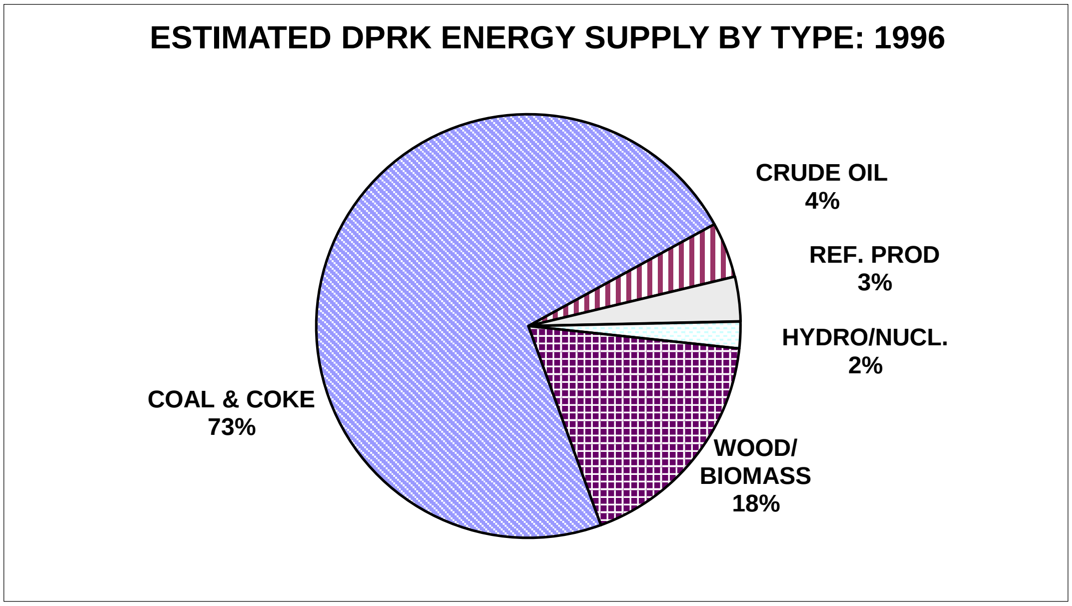


Figure 2-9a:

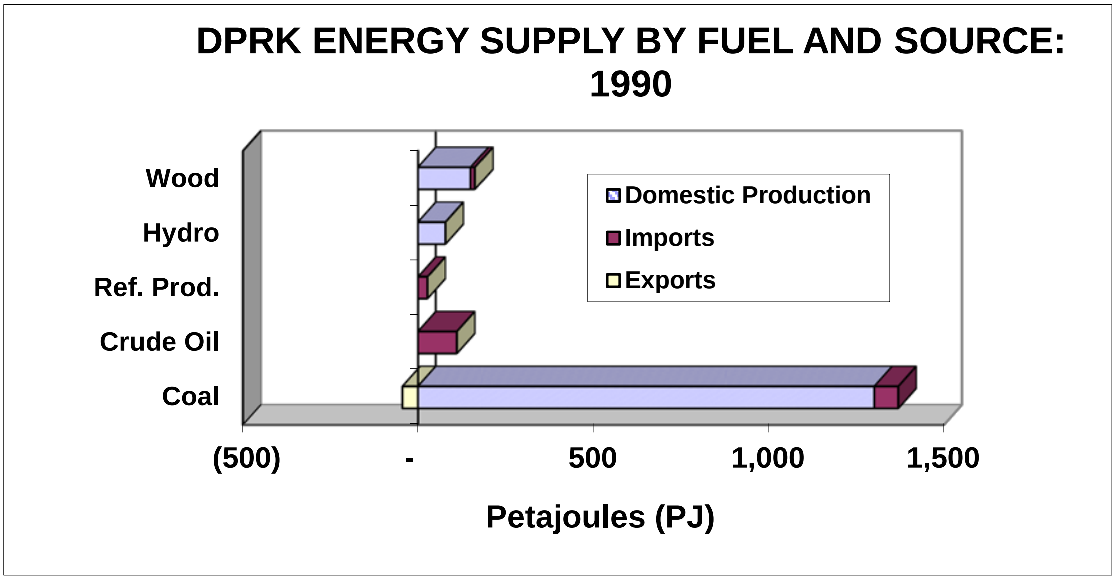
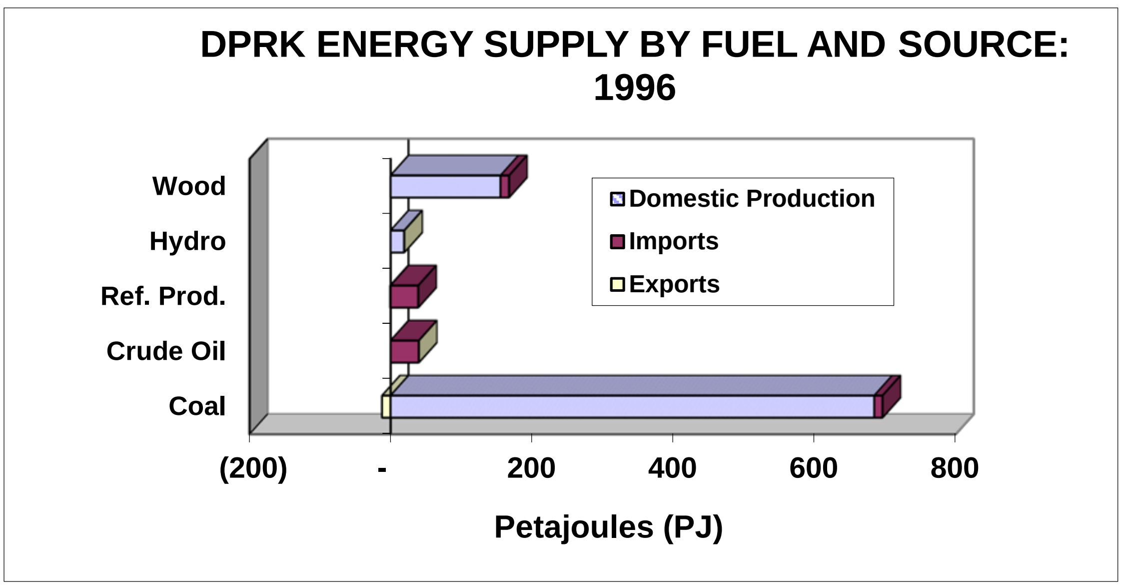


Figure 2-9b:



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, 16 percent of refined petroleum products (domestically refined and imported), and all (by definition) of the hydro energy used in 1990, and 30 percent of coal and coke plus 32 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 50 percent of refined products in 1996. Petroleum refining losses (own use) amount to approximately 5.4 percent of the crude oil input to refining.
- Coal production in 1990 used 8.5 PJ of electricity, just under 5 percent of gross national generation, and 4.1 PJ in 1996 (also 5 percent of generation).
- In 1990, charcoal production consumed 9.9 PJ of wood, producing 3.0 PJ of charcoal. Charcoal production in 1996 consumed 7.9 PJ of wood, producing 2.4 PJ of charcoal.
- "Own use" of fuels occurs for two fuel types: coal and electricity. The coal is consumed in coal mining operations 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 12.4 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 1.2 percent of total production on a calorific basis. Electricity losses in 1990 totaled 23.6 PJ, 14.3 percent of total gross generation[129]. Losses in 1996 were proportionally higher, totaling over 16 PJ, or over 20 percent of generation. District heat losses were estimated at about 14 percent of heat production (counting heat produced in both dedicated district heating plants and central combined heat and power units) in 1990, and about 18 percent in 1996.

2.5.4. Energy demand in 1990 and 1996

Of the total final energy demand in the DPRK in 1990, 71 percent was estimated to be provided by coal, 11 percent by wood and biomass, 9 percent by electricity, 8 percent by refined petroleum products, and a fraction of a percent each by charcoal and heat (Figure 2-10a). If charcoal and wood/biomass are excluded, the fraction of fuel demand provided by coal rises to 81 percent. Figure 2-10b 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.

[129] 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 2-10a:

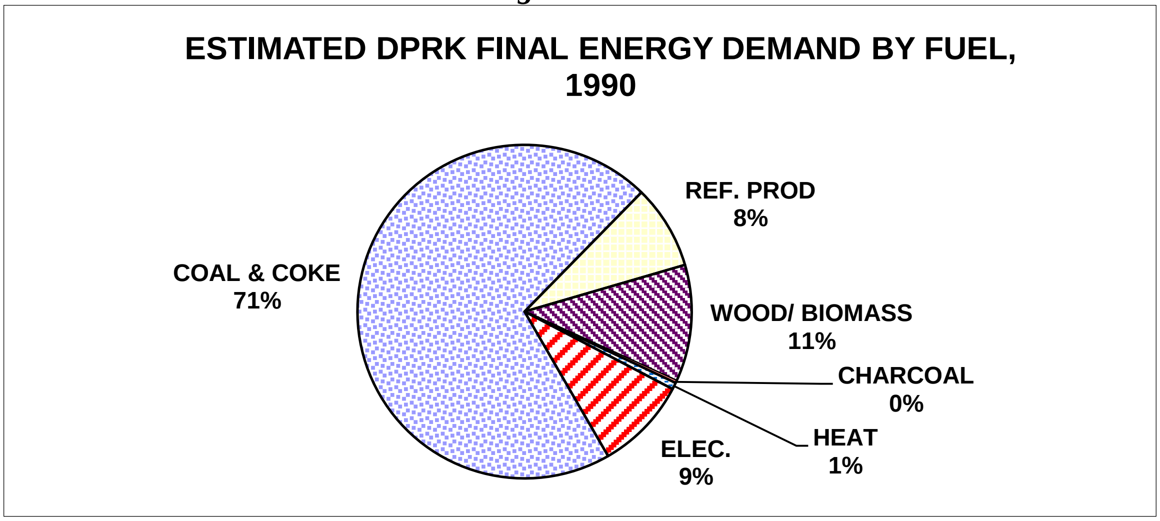
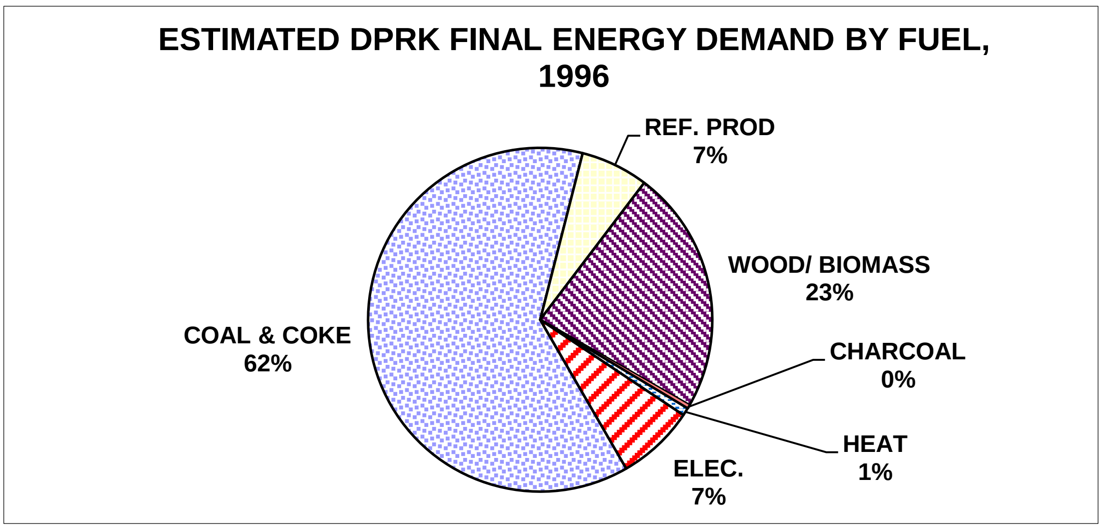


Figure 2-10b:



Looking at the sectoral shares of total energy demand, the industrial sector was estimated to be responsible for 776 PJ of total energy use, about 58 percent of all demand in 1990, but only 285 PJ (and 41 percent of demand) in 1996 (Figures 2-11a and b and 2-12a and b). In 1990, the residential sector contributed 22 percent of demand (29 percent of which is wood and biomass), and the transport, agricultural, military, public/commercial, and non-energy uses each contribute between about 2 and 5 percent to total fuel demand. The share of residential energy consumption increased 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 2-11a:

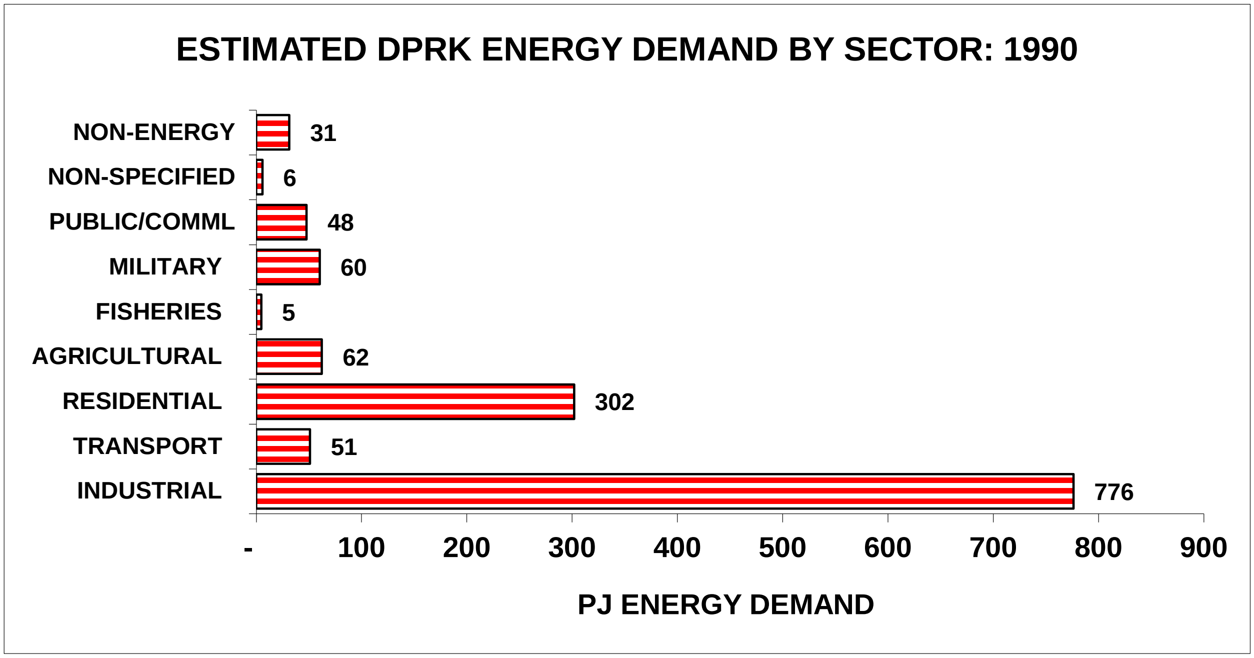


Figure 2-11b:

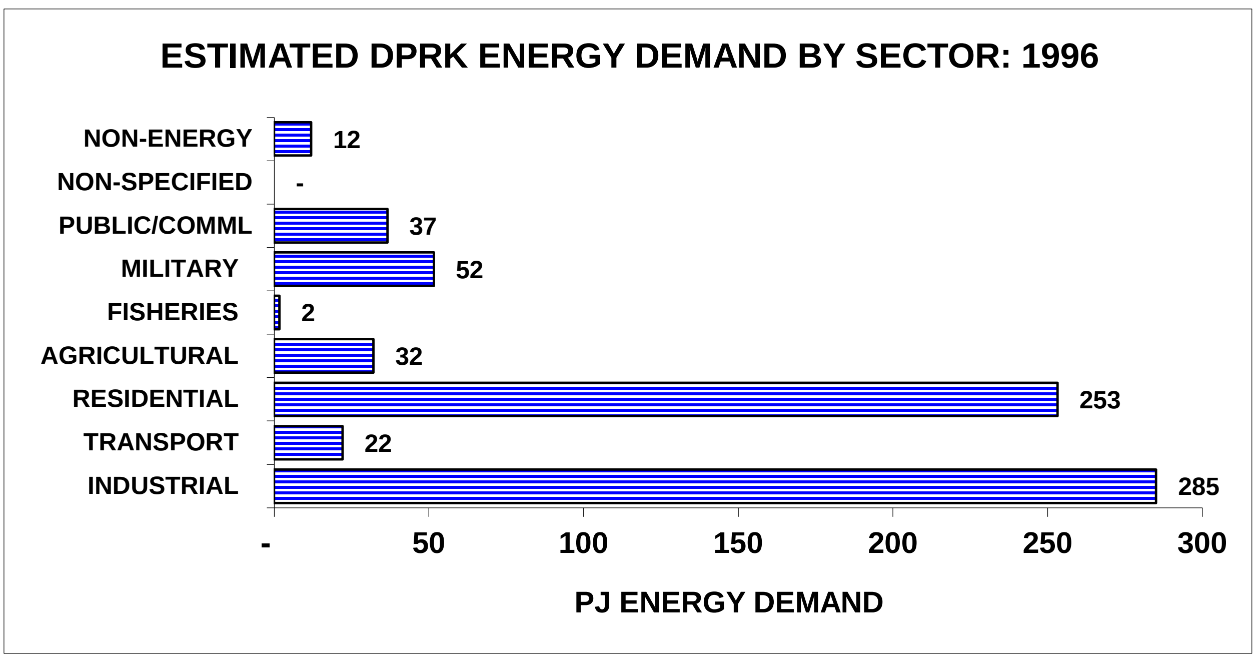


Figure 2-12a:

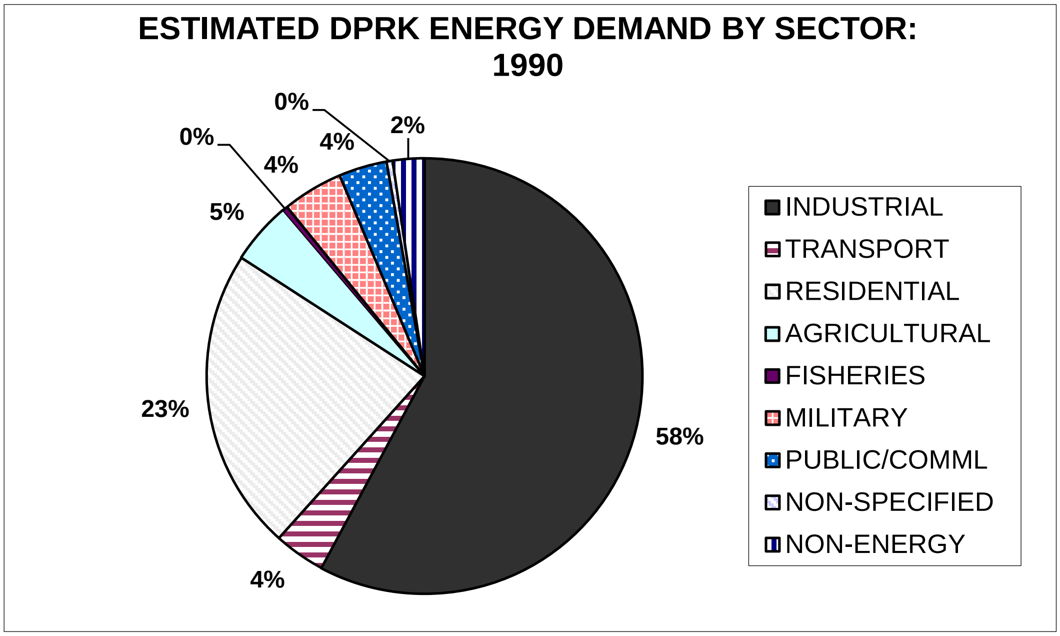
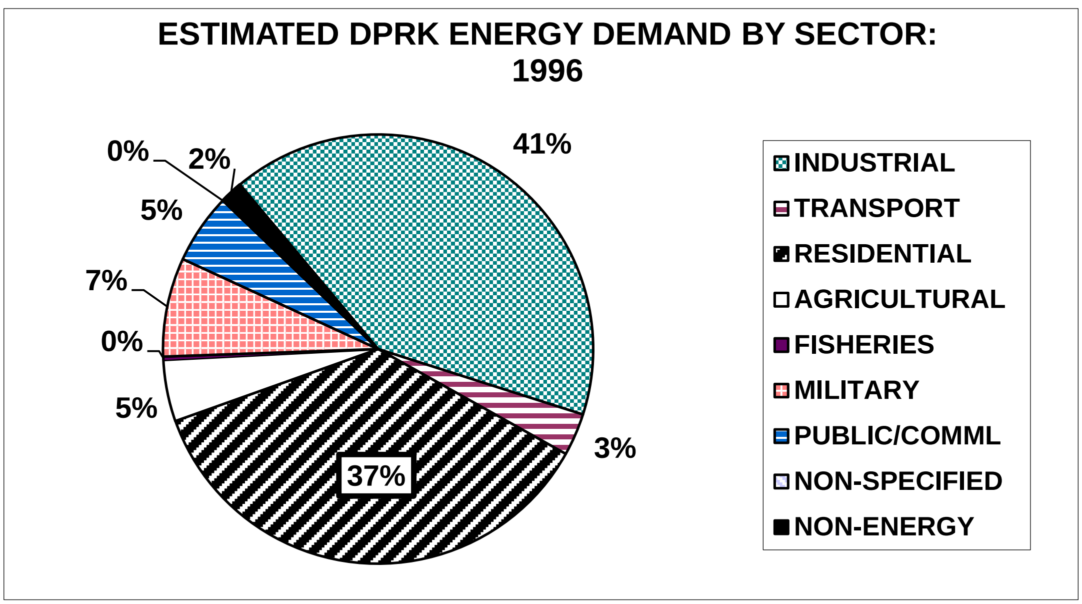


Figure 2-12b:



When consumption of specific fuels are considered, industry accounted for 71 percent of final demand of coal in 1990 (58 percent in 1996), while the residential sector accounted for 20 percent (28 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 2-13a and b).

Figure 2-13a:

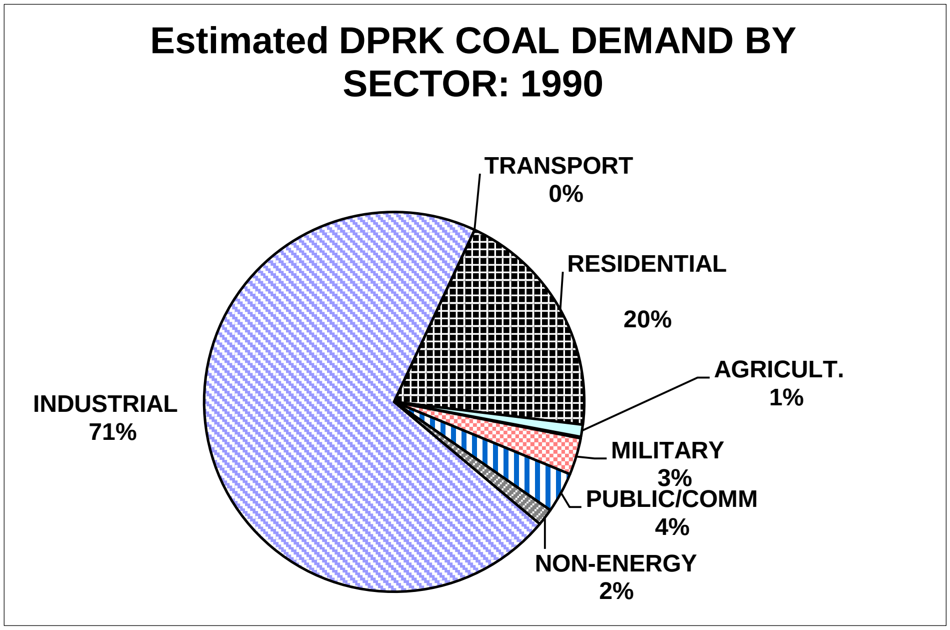
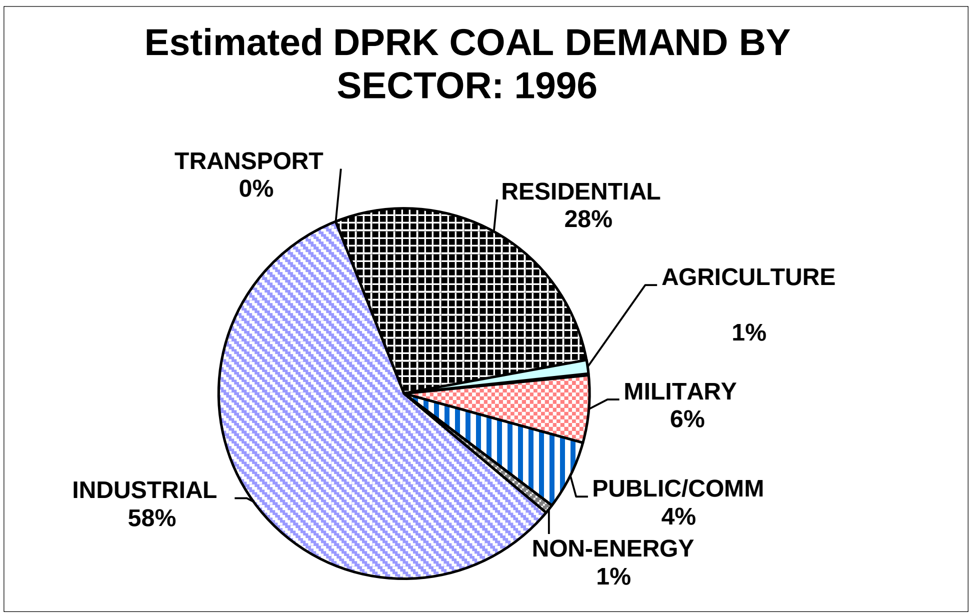


Figure 2-13b:



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 15 percent, respectively (Figure 2-14a). 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[132]. The major difference is that our balance includes much more use of heavy oil. Figure 2-14b 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 (though somewhat less absolute demand) in 1996, with substantial decreases in the fraction of petroleum products used by the residential, industrial, and non-energy sectors.

Figure 2-14a:

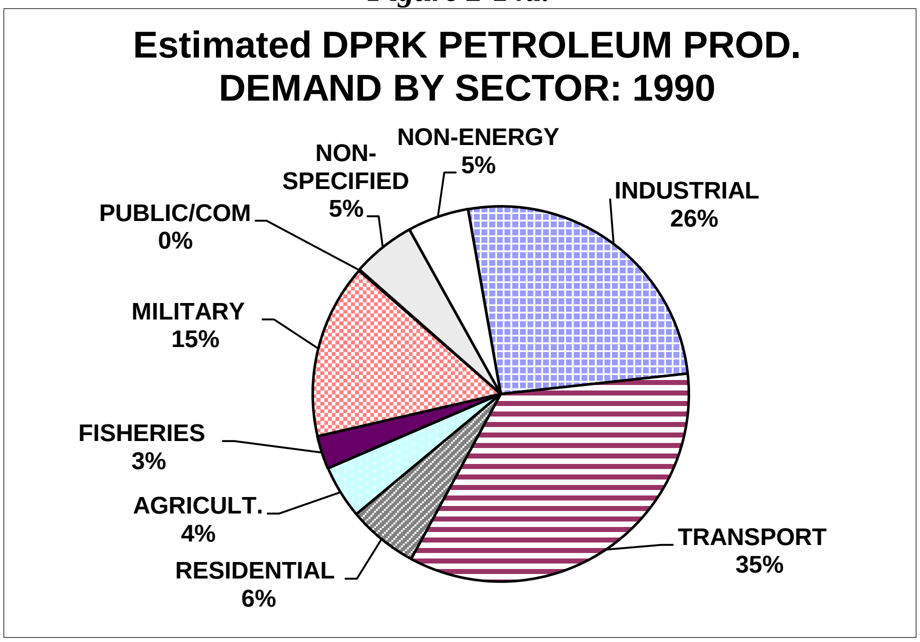
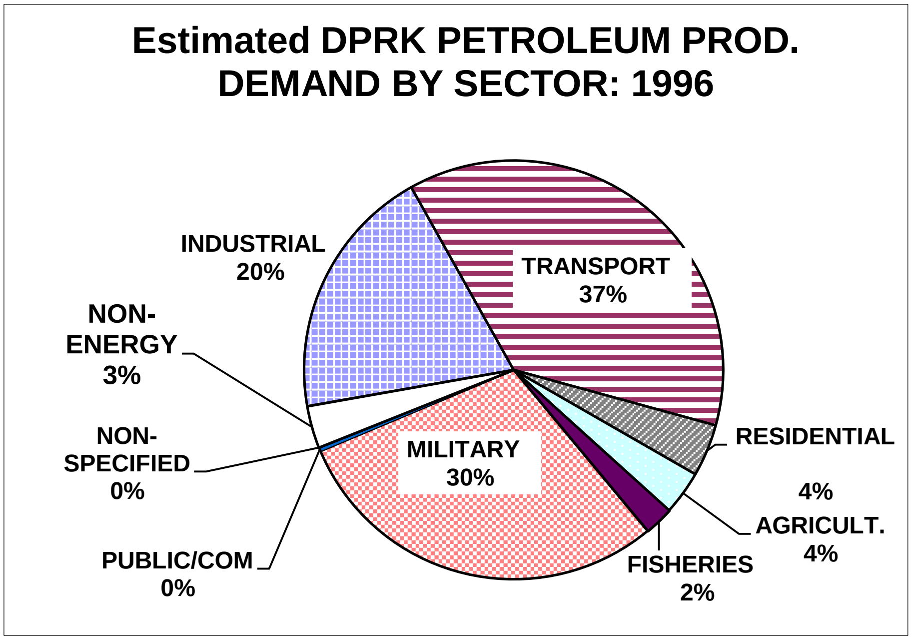


Figure 2-14b:



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 have used 10 percent, residences 9 percent, the military 12 percent, and the public/commercial sector approximately 5 percent of the electricity supplied to end-users (Figure 2-15a). The pattern for 1996 is shown in Figure 2-15b.

Figure 2-15a:

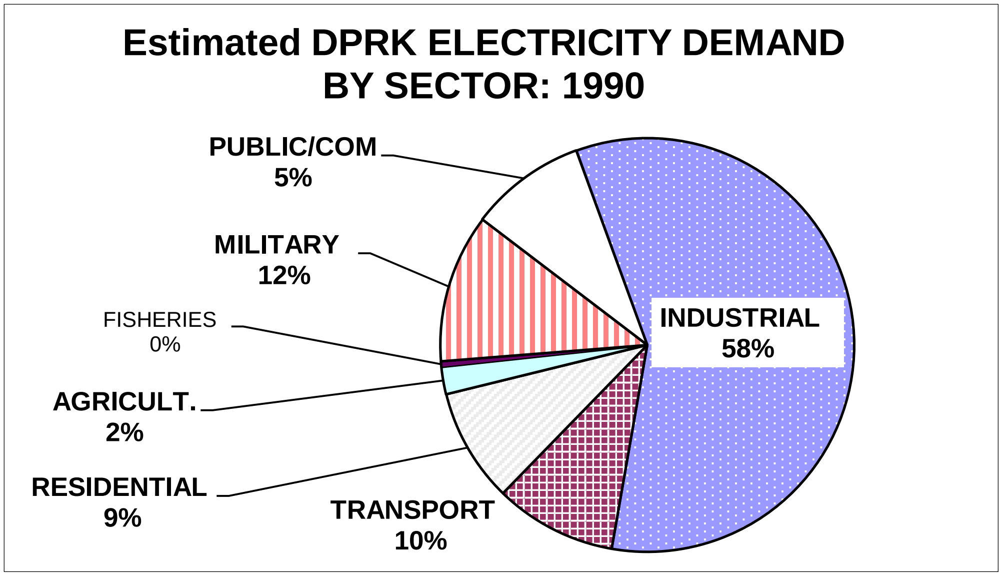


Figure 2-15b:

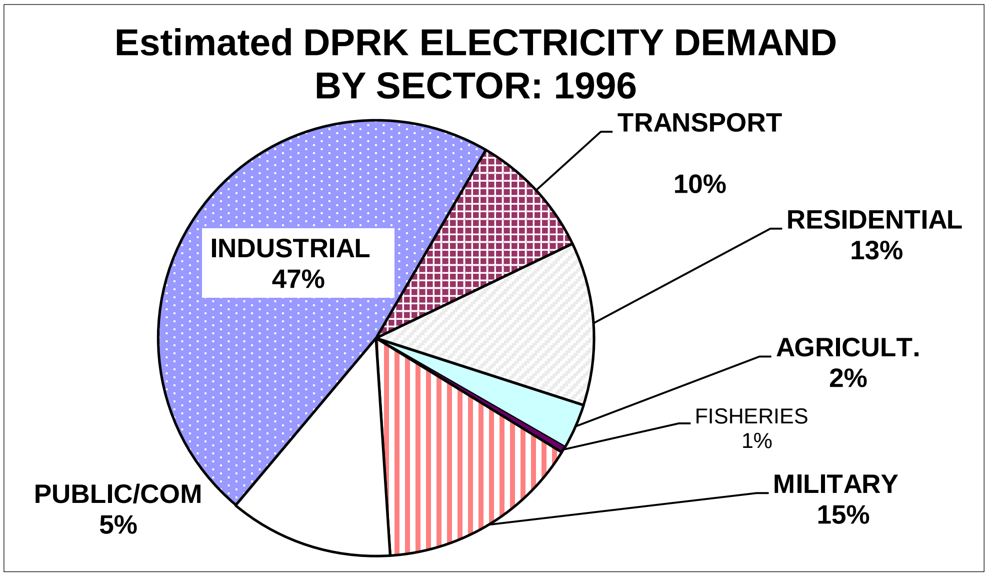


Figure 2-16a shows the estimated 1990 DPRK *Industrial* energy demand by fuel and by subsector. Coal was the dominant fuel in all subsectors except "Other Minerals", where we have included an estimate of petroleum products used for carbide production. The iron and steel production subsector was the largest consumer of coal in our estimate (nearly half of sectoral use, as shown in Figure 2-17a), while iron and steel, fertilizers, other chemicals, and cement were together responsible for approximately 67 percent of industrial sector electricity use (Figure 2-18a). The cement industry was another major consumer of fuels, accounting for an estimated 10 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—accounted for a substantial fraction of fuel use in our 1990 estimate. We would hope to obtain better information in order to reduce this fraction. Figures 2-16b, 2-17b, and 2-18b present industrial sector results for 1996.

Figure 2-16a:

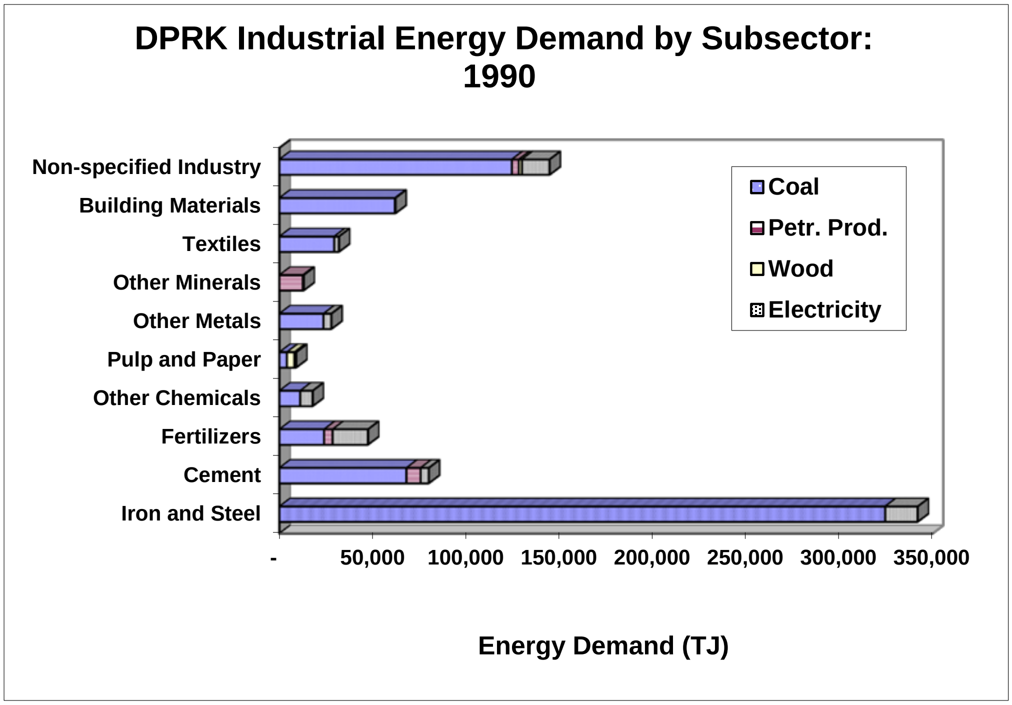


Figure 2-16b:

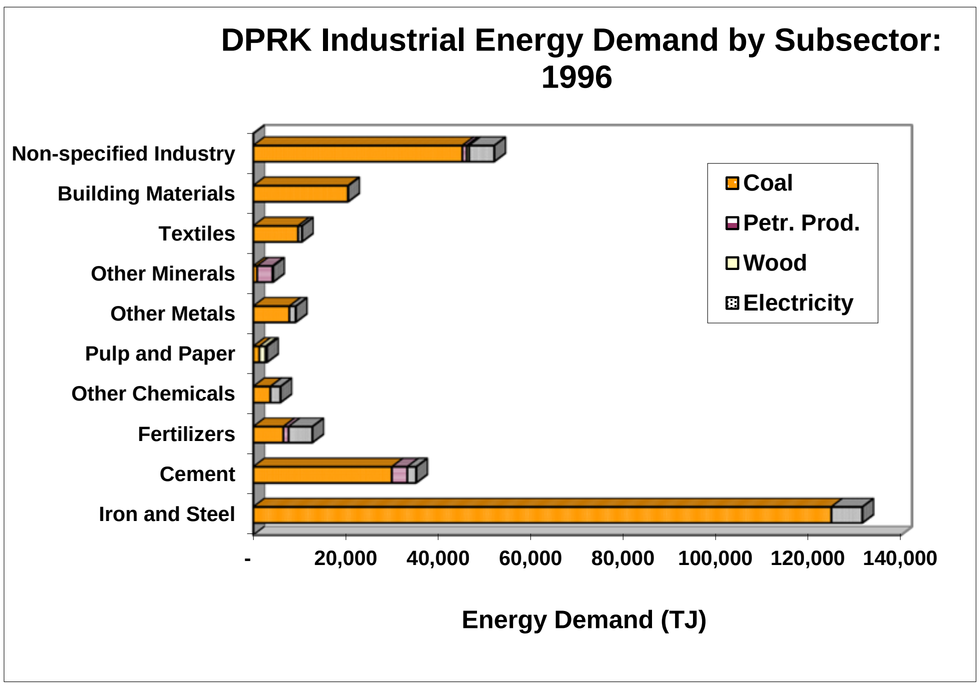


Figure 2-17a:

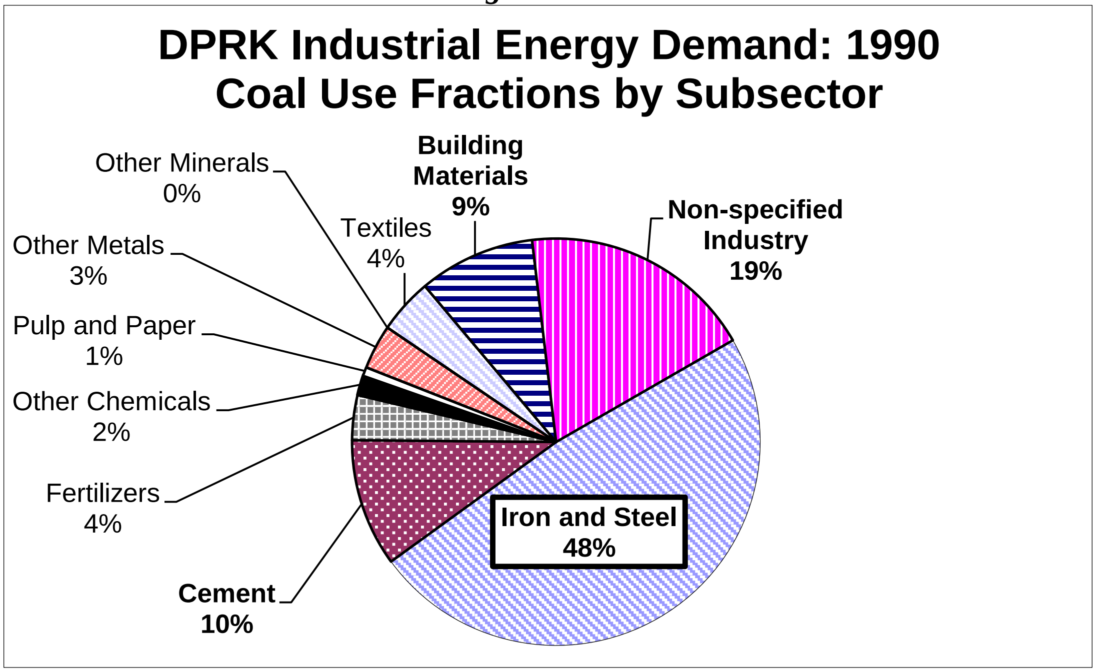


Figure 2-17b:

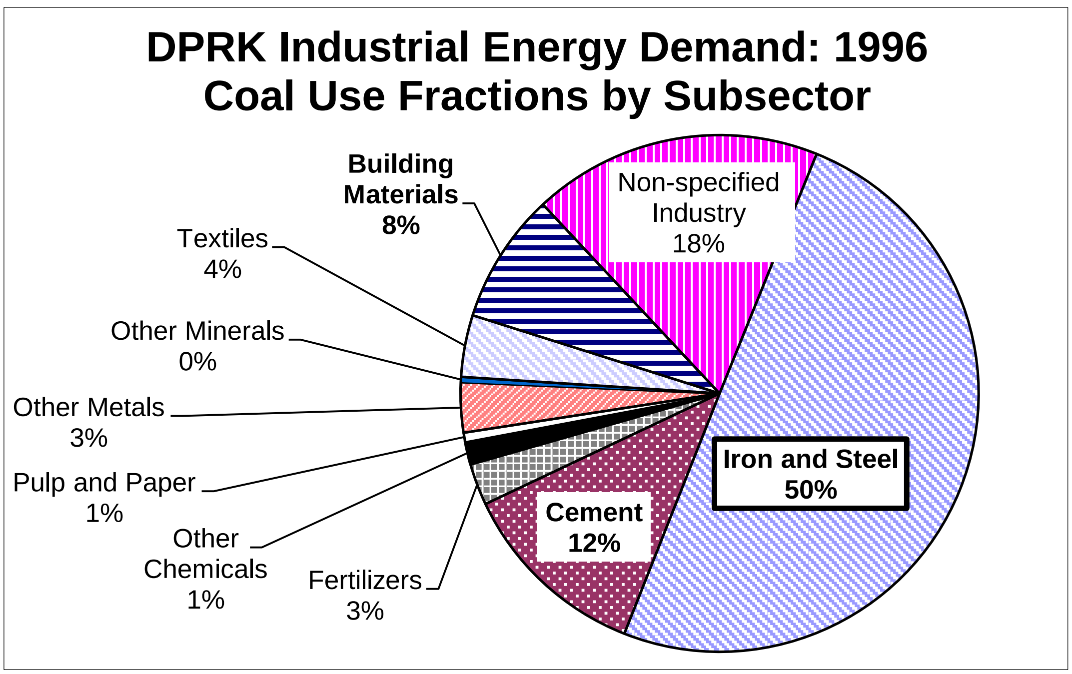


Figure 2-18a:

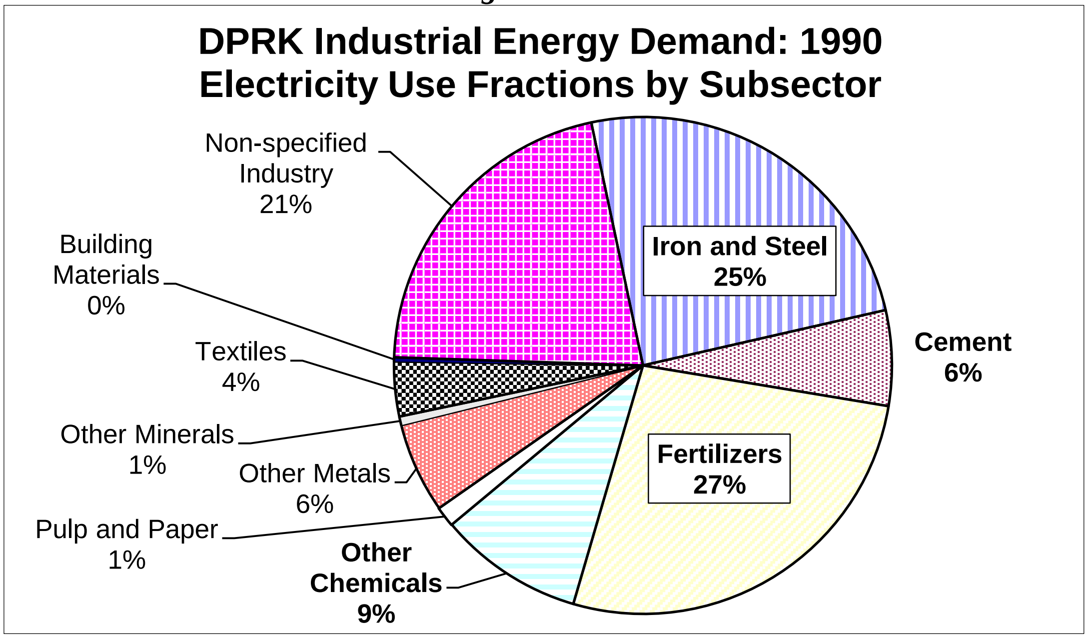
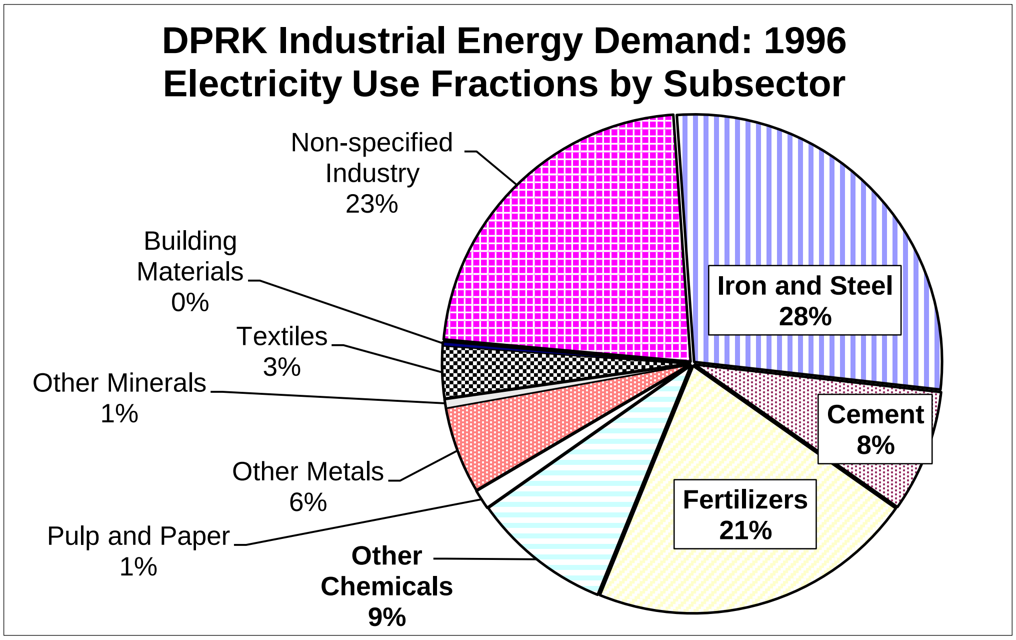


Figure 2-18b:



Transport sector energy demand as of 1990 was dominated by petroleum products used in the road transport subsector, as shown in Figure 2-19a. 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 have consumed approximately 10,900 TJ of electricity in 1990, 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 consumed about 3 percent of the total transport petroleum products used, though these values must be regarded, pending receipt of better information, as order-of-magnitude estimates only (see Figure 2-20a).   Similar qualitative patterns in subsectoral consumption, but with much lower absolute levels of fuels use, are shown for 1996 (Figures 2-19b and 2-20b).

Figure 2-19a:

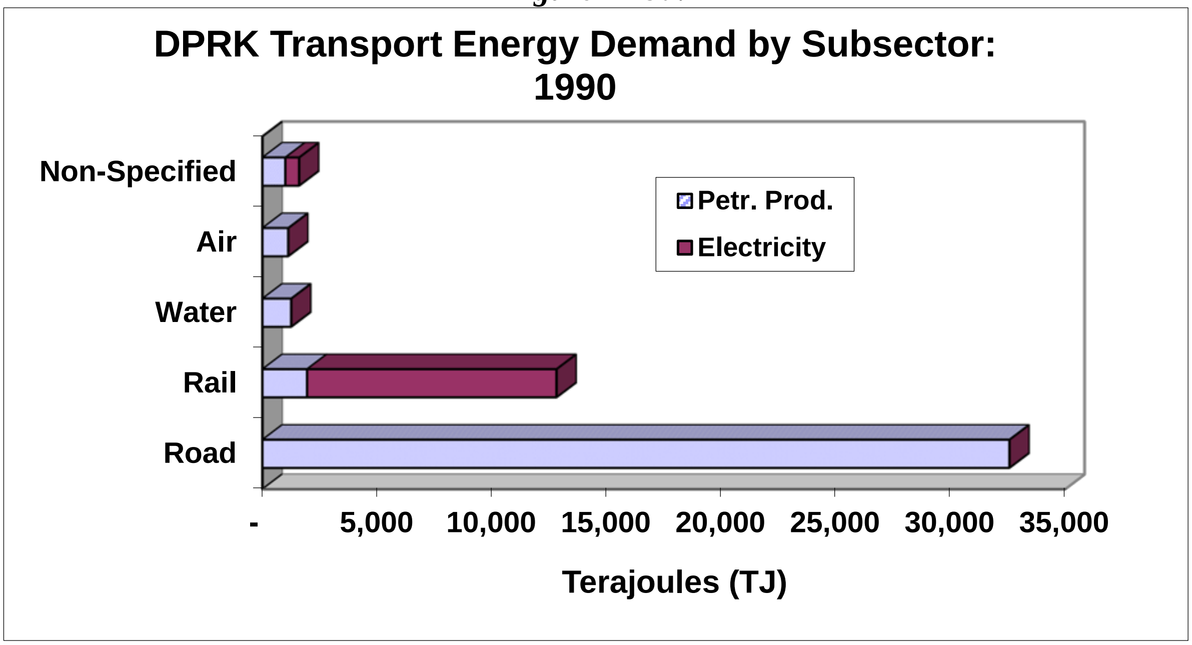


Figure 2-19b:

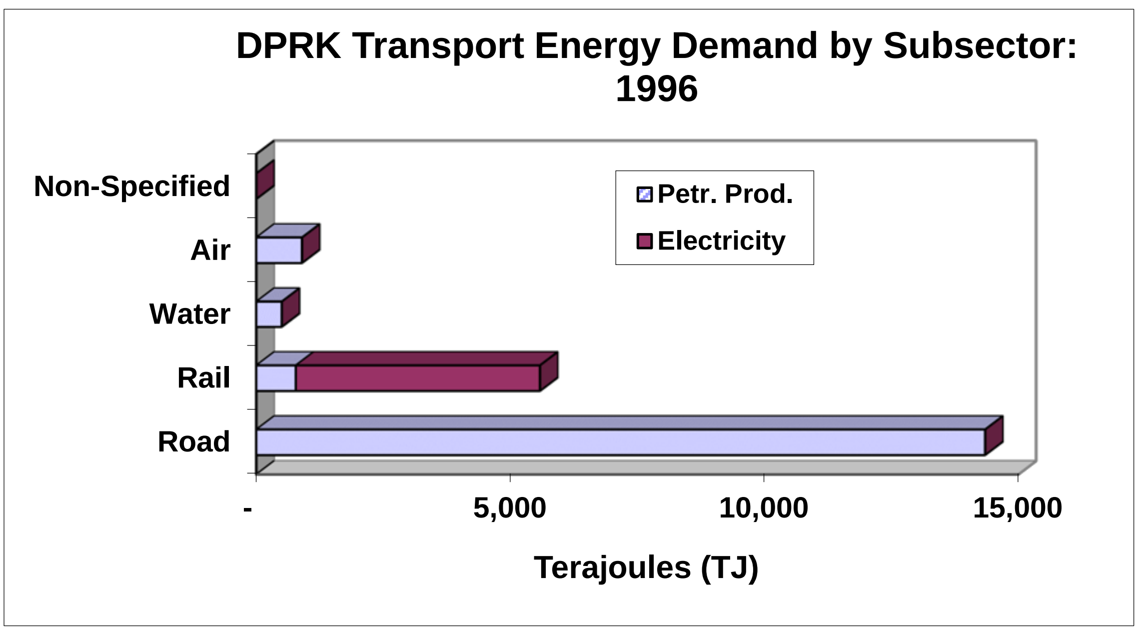


Figure 2-20a:

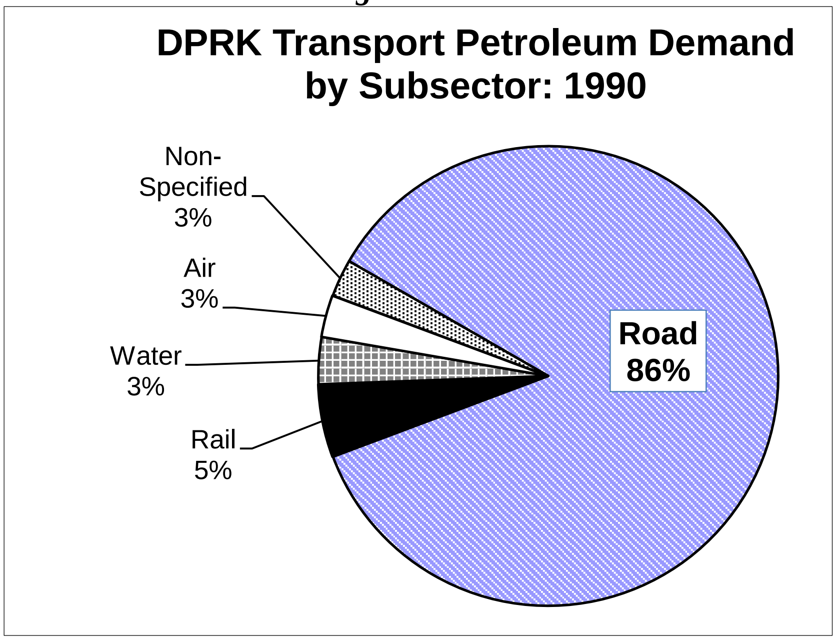
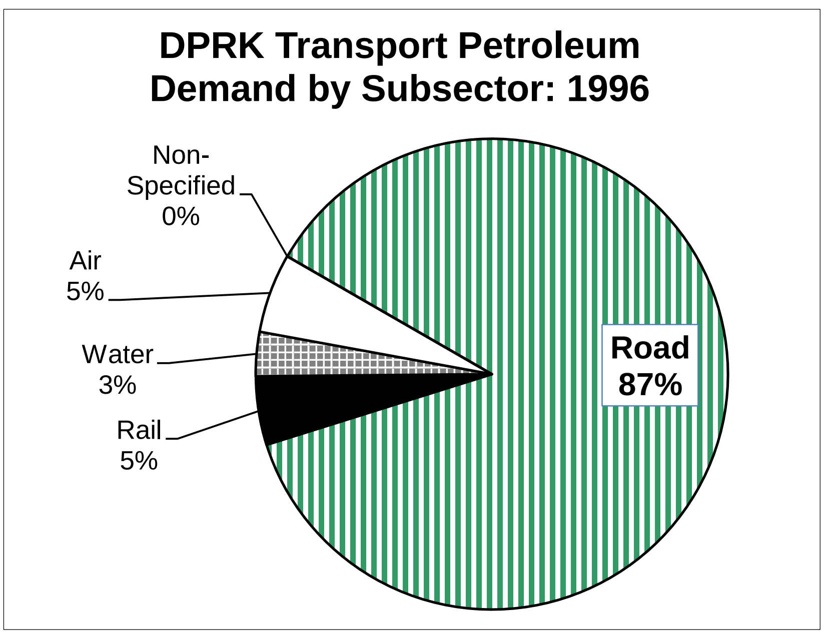


Figure 2-20b:



Demand in the *Residential* sector, as shown in Figures 2-21a and 2-21b (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 nearly 70/30, while more than twice as much electricity is estimated to have been used, in aggregate, in urban households than in rural households in 1990. This ratio is even larger in 1996. Wood fuel use in 1990 was, by assumption, limited to the rural subsector, and amounts to approximately 6.6 (dry) tonnes of wood fuel use per household using wood fuel per year, or an average of somewhat under 20 kg per day. Refined petroleum products (kerosene and LPG) and charcoal were assumed to be used for cooking in urban households, with LPG and kerosene also used in a limited number (2 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 increased by about 25 percent relative to 1990 levels.

Figure 2-21a:

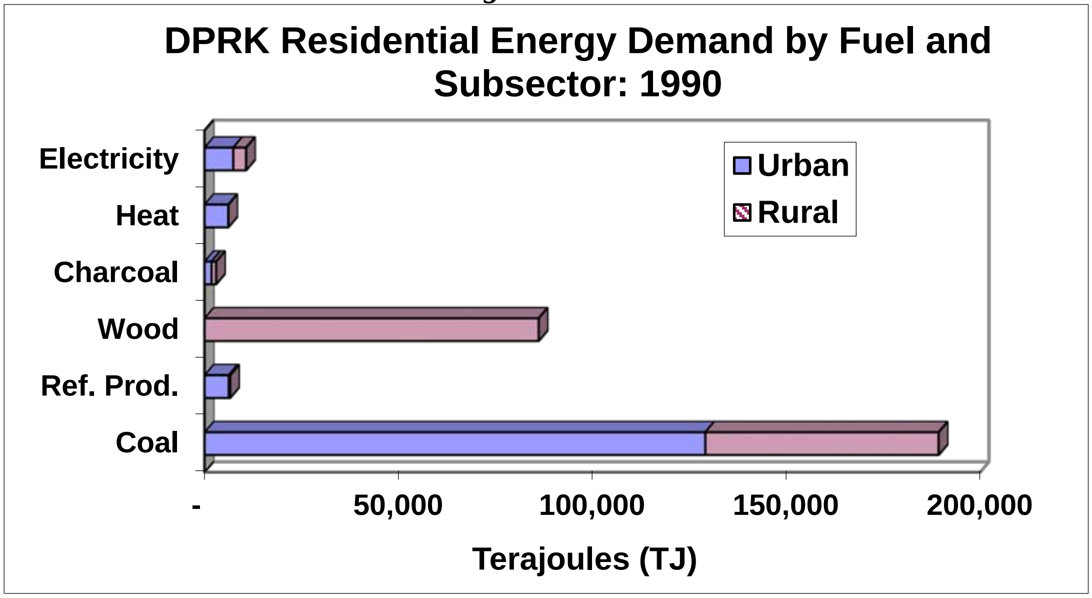
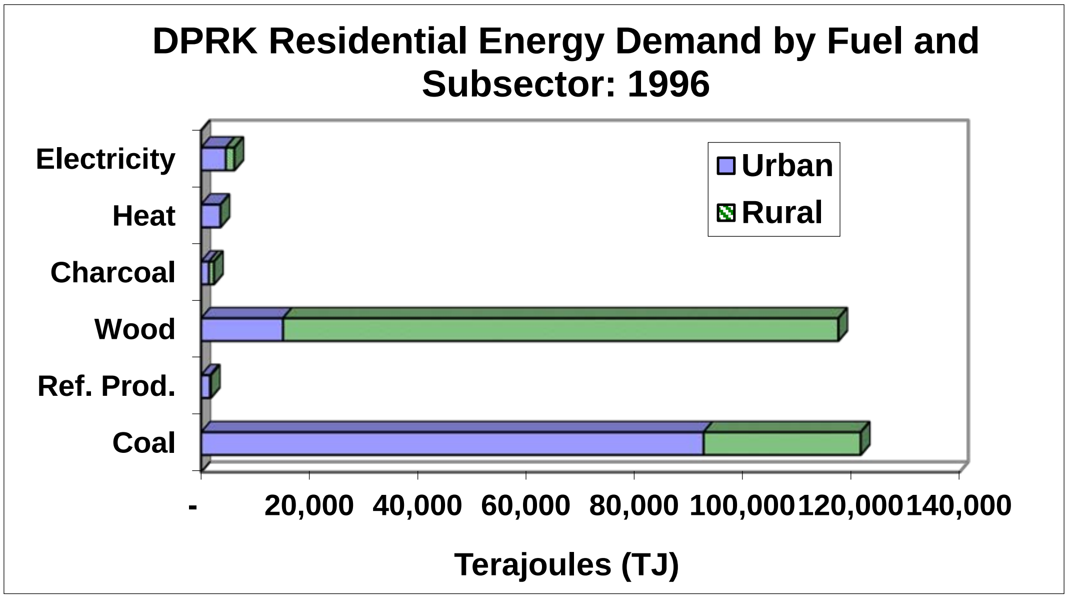


Figure 2-21b:



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 have totaled about twice the use of petroleum products in 1990, and over three 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 72 and about 74 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 (520 TJ) un 1990, but this amount is calculated using US-based (Alaskan) estimates of electricity consumption per unit processing facility output, and thus could be significantly different in the DPRK[133]. Fisheries energy use in 1996 is estimated to have been 36 percent of 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 2-22a and 2-22b. Total estimated sectoral demand for coal and electricity was dominated by use in military buildings (48 and 23 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 2-23a and 2-23b 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 were also likely to be 2 1/2 tonne trucks, for the most part, in 1990—the share of estimated military oil use by these trucks climbs to 43 percent. Aircraft accounted for about 14 percent of military petroleum demand in 1990, accounting for about the same fraction in 1996. Though aircraft use a great deal of fuel per hour of use, we have assumed that their use (especially use of fighter and bomber aircraft) is very 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 (27 percent in 1990), with tanks and other heavy armaments using a small fraction of total fuel demand, as their use in routine exercises by the DPRK military is estimated to be fairly limited (just 2 percent in 1990). Overall, in 1990, ground forces and naval forces each consume about 43 percent of total military petroleum products, with air forces using the remainder.

Figure 2-22a:

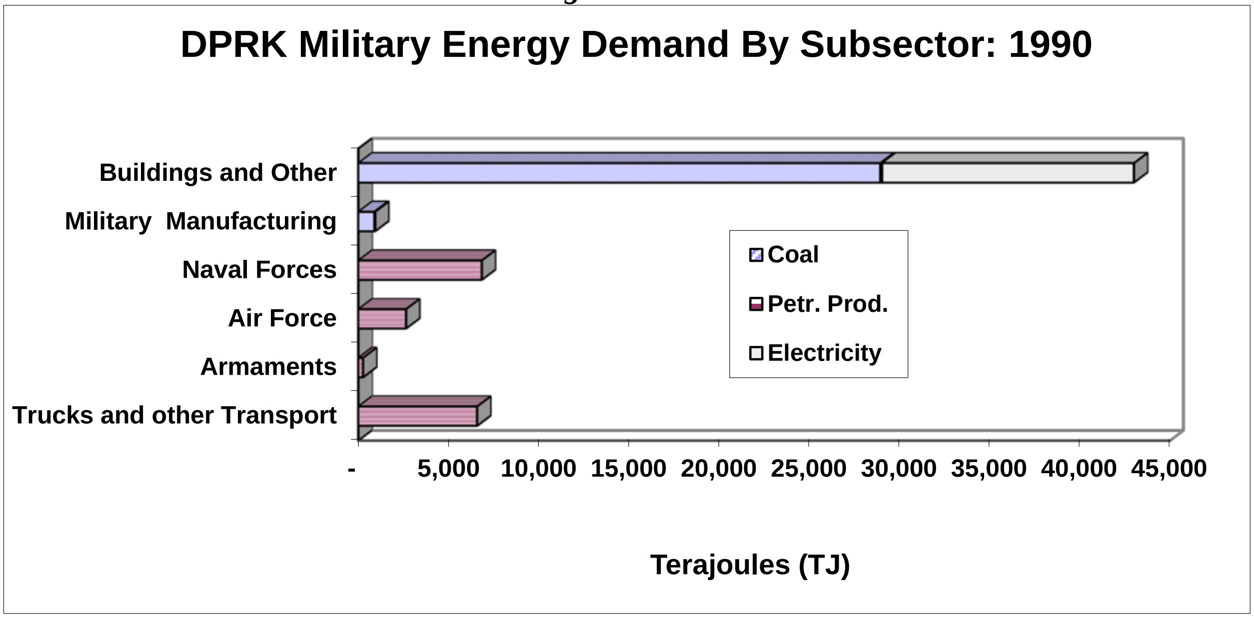


Figure 2-22b:

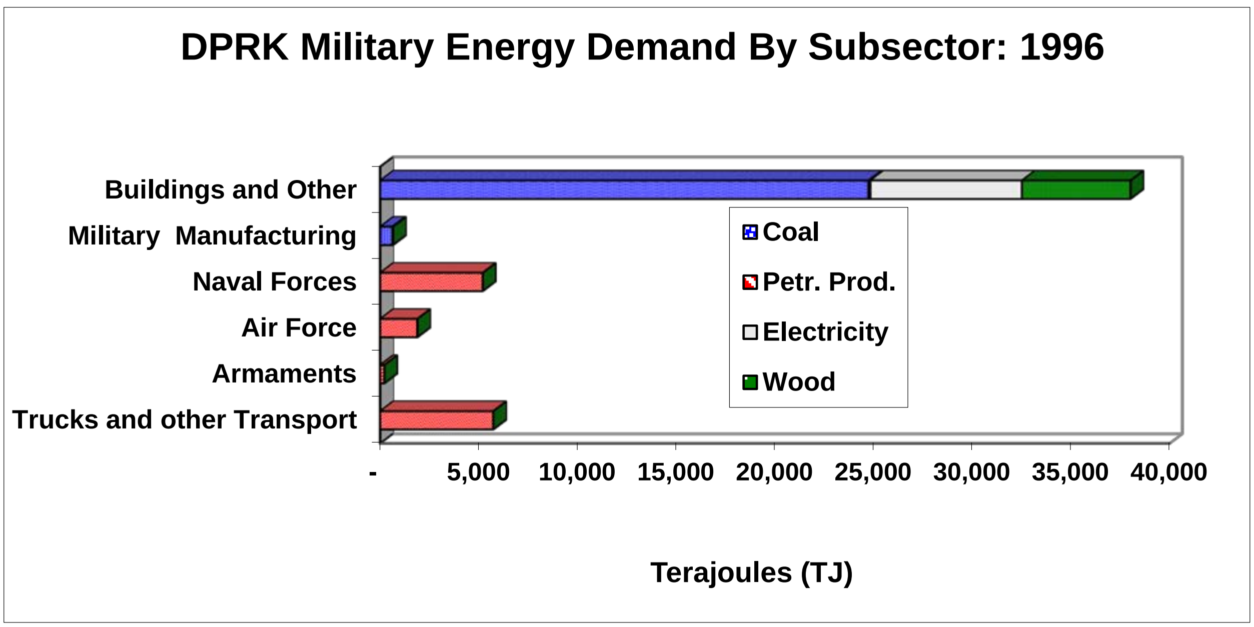


Figure 2-23a:

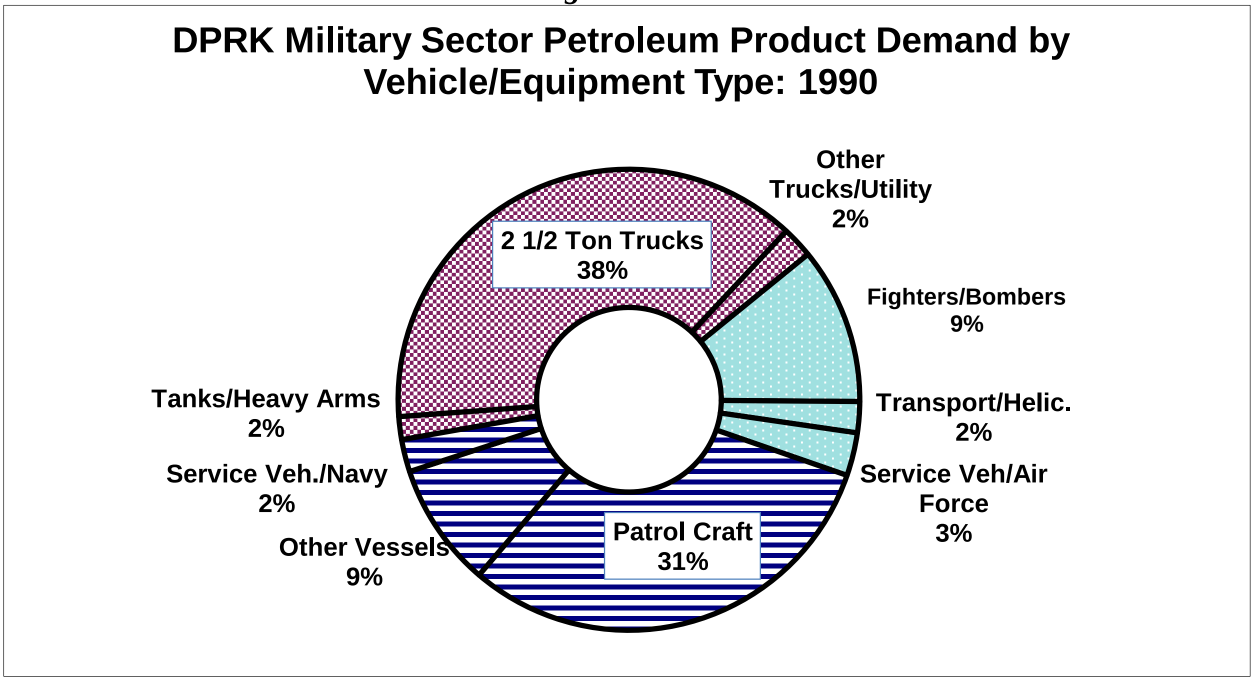
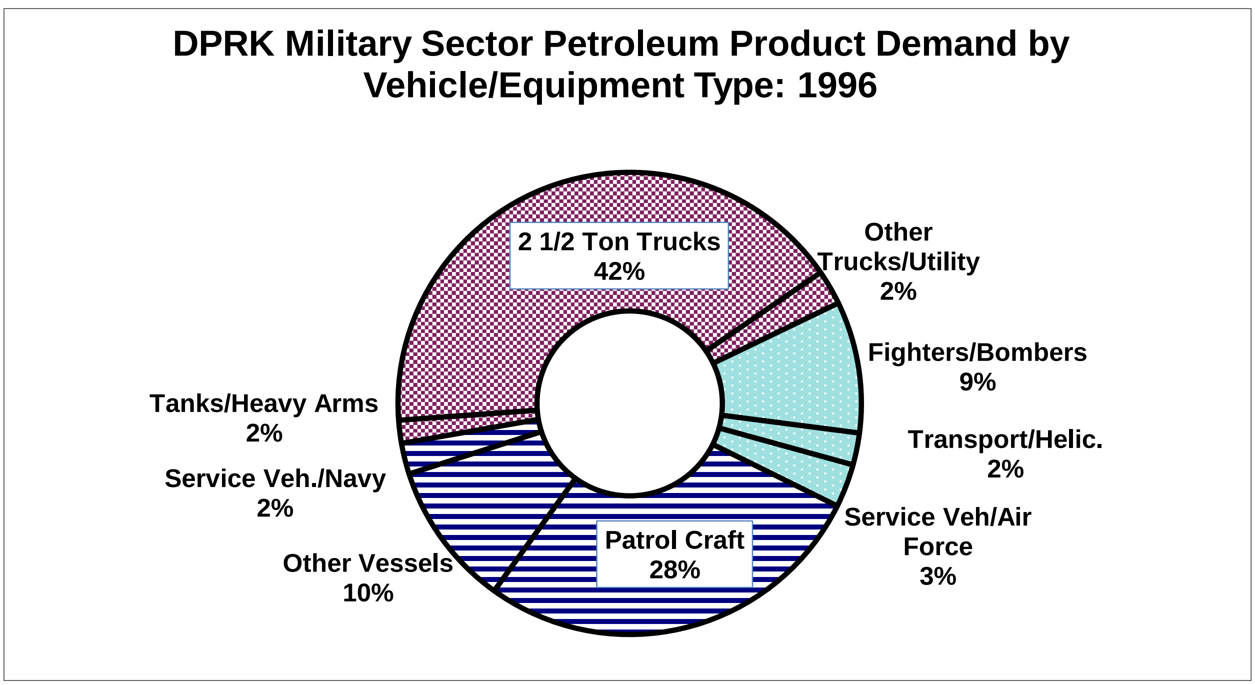


Figure 2-23b:



Our estimates of fuel demand in the *Public/Commercial* sectors are limited to coal, heat, and electricity used in public and commercial buildings, at roughly 33, 2.6, and 11 PJ, respectively, in 1990, and 26, 1.6, and 6.2 PJ in 1996, plus a small amount of use of refined products (about 0.10 and 0.13, in 1990 and 1996, respectively, or 0.3 and 0.5 percent of coal use) and wood for heating (1.6 PJ in 1990, and 2.6 PJ in 1996). We have included a relatively modest 5.9 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 and oil products used as feedstocks in fertilizer production, other non-energy use of oil products (for example, as lubricants or road construction materials), as well as wood used in construction, furniture making, pulp for paper, and other non-fuel uses. These quantities were approximately 14, 5.8 and 12 PJ for coal, oil products, and wood, respectively, in 1990, and 3.4, 1.4, and 7.2 PJ, respectively, in 1996.

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

There is no doubt that our estimated balances 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 needed is 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 the use of coal and other 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 (though they seem roughly consistent with figures from the 2008 DPRK Census).
  - -- 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 in the DPRK 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[130].
- *Fisheries Sector*
  - -- 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 (and amounts of 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*
  - -- Improved information/estimates on the average annual exercise tempos (hours per year in use) for military equipment, including tanks, trucks, light vehicles, planes, and naval vessels.

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

-- An estimate of what fraction of the DPRK's military hardware (by category) is typically operable/operated.

-- A better-grounded 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, particularly for products such as bitumen/asphalt.

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 2.5.4), 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 in part 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).
- More complete 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 annual rainfall and hydroelectric generation (or potential generation).
- More complete information on the impacts of the 1995 and 1996 floods on major hydroelectric plants, and estimates of the work and time that were 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 (though it is quite possible that accurate data on losses simply do not exist).
- 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[131].
- 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?).
- 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.

[131] 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.

2.5.8. Key uncertainties in 1996 energy data

The 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 the DPRK 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 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 Korean 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**: To what extent 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 held that it would take an investment of $1 billion or more just to keep the system from getting worse, but others thought that the system was not getting any worse as of 1996 (though history seems, based on the reports of most observers, to have proven them wrong, at least for the years from 1996 on). Report as of 1996 indicated that power outages, at least in the Pyongyang area, were 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, though it seems likely, based on information obtained since 1996, that little progress had actually been made. 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 and/or lack of electricity, 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[132], was used in some other way in the DPRK economy, or was somehow exported[133]. 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 to enter the DPRK in tanker trucks, train cars, coastal freighters, and individual barrels? Does the output of the small refinery in China that we understand has historically shipped oil products to the DPRK vary substantially from year to year[134]? Does the DPRK get a representative share of the output of that refinery, or are the products that the DPRK receives weighted toward the lighter fractions (of which the DPRK is and was 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 or coal-fueled trucks in the DRPK certainly were relatively common 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, and we have seen

[132] 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.

[133] Export markets for HFO accessible to the DPRK may have been limited, given a general glut of heavy fuel oil on the Asian market relative to other petroleum products as of the late 1990s.

[134] 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).

pictures of such vehicles. Others who have extensive experience in the DPRK profess to have seen them not at all or rarely. If biomass trucks (like the one shown in Figure 2-24) 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 7.6 percent of road freight we have assumed, the estimated availability of gasoline (and diesel) for other uses would decrease somewhat.

Figure 2-24: Photo of DPRK Truck Powered by a Coal (and/or biomass) Gasifier[134]

3. Estimated 2000, 2005, 2008, and 2009 Supply/Demand Energy Balances

3.1. Overall Approach

Our overall approach to preparing DPRK energy supply-demand balances for the years 2000, 2005, 2008, and 2009 included:

- Starting with the estimates of demand and supply prepared as above for 1990 and 1996.
- Modification of the 1990/96 estimates (and, for 2005 and on, year 2000 estimates) of demand for fuels to reflect reports of recent changes in conditions in the DPRK. These included changes in population, data (mostly from customs statistics of the DPRK's trading partners) on the availability of oil products, observed changes in the DPRK 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 and 2005 (and more recent) electricity demand.
- Revision of our 1996 estimates of electricity supply to meet 2000/2005/2008/2009 electricity demand and to reflect information about changes, by each balance year, in thermal and hydroelectric generating capacity (and its availability).
- Estimation of 2000 through 2009 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 those years (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, kerosene, and LPG/other).
- 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 2000/2005/2008/2009 energy balances, 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 and beyond, 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. Much of the analysis described here for the year 2000 energy balances was carried out for the 2002/2003 version of our energy sector analysis, but has been updated for this version of this report to make it consistent with information and insights received since 2003.

To further update energy balances to the year 2005, we took advantage of the invaluable input provided by the participants in the June, 2006 DPRK Energy Experts Working Group Meeting, held in East Palo Alto, CA, USA, in collaboration with (and co-hosted by) Stanford University's Preventive Defense Project[135]. In addition, as in our earlier (2002/2003) work, we reviewed available literature and news reports, and contacted experts in the field to augment the information at hand. Much of the analysis described for the 2005 energy balances was carried out for the 2007 version of our energy sector analysis, but has also been updated to reflect more recent information.

To produce updated estimated energy balances for 2008 and 2009, we similarly reviewed literature and news reports available to us, reviewed customs and other statistics (including the 2008 DPRK Census), consulted with experts including in the context of DPRK Energy Experts Working Group meetings in Beijing in 2008 and 2010[136].

The key assumptions and data used in preparing our estimated supply and demand balances 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

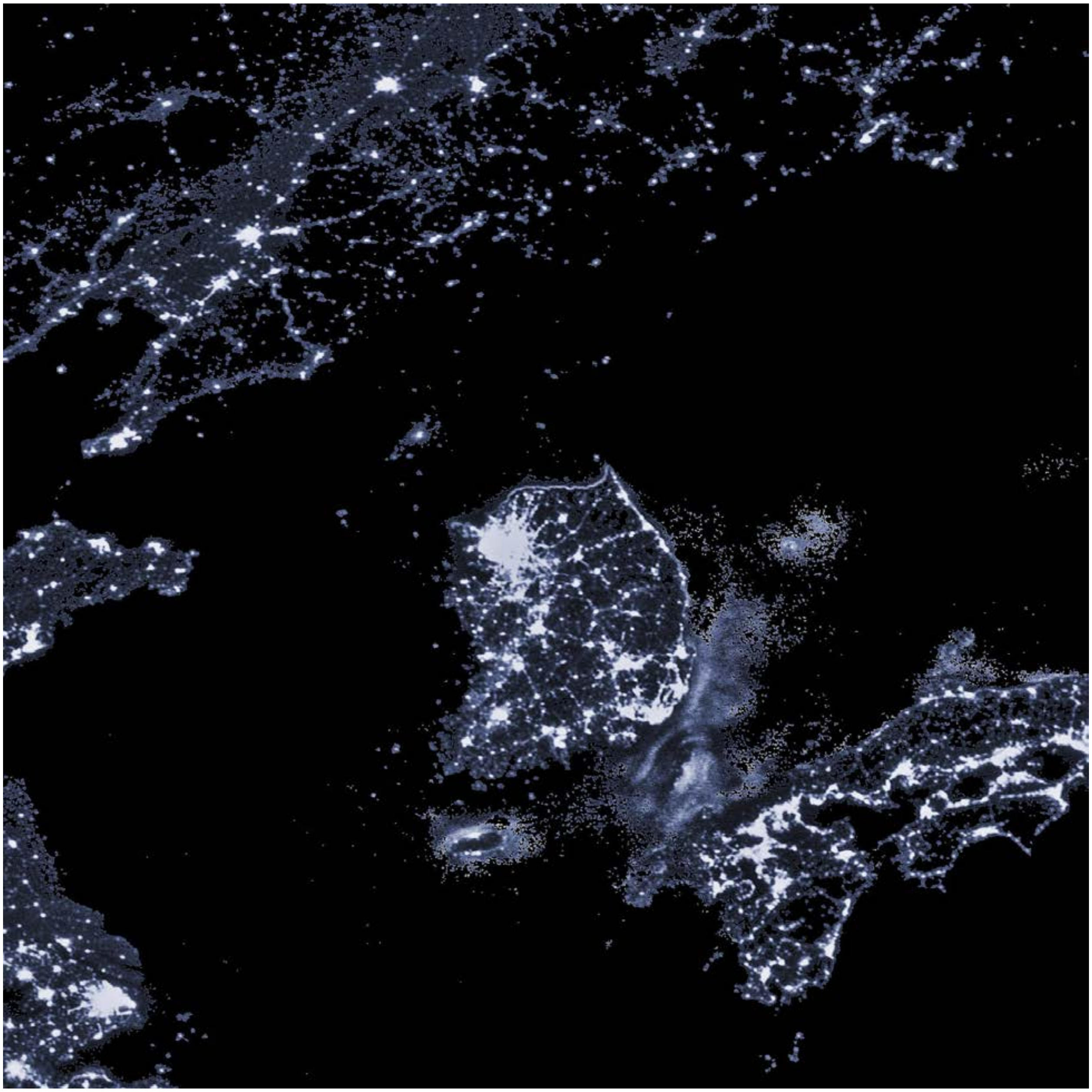
Changes in the DPRK energy sector between 1996 and 2000 were, for the most part, of a substantially more incremental nature than the changes in experienced during the first half of the 1990s. Individual changes are discussed in section 3.4, below. Among the key changes (or continuing processes) for the energy sector between 1996 and 2000 were:

- A continuing **decline in the supply of crude oil** from China, significantly reducing the overall output of the DPRK's remaining operating (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 3-1a and b present views of the lights of Northeast Asia from space as of 2000 and 2010 in which it is clear that significant amounts of electricity were 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).

[135] Please see http://nautilus.org/projects/by-name/dprk-energy/2006-meeting/ for information on and materials from this meeting.
[136] See http://nautilus.org/projects/by-name/dprk-energy/2008-meeting/ and http://nautilus.org/projects/by-name/dprk-energy/2010-meeting/ for information and materials from these meetings. The 2010 meeting also included a session on the minerals sector in the DPRK.

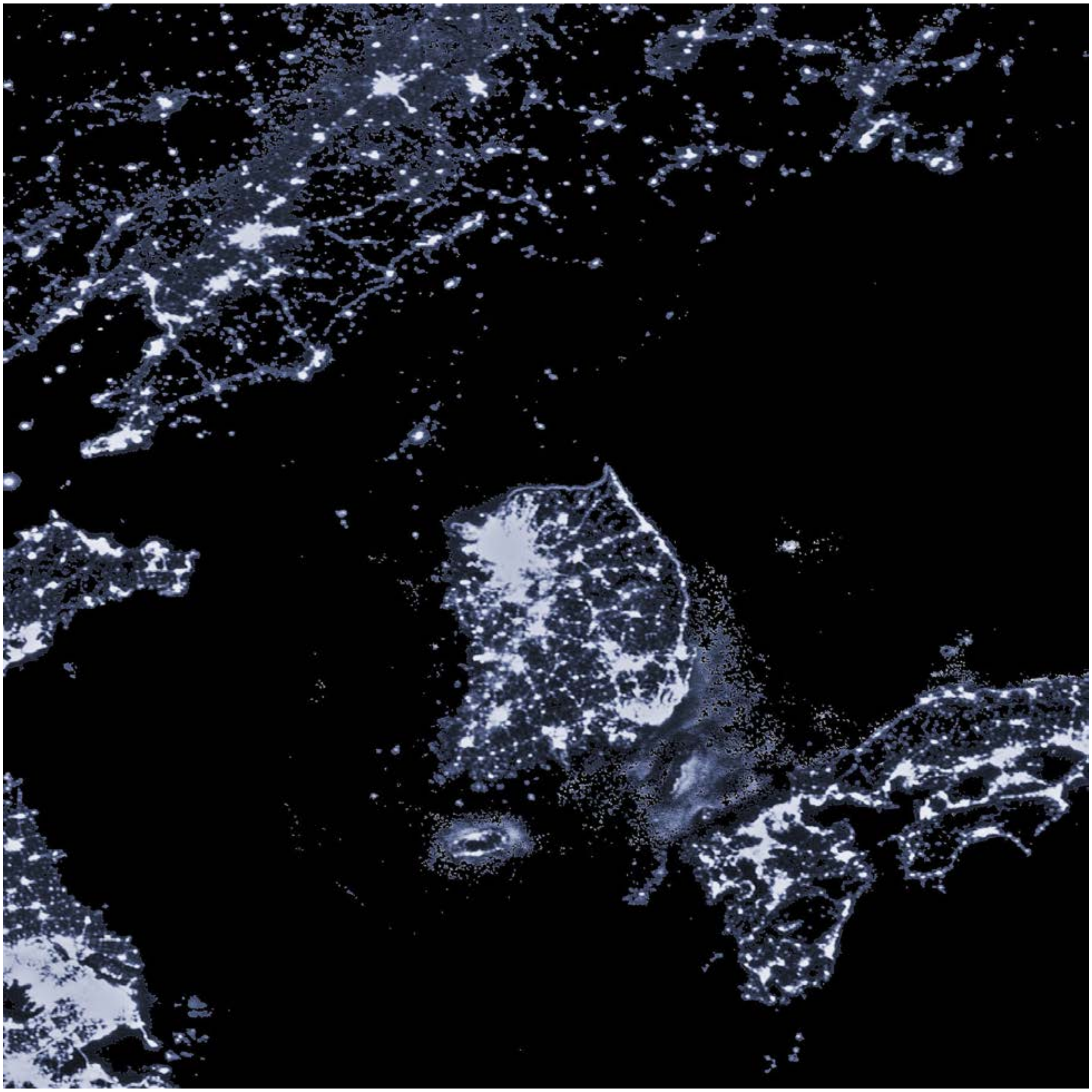
- Some **imports of used motor vehicles** (which are more efficient than existing vehicles made in North Korea).
- A continued decline in the **production of cement and steel**.
- Evidence of significant international trade in **magnesite (or magnesia)**.
- Some increase in **military activity**, relative 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 3-1a: Korean Peninsula and Surrounding Area from Space, 2000[137]



[137] Generated from U.S. National Oceanographic and Atmospheric Administration (NOAA, 2012) National Geophysical Data Center website "DMSP-OLS Nighttime Lights Global Composites (Version 4)" (available as http://mapserver.ngdc.noaa.gov/cgi-bin/public/ms/gcv4/dl), using "stable lights average" image series. The image presented here has been enhanced by Nautilus from the originally downloaded image by a process of adjusting brightness, sharpening, and "colorizing" the overall image.

Figure 3-1b: Korean Peninsula and Surrounding Area from Space, 2010[138]



[138] Generated from the same NOAA (2012) set of images referenced in the previous footnote, but with a "stable lights average" image for the year 2010 instead of the year 2000. Although it may be tempting to do so, readers are cautioned not to draw firm conclusions about changes in electricity use in the DPRK in the decade of the 2000s by comparing these two images. Although we have used the same procedure for enhancing both images, the original NOAA images have not yet been calibrated to assure that the same points of light yield the same intensity in images from different years (NOAA staff, personal communication, February 2012). Even with this consideration, however, it is clear that the growth between 2000 and 2010 in electricity use (as indicated by the extent of city lights) in China, and to a somewhat lesser extent in the ROK, has not been shared by the DPRK.

3.3. Summary of Key Changes in the DPRK Energy Sector between 2000 and 2005

The period between 2000 and 2005 was one in which the DPRK government put in place elements of economic change, including policies encouraging some forms of private markets and private production, at least on a small scale, and some price and wage reforms. For the energy sector, the government encouraged the development of small and medium-sized local power plants, particularly hydroelectric plants. Though most changes to the energy system in the DPRK seemed to be incremental, as in 1996 to 2000, most observers noted at least a modest improvement in the availability of energy services between 2000 and 2005, though these improvements are by no means uniformly distributed over the country. Individual changes are discussed in section 3.5, below. Among the key changes (or continuing processes) for the energy sector between 2000 and 2005 were:

- Some **economic revival**, but mostly, it seems, associated with foreign aid (especially from the ROK) and/or with areas of the economy that are not energy intensive (the developing of a flourishing restaurant trade in Pyongyang is an example of the latter that has been notable to visitors). Small markets in which individuals sell food and household items have become more numerous and visible. Gauging the overall economy, the (ROK) Bank of Korea reported a net gain in GDP in the DPRK of about 8 percent from 2000 through 2004, though the methods used for making this estimate were not transparent[135]. Chinese estimates also showed growth in the DPRK economy during the period, but slightly lower than that estimated by the Bank of Korea. Chinese estimates reported 0.5 to 1 percent per year GDP growth from 2000 through 2004, with 2 percent growth in 2005.
- The **substantial breakdown of the country's central distribution system**, accompanied, according to anecdotal reports, with changes in employment and pricing of basic foodstuffs such that workers were often obliged to have jobs, at least nominally, in both the official (that is, in state-run factories or other government workplaces) and the private sectors to survive.
- Significantly expanded **exports of coal and other raw mineral products** (largely iron and steel scrap and metals ores) to China, with coal exports to China reaching 2.8 million tonnes in 2005[136]. This is one manifestation of a recent increase in investment in the DPRK by Chinese businesses, particularly in the raw materials sectors, but also, to some degree, in manufacturing[139]. In general, DPRK imports from China showed a trend of becoming more energy-intensive, and exports to China showed a trend of becoming more labor-intensive.
- Continued overcutting and ecological **degradation of biomass fuel supply** with reduction in fuel availability and related erosion, as coal remained hard to obtain, and wood and other forms of biomass continued to be heavily used for cooking and heating, especially in rural areas.

[139] Issues related to Chinese investment in the DPRK, and changes in DPRK policies that have made investment possible, are addressed in the Nautilus Institute Policy Forum Online 06-70A, August 23rd, 2006, "DPRK's Reform and Sino-DPRK Economic Cooperation", by Li Dunqiu (http://www.nautilus.org/fora/security/0670Li.html). See also Professor Li's presentation as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as http://nautilus.org/publications/essays/napsnet/forum/security/0670Li.html.

- For agriculture, there was some **land re-zoning to larger plots** to encourage more efficient production, and **new natural-flow irrigation waterways** have been constructed to replace some of the need for electric irrigation pumps. Some new wind-powered water pumps, probably for local drinking water, have been introduced in the Western DPRK. Mechanization in agriculture remained low, however.

- In the transport sector, the DPRK **imported thousands of automobiles and trucks, and tens of thousands of bicycles**, from China in the years 2000 through 2005.

- **Cessation of KEDO heavy fuel oil** deliveries in 2002.
- **Continued problems with production in the coal sector**, including with electricity supply to provide basic needs such as air supply, lighting, and pumping of water out of mines. There was some localized investment in coal mines by Chinese firms.
- **Discussions and agreements by the DPRK regarding oil and gas exploration**, including with the Chinese government, the Russian Gazprom, and at least one Western company.
- Supply of modest amounts, by the end of 2005, of **electricity to the Kaesong** industrial area from the ROK.
- **Electricity imports from China** (also modest in scale).
- Construction of **smaller, mostly hydroelectric power plants** (many of which are possibly not connected to the main grid).

3.4. Summary of Key Changes in the DPRK Energy Sector from 2005 through 2009

The years 2006 through 2009 included some periods of marginally improved relations between the DPRK and the international community, as exemplified by agreements at the Six-Party Talks, but the period ended with relations between the Koreas and between the DPRK and the international community on a downward trajectory. Six-Party Talks agreements in February and October of 2007, a meeting between the leaders of the DPRK and the ROK, also in October of 2007, and the transfer of heavy fuel oil and materials and equipment to help rebuild energy infrastructure to the DPRK as a part of the Six-Party Talks agreements were highlights of the period. By the end of 2009, however, the Six-Party Talks were all but abandoned, the DPRK had conducted a second test of a nuclear explosive device, and had test-launched a rocket, bearing what it said was a communications satellite, on a trajectory over Japan[140], and prospects for additional near-term energy sector assistance from the international community looked bleak. Insofar as we can determine, changes in the DPRK energy sector through 2009 were modest, at best, with overall energy supply and demand conditions for the country changing relatively little over the period. A few of the notable occurrences and trends affecting the energy sector and broader economy in the DPRK from 2005 through 2009 include the following:

[140] See, for example, Arms Control Association (2011) "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy", available as http://www.armscontrol.org/factsheets/dprkchron.

- Reduced **production of cereals** from 2005 through 2007, followed by a better crop in 2008, with another, but more modest, decline in production in 2009[141].
- **Deliveries of heavy fuel oil** to the DPRK in 2007 and 2008 as part of the Six-Party Talks agreements reached during the period, with deliveries ceasing in late 2008 due to disagreements between the Parties.
- Continued increases, in most years, in exports of **minerals and coal to China**.
- Continued, relatively stable **exports to the DPRK from China of crude oil and oil products**, with some additional oil products sourced from other nations. In general, however, supplies of oil products are sufficiently constrained that relatively modest year-to-year differences in supply can have magnified impacts on some categories of transportation fuel use (as we estimate to have occurred in 2009—see below).
- Additional **flooding** in many years of the period (particularly 2007) and more recently, including severe flooding in the Northern part of the DPRK and other areas in 2010 and 2011 (see Figure 3-2).
- Continued efforts to construct new **hydroelectric facilities**, focusing, it appears, on medium-sized facilities (in the range of tens to a hundred or so megawatts of capacity in each of several installations), but with continued stated commitment to developing smaller hydroelectric plants (though with unknown total impact).
- Continued **slow degradation of electricity sector infrastructure**, particularly electricity transmission and distribution infrastructure.
- **Increased electricity imports from the Republic of Korea** for use in the joint ROK/DPRK Kaesong industrial area located just north of the border between the two nations.
- In recent years, **greatly expanded use of mobile phones in the DPRK**, with a network in at least the Pyongyang area developed by the Egyptian company Orascom. This change has probably had relatively little impact on overall energy use in the DPRK (though one could surmise that Orascom was probably obliged to install diesel generators to provide back-up electricity supplies for its network), but may be a harbinger of substantial change in the way information flows in the DPRK[142].

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[141] See, for example, FAO/GIEWS Global Watch (2008), "Severe Food Shortage in the Democratic People's Republic of Korea", dated 25 March 2008, and available as http://www.fao.org/giews/english/shortnews/dprk080325.htm; and FAO/GIEWS (2010) Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea, dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.htm.

[142] See, for example, Alexandre Y. Mansourov. North Korea on the Cusp of Digital Transformation, Nautilus Institute NAPSnet Special Report, dated November 1, 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK_Digital_Transformation.pdf; and Peter Hayes, Scott Bruce and Dyana Mardon, NAPSnet Policy Forum 11-38: "North Korea's Digital Transformation: Implications for North Korea Policy", dated November 8, 2011, and available as http://nautilus.org/napsnet/napsnet-policy-forum/north-koreas-digital-transformation-implications-for-north-korea-policy/.

Figure 3-2: Flooding in Wonsan, DPRK in 2011[143]

3.5. Key Input Parameters, Sources, Assumptions and Methods Used in Estimating Energy Supply-Demand Balances for 2000, 2005, 2008, and 2009

Key parameters, sources, assumptions and methods drawn upon in preparing the estimated DPRK energy supply-demand balances for selected years from 2000 through 2009 are discussed below for key energy demand 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 notes and references to data sources can be found in Attachment 1 to this report.

3.5.1. 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 (30 percent), and fertilizers (7.5 percent)[144]. The

[143] Photo originally labeled "File Photo: AP", from M. Weingartner (2011), "CIA Assesses Flooding in DPRK", CanKor, dated 3 April 2011, available as http://vtncankor.wordpress.com/2011/04/03/cia-assesses-flooding-in-dprk/.

[144] 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 25 percent of 1990 production levels, seems plausible (though possibly high). A figure that is probably from the same ultimate source, the Korea Iron & Steel Association, suggests a value of 1.086 million tonnes in 2000, along with 1.208 million tonnes in 1996, and 1.168 million tonnes in 2005. It is unclear how these figures were derived. Based on consideration of existing estimates, observations of the overall DPRK economy, we adopt the estimate of 1.08 million tonnes in 2000. The www.koreascope.com source, in the "Economic and Social…" page, lists a DPRK cement production of 4.1 million tonnes, or about 41 percent of year 1990 production, in 1999, which seems plausible. Data that are probably from the same ultimate source, the Korean National Statistical Office and the Korea Cement Industrial Association, suggest that year 2000 cement output was 4.6 million tonnes, and output in 1996 was 3.79 million tonnes. It is unclear how these numbers were derived, and though one would expect the cement industry to decline somewhat less than other industries, as it is/was not largely an export industry, the observed lack of recent construction activity in the DPRK would suggest that the level of 1996 to 2000 increase that the latter source shows is not what one would expect. We assume cement output of 3.3 million tonnes in 2000, and

building materials and "other minerals" sectors were assumed to have the same relative output as the cement sector[145]. 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. For 2005, we assumed that iron and steel production in the DPRK continued to decline (to 0.87 million tonnes, or 14.5 percent of its 1990 level), cement production increased slightly (with the overall increase in economic activity) to 32 percent of 1990 levels, fertilizer output increased slightly from 2000 (to 11 percent of 1990 levels)[146]. Activity in 2005 in the building materials, pulp and paper, and other chemicals subsectors are assumed to be unchanged from 2000 levels, with textiles output up slightly, but output is assumed to have increased substantially in the other metals and other minerals sectors[147], due in part to output destined for export to China. As a result of closing of some inefficient plants, improved capacity factors in some industries, and some investment in industrial infrastructure, particularly by Chinese firms[148], the overall average energy efficiency of DPRK industrial plants is assumed to have increased slightly between 2000 and 2005, with energy intensities averaging 112 percent of 1990 levels, in part as a result of simply closing the oldest plants. For 2008 and 2009, we assumed that iron and steel production remained at 2005 levels, though more of the iron and steel produced was probably exported. Cement production remained at 32 percent of 1990 levels in 2008, but was assumed to fall slightly in 2009, possibly as a result of decreased electricity availability. Based on estimates from the UN Food and Agriculture Organization and World Food Program, fertilizer output was assumed to fall to 10.9

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. As an alternative source, the presentation "Agriculture and Fertilizer Situation in DPR Korea", by R.V. Misra, available as http://www.fertilizer.org/ifa/publicat/PDF/2006_crossroads_misra_slides.pdf (from the International Fertilizer Industry Association), presented as part of the "IFA Crossroads ASIA-PACIFIC 2006 Conference 'Growing markets, nurturing success'", Chiangmai, Thailand, 13-16 November 2006, suggests that 1999 production of fertilizer in the DPRK was 63 thousand tonnes (of nitrogen), which is roughly consistent with the level suggested in the article by Tony Boys that is quoted above. Assuming this figure is correct, we adopt Misra's 2000 fertilizer production figure of 37.5 thousand tonnes of nitrogen.

145 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.

146 Based on data in 2006 presentation by R.V. Misra—see reference above.

147 Estimates for these sectors based in part on data provided by Dr. Chung Woo-jin, in his presentation entitled "Mineral Resources in DPRK", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Chung.ppt. Additional details of how Dr. Chung's data were interpreted for this analysis are available in Attachment 1 to this Report.

148 See, for example, Professor Li Dunqiu's presentation entitled "DPRK's Reform & Sino-DPRK Economic Cooperation", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Li.ppt.

and 7.2 percent of 1990 levels in 2008 and 2009, respectively[149]. Activities in the Other Metals and Non-Metallic Minerals subsectors were assumed, again based on increasing exports to China, to be somewhat higher in 2008 and 2009 than in 2005. Output in the Other Chemicals, Pulp and Paper, Textiles, and Building Materials subsectors were assumed to decline slightly by 2009, relative to 2005, as was energy use in "non-specified industries". We assumed that, as a result of a combination of continued decommissioning of older, inefficient facilities, plus some investment in new or refurbished facilities, particularly by Chinese firms producing materials for export, that the relative energy intensity per unit of product fell slightly between 2005 and 2008/2009, to 110 percent of 1990 levels.

3.5.2. 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 14 percent of 1990 levels by 2000, increasing to 25 percent in 2005 (as a result of somewhat increased industrial production, increased trade with China, and some increase in freight related to food aid). Road freight in 2008 was assumed to be slightly higher, at 25.5 percent of 1990 levels, in 2008, but lower in 2009 (18 percent of 1990 levels) due primarily to a reduction in the availability of motor fuels. We assume that biomass (gasifier) trucks account for somewhat less than 10 percent of road freight in 2000 through 2009 (which is somewhat higher than in 1996) but that the share of freight carried by diesel trucks, including recently imported vehicles, increased to about 35 percent in 2000 and 66 percent in 2005, before decreasing to 47-49 percent in 2008/2009 due to the estimated relative availability of diesel fuel and gasoline (gasoline trucks carry the remainder of road freight). "Civilian" auto transport is assumed to be decreased by 25 percent from 1996 levels in 2000, then increased back to 90 percent of 1990 levels by 2005, and 120 and 109 percent of 1990 levels by 2008 and 2009, respectively, consistent with the increased in imports of private autos in recent years (and reduced fuel availability in 2009). Other mechanized passenger road transport and rail transport is also assumed to have been lower than in 2000 than in 1996, increasing somewhat for most conveyances in 2005 and 2008, with the use of diesel and gasoline buses (measured in passenger-km) decreasing in 2009 due to reduced fuel availability, but the use of electric rail passenger transport increasing somewhat. Diesel rail freight is assumed to be 30 percent of 1990 levels in 2000, and electric rail freight decreased to 33 percent of 1990 levels by 2000 as a result of lack of availability of electricity. Diesel rail freight activity is assumed to have increased slightly by 2005, but to decrease again in 2008 and 2009, with improvement in electric rail allowing an increase in transport of goods by that mode to 40 percent of 1990 levels by 2009. Air travel is slightly decreased relative to 1996 by 2000, but assumed to have returned to 1996 levels by 2005 and 2008, decreasing again somewhat (back to 80 percent of 1990 levels in 2009.

In general, no specific data were available for the transport sector for 2000 through 2009, so estimates of the parameters in the text above 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 small "private" cars and mini-vans in the years before 2000, but mainly in the Pyongyang area—thus we have assumed a small overall decrease in this activity, consistent

[149] Derived from data in UN Food and Agriculture Organization and World Food Program (2010), Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea, dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.pdf. Estimates are derived from data in Table 2 of that document.

with constricted availability of fuel, between 1996 and 2000, but an increase thereafter through 2008. The use of other vehicles, however, seems to have stayed the same or decreased slightly between 1996 and 2000, thus the slight decrease in vehicle use by 2000 relative to 1990. Since 2000, imports of vehicles from China have increased, and visitors have noted more vehicles on the road, though again, mostly in the Pyongyang area. The efficiency of trucks and buses and "private" vehicles was assumed to have improved slightly between 1996 and 2009, with some efficiency gains through the introduction of imported vehicles not quite counterbalanced by continuing problems with the availability of spare parts and other maintenance supplies for existing vehicles. We saw many disabled trucks along the road in areas not far from Pyongyang during our visit in 2000.

3.5.3. Parameters of residential energy use in 2000-2009

Based on the population growth rate for 1990 to 2000 that we assumed as described in Chapter 2, based on an average population growth rate above zero for the decade, we estimate that the year 2000 population in the DPRK was roughly 22.2 million, and that roughly 60.3 percent of the population could be classified as "urban"[150]. From the year 2000 through 2009, with some reservations, we assumed that the DPRK population increased at an average rate of 1.02 percent annually, and that a small net rural-to-urban migration continued, with the national fraction of urban households rising to 60.8 percent of the total by 2009[151]. Our reservations about using these population projections are as follows. The growth rate shown is calibrated to yield the 2008 total population reported in the landmark 2008 DPRK Census (D P R Korea 2008 Population Census National Report[152]) prepared under United Nations supervision. This document was welcomed as the first systematic census to be carried out on the DPRK in many years, and is generally accepted by demographers as a useful picture of life in the DPRK, especially as no demonstrably superior estimate is available. A number of researchers, however, have expressed doubts, privately and in some cases publically, as to whether the 2008 population of the DPRK was likely, in fact, to be as high as the 24.05 million reported in the Census document. Inconsistencies have been noted between the size and age composition of the population reported in the 2008 Census and what had been known or imputed about population trends since 1990 in the DPRK. As of yet, however, neither we nor any other public documents we have seen have offered a definitive alternative estimate of 2008 population, so we adopt it for the estimated described here. We remain wary, however, of the fact that the 2008 population estimate that we are using could be overstated, perhaps by as much as 20 percent.

To estimate trends in the number of households in the DPRK, we started at our 1990 average values (4.65 persons per household in both the rural and urban sectors), and interpolated between those values and 2008 values as reported in the 2008 Census, yielding estimates of just under and just over 3.9 persons per household in the urban and rural sectors in 2009,

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[150] By way of comparison, the USDOE Energy Information Administration listed a year 2000 population of 21.7 million in its North Korea Country Analysis Brief (www.eia.doe.gov/emeu/cabs/nkorea.html, as of 5/2002).

[151] Though some observers of the DPRK report a significant urban to rural migration, others suggest that the migration is largely seasonal with urban dwellers going to rural areas during the agricultural season, and returning to cities at other times of the year. Depending on how "urban" is defined in allocating the DPRK's population, the fraction of the population living in urban areas may be close to 65 percent, though observers suggest that in recent years there has been a "ruralization" of urban life, with many nominally urban dwellers making their living (or much of it) from farming or raising livestock.

[152] D P R Korea 2008 Population Census National Report, Central Bureau of Statistics, Pyongyang, DPR Korea, 2009, available as http://unstats.un.org/unsd/demographic/sources/census/2010_PHC/North_Korea/Final%20national%20census%20report.pdf,

respectively. This means that the number of DPRK households (from which “population not in households”, meaning mostly those in the military, were excluded) grew faster than the rate of population growth through 2009.

Also included in the 2008 Census are data on the fraction of households using different fuels for cooking and heating, though not, unfortunately, data on the amount of those fuels used per household. Where possible, we used those data in the estimates prepared below. Again, the reader is urged to consult Attachment 1 for further details and sources used for developing the inputs described below.

We assumed that the fractions of residences using coal in urban and rural settings were about 77 and 33 percent of 1990 levels, respectively, by 2000 (both having decreased somewhat further from 1996 estimates), with urban coal use continuing to fall in subsequent years, due mostly to limited availability, to about 65 percent of 1990 levels by 2009, with the fraction of rural households using coal falling to just under 19 percent by 2008 (remaining at that level in 2009). At the same time, we assumed a modest continued decline in the amount of coal used per household, to starting at 65 percent of 1990 levels in the urban sector in 2000 and decreasing to 50 percent by 2009, with per-household usage in the rural sector set at 50 percent of 1990 levels in 2000, declining to 45 percent in 2005 and remaining at that level through 2009. The fractions of households using of wood/biomass fuels was assumed to have increased in both the urban and rural sectors, rising from 10 percent in 1996 in the urban subsector to nearly 28 percent in 2008/2009 (based on 2008 Census figures), and rising from 60 percent in 1996 to over 79 percent in 2008/2009 in the rural subsector. Average wood/biomass use per household, however was assumed to decline slowly over time, from 80 percent of 1990 values in 2000 to 65 percent in 2008 and 2009 for both the urban and rural sectors, due to a combination of increasing scarcity of fuel, more households in competition for fuel resources, and (relatedly) less use of heating and cooking.

The use of charcoal was assumed to have decreased since 1996, to 55 percent of 1990 levels in 2000 and 45 percent of 1990 levels in 2008 and 2009. The fraction of households using oil products for cooking was assumed to have decreased, due to low availability of fuel, from 13 percent of urban households and 1.5 percent of rural households in 1996 to about 7 percent of urban households and less than 1 percent of rural households in 2008/2009. Per-household urban and rural use of oil products was assumed to have increased, in part due to use of kerosene as a substitute lighting fuel, through 2008, falling slightly (with reduced availability of petroleum fuels) in 2009. The use of electricity in residences is assumed to have been severely curtailed (by availability) relative to 1990, but improved somewhat between 2000 and 2008, declining somewhat again in 2009. Visitors to the DPRK in 2000 described electricity in Pyongyang as having been generally available, but electricity in at least major portions of other cities being largely unavailable. Based on Korea Trade-Investment Promotion Agency (KOTRA) data[153] that listed 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 14 percent of the time, we estimate that the average consumption of power per household was about 32 percent of that in 1990. Nautilus Institute's

[153] From http://www.kotra.or.kr/main/info/nk/eng/main.php3, visited 6/3/02.

rural energy survey in the village of Unhari, on the West Coast of the DPRK[154], 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. Since 2000, visitors' observations of electricity supplies in the DPRK have varied dramatically depending on where and, to some extent, when the observations occurred. In some cities, particularly Pyongyang and areas near the Pukchang power station (the largest plant in the DPRK), close to round-the-clock supplies were reported, while only sporadic availability was reported for other areas. Overall, the electricity supply situation seems to have improved, at least marginally, since 2000 through about 2008, and the estimates above reflect that improvement. The most recent (late 2011/early 2012) anecdotal evidence, however, suggests that electricity supplies are once again on the downswing, as evidenced by reports of more extensive and longer-duration blackouts, even in the Pyongyang area[155].

The fraction of urban households using district heat is assumed to have decreased slightly over time since 2000, essentially because the number of households has grown but we assume that the deployment of district heating systems has not. The use of district heat per connected household is assumed to parallel the use of electricity, since the two are either co-produced or depend on the same sorts of central power plant/central heating plant fuels and infrastructure, and thus would be subject to the same sorts of constraints, on average.

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

We assumed that the availability of mechanized aids to agriculture continued to decrease from 1996 to 2000, increased slightly by 2005, then continued to decline slowly through 2009, resulting in the use of diesel tractors and other oil-fueled equipment in the agricultural sector decreasing to 25, 27, and 24 percent of 1990 levels in 2000, 2005, and 2008/2009, respectively, from 30 percent in 1996. The lack of spare parts and fuel play a significant role in this reduction[156]. The use of electricity in fields (mostly for water pumping) in the agricultural sector were also assumed to decline relative to 1996 through 2009, though the total area cropped was assumed to remain the same. Reduced electricity use "in fields" was due in part to the completion of major gravity-flow irrigation systems in the western agricultural area of the

[154] 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 is available as a Nautilus Report at http://www.nautilus.org/DPRKBriefingBook/energy/Unhari_Survey.pdf.

[155] See, for example, North Korean Economy Watch, "Power shortage in Pyongyang prompts residents to move to older housing", providing two related stories describing electricity shortages of the winter of 2011/2012, originally dated 2012-1-13 and 2012-2-1, and available as http://www.nkeconwatch.com/2012/02/01/power-shortage-in-pyongyang-prompts-residents-to-move-to-older-housing/.

[156] See, for example, Hugh Bentley, "Trends in the DPRK Agricultural Sector & Implications for Energy Use", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://www.nautilus.org/wp-content/uploads/2012/01/Bentley.ppt, Bentley notes that ongoing post harvest losses during threshing, drying/, and cleaning operations, early crop consumption, shortages of fertilizer, lack of timely field operations, and soil erosion caused by deforestation in the DPRK all have implications for agricultural energy use.

country (see, for example, Figure 3-3)[157], in addition to reduced electricity availability and probable continued degradation of pumping infrastructure. The use of coal, electricity, and biomass for crop processing are estimated to have declined from 1996 to 2000 due to a combination of lower crop output and reduced fuels availability. From 2000 to 2005, we assumed an increase in the availability (and use) of electricity for crops processing, and also an increase in biomass use (as well as coal and electricity) related to increased crop output. After 2005, use of these fuels is assumed to vary somewhat year to year, but to remain near 2005 levels. In the fisheries sector, based on data on DPRK marine catch, we assumed that fisheries effort and energy use would be 25 percent on 1990 levels in 2000, with activity increasing slightly from 2000 levels by 2005, but declining slowly thereafter due to lack of fuel and equipment maintenance issues[158] [159].

[157] A KCNA news item, "Power Stations Built along Kaechon-Lake Thaesong Waterway", dated December, 2004 (available as http://www.kcna.co.jp/item/2004/200412/news12/23.htm#9) reads in part "power stations have been built along the Kaechon-Lake Thaesong Waterway in South Phyongan Province, the Democratic People's Republic of Korea. The 150-kilometer-long natural-flow waterway has been built from Taegak-ri in Kaechon City to Lake Thaesong. It saves 140 million kWh of electricity a year." 140 million kWh, or 140 GWh, is substantially larger than the reduction in the field use of electricity we estimate which could mean that our estimate of savings is understated, the KCNA figure is overstated, some of the reduction in electricity use from the waterway has meant that more electricity is available for use in water pumping in other areas, which would tend to reduce savings—or, most likely, a combination of all three factors.

[158] The Korea Trade-Investment Promotion Agency (KOTRA) suggests that DPRK marine products catch decreased substantially between 1996 and 1997, but increased somewhat from that point through 2001. 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 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 as of 2005 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. The ROK Ministry of Unification web site http://www.unikorea.go.kr/en/index.jsp, as of about 2007, included a listing of fisheries output suggesting that total marine products production in the DPRK had increased to 1.16 million tonnes by 2004, a significant jump from 2002 and 2003 (0.81 and 0.84 million tonnes). Much of this production increase, however, may have been in products that were relatively less energy intensive to harvest, such as seaweed.

[159] The United Nations Food and Agriculture Organization (UNFAO) global fisheries database "FishStat" (downloaded from http://www.fao.org/fishery/statistics/software/fishstatj/en on 3/28/2012) includes what appear to be estimated data for DPRK fisheries output from about 2000 on, typically with little or no change over time, suggesting that no significant data were available on DPRK fisheries to UNFAO in recent years.

Figure 3-3: Recently-completed Natural-flow Irrigation Waterway in the DPRK[137]

3.5.5. 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 in the year 2000—about 29 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. For 2005 through 2009, the electricity use per unit floor area was between 40 and 45 percent of the 1990 rate, which is slightly higher than the rate in urban households for those years. The fraction of 1990 coal use per unit area assumed for 2000 through 2009, 45 percent, reflects the observation that coal availability was and continues to be poor in many areas of the country. Visitors to the DPRK within the last few years report that most public buildings are unheated in the winter, and many of those that have some heat are heated with biomass fuels. We have accordingly assumed that the use of wood and biomass fuels in the commercial sector, on a per unit floor area basis, increased from 10 percent of the 1990 rate of coal use in 1996 to 20 percent in 2000 to 30 percent in 2005 and thereafter. As in the residential sector, the change in electricity availability noted by observers varied substantially by area and by season in the DPRK, as well as varying in relation to proximity to new or existing power plants, or to priority users of power.

3.5.6. Military energy use parameters in 2000 through 2010

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 in 2000 (and in 2005-2009) as it was in 1996 (and 1990)[160] [161]. 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 lower (20 - 25 percent) than in 1996[162], with a smaller decline from 2000-2009, while aircraft use in 2000 was substantially less than the already low levels of 1996[163], due in part to the particularly constrained supplies of fuel in that year, but somewhat higher (close to 1996 levels) in 2006-2009. Naval vessel use in 2000 was modestly (7-10 percent) lower, on average than the levels assumed for 1996[164], with the assumed number of hours of use of different naval vessels and related equipment assumed to be mostly similar to 2000 levels in 2005, but slightly lower in 2008/2009. The level of military manufacturing is assumed to be lower in 2000 through 2009 than was assumed for 1996, at 45 percent of the 1990 level of activity. Similar to the public/commercial sector, we assume that from 2000 to 2005 and thereafter the use of coal and oil in military buildings decreased somewhat, but the use of wood fuels, for cooking and some heating, continued to increase, as soldiers were increasingly asked to produce and forage food and fuel for themselves. For 2005 and thereafter, the typically small decrease in activity levels we have assumed for in all branches of the military relative to 2000 levels is the result of energy-consuming training activities being limited by fuel supplies, lack of spare parts, and also, possibly, increased time spent by military personnel in economic pursuits[165]. Another possible reason for reduced military activities could be the reportedly lower physical capabilities of soldiers working on shorter rations.

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[160] Two recent ROK media reports--"North Korea Deploys Air Cushion Warships", Seoul, The Korea Times (Internet Version-WWW) in English, by Cho'ng Su'ng-ki, dated April 1, 2007 (and quoting the 2006 ROK Defense White Paper); and "N.Korea Develops High-Speed Military Hovercraft", Seoul, Chosun Ilbo WWW-Text in English, dated April 2, 2007--report the development of DPRK hovercraft, but these appear to be the same as the Kong Bang hovercraft developed deployed during the 1990s, with no apparent change in the number of such vessels (both of the 2007 articles give a number of 130 hovercraft) that have been present in the DPRK fleet since about 2000.

[161] A fairly recent publication covering the DPRK's overall military readiness, North Korea's Military Threat: Pyongyang's Conventional Forces, Weapons of Mass Destruction, and Ballistic Missiles, by Andrew Scobell and John M. Sanford, Strategic Studies Institute, U.S. Army War College, dated April 2007, and available as http://www.strategicstudiesinstitute.army.mil/pdffiles/pub771.pdf, implies that DPRK production of armaments continues, but does not, based on our quick review, seem to indicate any substantial net addition of armaments to the DPRK working inventory in recent years.

[162] 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 had increased somewhat to that point, 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 or use of fuel-using vehicles and armaments. Accordingly, we assume that the average hours of annual use (and fuel use) by ground vehicles in 2000 was somewhat lower in 2000 than in 1996.

[163] 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.

[164] 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 around 2001 in researching an update of this document, however, indicated that the DPRK Navy did not seem to be operating under any particular fuel restrictions, and that the level of incursions (from DPRK vessels) experienced in ROK waters seemed to be fairly consistent with prior years. As a result, we have assumed that DPRK naval activity (at least for patrol craft) was only somewhat lower (in average terms of activity per vessel—which would include both serviceable and inactive vessels) than in 1996.

[165] Reviews of the literature describing DPRK military equipment stocks in the different branches of the armed forces are available on http://www.globalsecurity.org, for example, on http://www.globalsecurity.org/military/world/dprk/air-force-equipment.htm for air force equipment, http://www.globalsecurity.org/military/world/dprk/kpa-equipment.htm for ground forces equipment, and http://www.globalsecurity.org/military/world/dprk/navy.htm for the navy. These reviews find relatively little

3.5.7. Non-specified and non-energy commodities demand

We have included no non-specified fuels demand in the estimated balances for 2000 through 2009, with the exception of heat from the re-started Yongbyon reactor in 2005 (at the 1990 level), but not in 2008 or 2009. For non-energy commodities included in the balance, we have assumed that coal and oil used as feedstocks for ammonia production scaled with overall fertilizer output, and are thus 8 percent of 1990 levels in 2000, rising to 11 percent in 2005 and 2008, but falling again to 7 percent of 1990 levels in 2009. Other non-energy petroleum products use is assumed to be greater than 1996 levels at 38 percent of 1990 levels in 2000, but the increase relative to 1996 is mostly due to our estimate for the amount of asphalt required to build the Pyongyang-Nampo superhighway in that year. In 2005 and 2008, non-energy oil products use is estimated to have been about 12 percent of 1990 levels, rising by a few percent in 2009. Roundwood (logs) consumption declines to 50 percent of 1990 levels in 2000, and stays at that level through 2009.

3.5.8. Energy resources, imports, and exports in 2000

We based our estimates of energy resources, imports, and exports for 2000 through 2009 on the following data and assumptions:

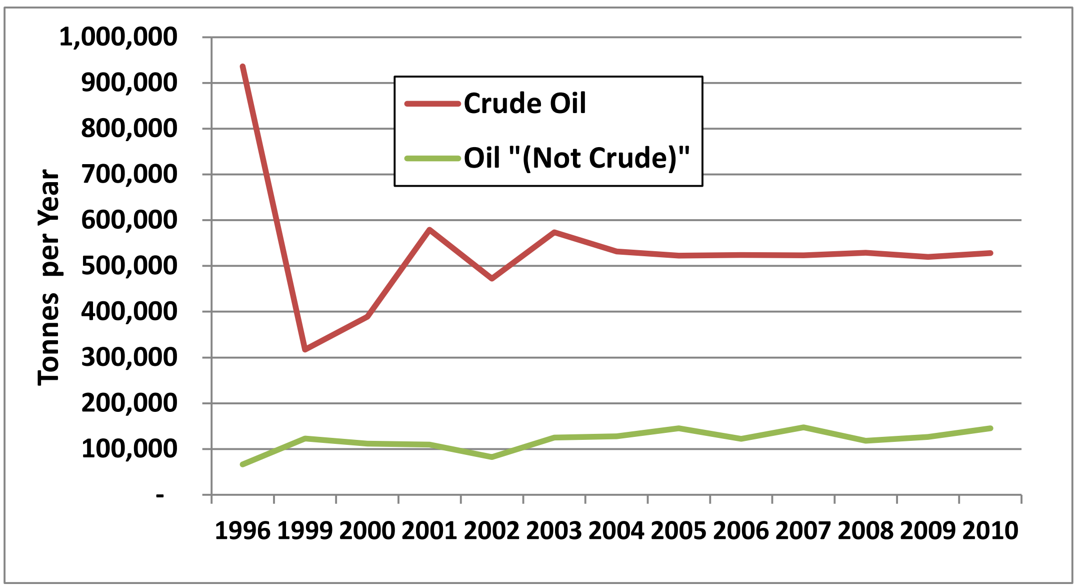
- Domestic coal and biomass resources were sufficient for any level of production that could be sustained by the DPRK infrastructure.
- In 2000, coal was imported by the DPRK from (at least) China (about 226,000 tonnes, including bituminous, coking, and unspecified coals), Russia (82,000 tonnes of coal, and 2000 tonnes of coke) and Australia (about 31,000 tonnes of coal), and exported to (at least) China (8,100 tonnes) and Japan (351,000 tonnes of anthracite)[166, 167, 168]. There may have been additional off-the-records coal imports from or exports to China (and/or Russia), but we have no information about such transactions.
- In 2005, 147,000 tonnes of coal and coal products were imported from China, along with about 26,000 tonnes of coke. An additional 1.17 million tonnes of coal was imported from Russia. A significant amount of coal was exported to China—2.8 million tonnes[169]--and 277,000 tonnes of coal were exported to Japan[138]. Again, there may have been some off-the-record imports or exports.

change in the DPRK's stock of energy-using military equipment in recent years, but note that it is not entirely clear whether these results stem from a lack of recent insights, on the part of analysts, as to any changes in the DPRK military, or to a lack of changes in the actual equipment inventory in the DPRK.

[166] Chinese import/export data from China Customs Report 2000, pp. 1483-1495 (in Chinese).
[167] 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.
[168] From data in Japan customs statistics, http://www.customs.go.jp/toukei/info/index_e.htm.
[169] From China Customs Statistics as compiled by Nathanial Aden, 2006. For related analysis, see also N. Aden, North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Mr. Aden's paper is available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/0679Aden1.pdf. Updated analyses prepared for Nautilus by Mr. Aden in 2008 and 2010 were drawn upon for the 2008 and2009 statistics on DPRK energy trade with China reported on here, and are summarized as http://nautilus.org/wp-content/uploads/2011/12/Aden.pdf and http://nautilus.org/wp-content/uploads/2011/12/02.-Aden.pdf.

- In 2008, the DPRK imported about 232,000 tonnes of coal from China, along with 7600 tonnes of coke. 192,000 tonnes of coal were imported from Russia. 2.54 million tonnes of coal were exported to China, but exports of coal to Japan were nil, having been discontinued by Japan after 2006.
- Coal imports to the DPRK from both Russia and China declined in 2009, to about 28,000 and 90,000 tonnes, respectively along with about 4000 tonnes of coke (from China). Exports of coal to China rose to 3.6 million tonnes, rising again to 4.6 million tonnes in 2010[170].
- Crude oil imports in 2000 were limited to the 389,000 tonnes reported (in China Customs Statistics) as imported from China[171]. Imports from China in 2005 were 523,000 tonnes[172]. It is possible that a modest volume of additional crude oil was imported in one or both years from an unknown location--possibly by rail from Russia or China, or by ship from Russia, China or elsewhere. Reported crude oil and oil products exports from China to the DPRK remained remarkably stable from 2005 through even 2010, as shown in Figure 3-4[173].

Figure 3-4: Crude oil and Oil Products Imported by the DPRK from China, 1996 – 2010



- 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

[170] Data on Russia's energy trade with the DPRK, and on China's coal imports from the DPRK in 2010, are taken from the United Nations "Comtrade" database (http://comtrade.un.org/db/default.aspx, accessed on several occasions).
[171] 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.
[172] From China Customs Statistics, compiled by Nathanial Aden—see footnote above.
[173] Data for Figure 3-4 China Customs Statistics, compiled by Nathanial Aden—see footnote above, except for 2010 data, which are from the United Nations "Comtrade" database (see above).

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, and as a result have assumed that year 2000, 2005, 2008, and 2009 domestic oil production in the DPRK was 30,000 tonnes, though this figure may well be too high[174]. We further assume that this oil (or a similar quantity imported by rail or ship) was refined in the small West Coast refinery (see below).

- In 2000, refined products imports to the DPRK included products from the ROK (reported informally to be "off-spec" products[175], probably heavy oil and diesel fuel, and in not well-known quantities, but estimated at 50,000 tonnes), Singapore (probably mostly gasoline and some diesel, totaling about 60,000 tonnes), and Japan (44,000 tonnes of heavy fuel oil, plus a minor amount of solvents and lubricants, 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 of heavy fuel oil delivered by KEDO during the 2000 calendar year[176]. 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

[174] Though our conversations with some experts in the industry have suggested that any production from DPRK wells was minimal, other sources in the literature suggest that DPRK oil production has indeed been enough to supply a significant fraction of DPRK needs. For example, Selig Harrison writes in Toward Oil and Gas Cooperation in Northeast Asia: New Opportunities for Reducing Dependence on the Middle East (published as Woodrow Wilson Center for International Scholars Asia Program Special Report No. 106, dated December 2002, and available as http://www.wilsoncenter.org/topics/pubs/asiarpt_106.pdf), that "an oil well [in Sukchon] began producing 2.2 million barrels annually in 1999". This is similar to a figure of 300,000 tonnes crude oil per year quoted in several publications by Keun-Wook Paik, including Pipeline Gas Introduction to the Korean Peninsula, published by Chatham House, January 2005, and available as http://www.chathamhouse.org.uk/pdf/research/sdp/KPJan05.pdf. In the Chatham House report, Paik writes (p. 37) "Even though the scale of annual crude oil production from the Sook-Cheong County's Anju Basin is very small (0.3 mt/y), to the North Korean authorities it is a significant volume." In personal correspondence with Dr. Paik, he indicates that the information for this estimate came from an article in the ROK press in approximately 2001—probably the chosun.com article referenced above, and that while he has not seen the quantity of oil production confirmed, he believes that some oil production is ongoing. Dr. Harrison indicates that his figure for DPRK oil production was likely taken from the work of Dr. Paik, or from the same original source. Other experts in the field consulted on this question have expressed skepticism that DPRK domestic oil production to date, if any, has been even close to as significant as the quantity reported. Accordingly, we assume that a more reasonable figure for ongoing DPRK domestic oil production is one the order of 10 percent of the reported (300,000 tonne) value (which might also have been misreported due to an error in reporting units, as happens occasionally in the DPRK and elsewhere). Another estimate of DPRK oil production is offered in index mundi (http://www.indexmundi.com/g/g.aspx?c=kn&v=88), based on data from the CIA World Factbook, which suggests that DPRK oil production in 2004 to 2007 was about 140 bbl per day, declining to 118 bbl per day in 2009 (and 2010, according to the CIA World Factbook). The index mundi (CIA) estimate of 140 bbl/day is the equivalent of 7,000 tonnes/yr, considerably lower than the estimate we are using, but on the same order of magnitude, and perhaps equally plausible (but also equally speculative).

[175] "Off-spec" denotes products which may not have met quality or other standards for sale in the ROK or other countries. These could include, for example, fuels with higher-than-allowed levels of impurities, or fuels that did not meet octane or other specifications.

[176] 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.

products are estimated to have totaled about 300,000 tonnes in 2000. For 2005, the DPRK received just under 150,000 tonnes of oil products "officially" from China, with gasoline, diesel fuel, and kerosene/jet fuel the dominant products. We assume that the DPRK also received a smaller share (a total of 150,000 tonnes) from the output of the Chinese refinery near the border, and about 60,000 tonnes of fuel (mostly diesel oil) from the ROK. 2005 imports of oil products to the DPRK from Japan were very limited (100 tonnes).

- We estimate that the total DPRK refined products imports in 2008 were about 685,000 tonnes. Of this total, 304,000 tonnes were in the form of heavy fuel oil provided to the DPRK as a part of the Six-Party Talks agreement. Most of the rest was imports from China and Russia, but trade statistics show that the DPRK also imported much smaller amounts of various products from Malaysia, Singapore, Japan (a tiny amount), the Netherlands, and (probably) India[177].
- In 2009, we estimate that oil products imports to the DPRK were about 270,000 tonnes, with much (but not all) of the large drop related to the cessation of HFO shipments from the Six-Party Talks agreement. The largest portion (but less than half) of these imports came from China, with the rest being cobbled together from most of the same sources the DPRK received oil products from in 2008, with additional small quantities probably coming from other countries as well.
- Also listed under refined products in 2000 are the imports of about 22,000 tonnes of used tires (or fuel derived from same) from Japan (additional shipments may have originated in Taiwan) for use as a boiler fuel (for electricity generation)[178]. Cargoes of tires from Europe have reportedly also been requested by the DPRK. Imports of used tires/tire-derived fuel to the DPRK from Japan in 2005 were 26,000 tonnes, with imports declining to about 8600 tonnes in 2006, the last year that such shipments were reported.
- 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). Although there may have been similar trading of oil products in 2005, the only on-the-record exports of oil products from the DPRK to China in 2005 were about 4,400 tonnes of liquefied petroleum gases. The DPRK exported about 3000 tonnes of similar products to China in both 2008 and 2009, and also exported a tiny (just under 4 tonnes) amount of oil products to Russia in 2008.

[177] Indian trade statistics show substantial (on the order of one million tonnes, with value near a billion dollars) shipments of oil products to the DPRK in 2008 and 2009. The sizes and types of these shipments (including large amounts of naptha, typically used as an input to the plastics industry), however, have led us and other analysts to conclude that most or all of these reported trades were in fact between India and the Republic of Korea, not the DPRK, and that there were simply clerical errors in reporting the trades. India's petroleum product trade with the ROK in recent years has been very large. We have assumed that a just small fraction of the reported imports of oil products from India actually did go to the DPRK—perhaps one smaller tanker's worth (20,000 tonnes).

[178] A source from the industry reported that the DPRK likely received a total of 25,000 tonnes of used auto tires from Japan and Taiwan in 2000 for use as a supplemental boiler fuel. This estimate corresponds well with data from Japan Customs Statistics (data from files downloaded from http://www.customs.go.jp/toukei/download/index_d012_e.htm) that lists year 2000 exports from Japan to the DPRK in a category (HS # 400400000) that is defined as "Waste, parings and scrap of rubber (other than hard rubber) and powders and granules obtained therefrom" at a total level of 22,156 tonnes in 2000, and 25,599 tonnes in 2005.

3.5.9. Data and assumptions regarding energy transformation processes in 2000, 2005, 2008, and 2009

Below we present the key data and assumptions used for our estimated of year 2000/2005/2008/2009 activities 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 through 2009 energy balances. 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 were operating as of 2000, 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. Recent investments in selected coal mines by Chinese companies have been noted, doubtless supporting the 2.8 million tonnes of coal exports from the DPRK to China recorded in 2005 (up to 4.8 million by 2010). Further, the DPRK government seems to be revising ownership rules to encourage any (foreign and, presumably, domestic) groups to undertake coal mine operation, whether those groups have coal supply expertise or not[179].
- We assume that the **East Coast (Sonbong) 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, 37 percent of capacity in 2005 and 2008, and 36 percent of capacity in 2009.
- 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.
- Conversations with industry sources indicated that the **thermal power generation** system in the DPRK was rapidly eroding as of 2000. 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

[179] For example, NK Brief No 06-12-14-1, titled Independent Coal Mines Get Legal Backing in DPRK, and based on a Korean Central Broadcasting Agency report dated 12/112006, describes a December, 2006 law, the "Small-Medium Coal Mines Management Development Regulations", that a number of different types of foreign organization now have the "legal support", upon receiving official permission, to develop small and medium coal mines. The article also cites a recognition that coal production has decreased.

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[180]. 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 at all, anywhere—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 were operable, we estimate an average capacity factor in the range of 50 percent or less, due to maintenance problems and lack of fuel.

Many of the problems noted above reportedly persisted through 2009, continuing to the date of this writing, but we have little direct evidence of significant changes in the sector since 2002. We have heard reports of some repairs at major power plants, including the (nominal) 1600 MW Pukchang plant, as well as reports of arrangements for importing of used power plant boilers, possibly from Eastern Europe[181]. Based on what we have heard from other observers, estimates by the (ROK) Korea Electrotechnical Research Institute (KERI) that operable thermal capacity was about 2 GW, and output 5.4 TWh, in 2005, seems reasonable, and we have adopted these estimates[139]. We estimate the output of thermal generation in 2008 at nearly the same level as 2005—5.3 TWh, but, based on consideration of the ratio of ROK overall generation estimates in 2008 and 2009, we estimate the total thermal generation in 2009 to have been lower—about 3.9 TWh[182].

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[180] 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.

[181] Observers suggest that the coal mine feeding the Pukchang power plant was working at less than full capacity (as of several years ago), as the use of largely older, manual tools limited output despite the mine being in operation around the clock. The mine provides coal to other DPRK counties and provinces. Observers report that the Pukchang power plant itself appeared to be operating at near-full capacity during approximately 2005, with most or all boilers in use most of the time.

[182] 13 For 2009, we assume that there was a decrease in overall gross generation approximately equal to that estimated by J.Y. Yoon in his presentation for the 2010 Energy and Minerals Experts Working Group Meeting in Beijing, September 2010 (available as http://nautilus.org/wp-content/uploads/2011/12/01.-Yoon.ppt, and in narrative form at http://nautilus.org/napsnet/napsnet-special-reports/the-dprk-power-sector-data-and-interconnection-options/), "Analysis on DPRK Power Industry & Interconnection Options". In the presentation, Yoon quotes ROK analysts as estimating that the DPRK's generation in 2008 was 25.5 TWh, and generation in 2009 was 23.5 TWh. We do not use these absolute generation estimates, because we believe that they are too high (Mr. Yoon agreed that a "minimum" value could be closer to 16 TWh for 2007, for which ROK analysts estimate output of 23.7 TWh), but we use the ratio of these 2009 and 2008 estimates, 92.2%, to estimate a target value for 2009 output. As another point of comparison, a recent article by the Yonhap News Agency ("N. Korea's power consumption per capita at 1970s levels", dated 8/6/2010, and available as http://english.yonhapnews.co.kr/news/2012/08/06/0200000000AEN20120806003300315.HTML?source=rss), quoting the ROK's Statistics Korea, describes per-capita consumption in the DPRK of 819 kWh per capita, which would, based on the

- As a consequence of the difficulties with thermal power plants, **hydroelectric plants** had shouldered the burden of power generation in the DPRK by 2000. 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, for the year 2000, that of the approximately 3900 MW of other hydroelectric plants, 75 percent of capacity was operable, and those operable hydro plants had a capacity factor in 2000 (a low water year) equaling 75 percent of the capacity factor assumed for 1996, or about 33 percent overall. This could, in fact, prove an over-estimate.
- A major "Youth Dam" including a tunnel system for carrying water, had recently been completed, but its hydroelectric capacity, if any as of 2000, was unclear. Also underway, at the time of 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. That project has since been completed (see Figure 3-3), but it is not clear to the authors whether the latter project has or is expected to have significant associated hydroelectric capacity, or whether the "Youth Dam" and the Taedong water diversion project are related.
- For 2005, we have based our estimate of hydroelectric output on data from KERI (see endnote reference above), but added 100 MW of large hydroelectric capacity, plus 86 MW of medium-sized hydroelectric capacity, to account for facilities completed (or likely completed) in 2005. The resulting estimate of hydroelectric capacity for 2005 is about 4100 MW, with output of about 11 TWh and thus an average capacity factor of a bit over 30 percent. In 2008 and 2009, hydroelectric capacity is assumed to have increased somewhat over 2005 as a result of the completion of several medium-sized (tens of MW) hydro plants. Average capacity factors for hydroelectric plants in both years were estimated at just under 32 percent, with total output of just under 12 TWh in both years.
- The above assumptions as to electricity generation imply a gross output of about 12.6 terawatt-hours in 2000, 16.5 TWh in 2005, 17.15 TWh in 2008, and 15.8 TWh in 2009. Chinese customs statistics cite export of 22.7 GWh to China from the DPRK in 2000, apparently in addition to the shared output of the plants on the border rivers[183]. No exports of power from China to the DPRK were recorded in 2000. China Customs statistics reported DPRK electricity exports to China in 2005 of 90 GWh, along with exports of 143.5 GWh in 2008 and 128.9 GWh in 2009. Imports of power to the DPRK from China had fallen to

population assumptions used in this report, equate to about 19.7 TWh of overall consumption. Whether the quoted figure is intended to be actual end-use consumption, or simply overall estimated electricity production divided by population, is unclear, as is the ultimate source used by Statistics Korea to prepare the estimate.

[183] 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.

about 660 MWh in 2005, but rose again to 17.9 GWh in 2008, falling to 6.9 GWh in 2009 (and 3.3 GWh in 2010). Imports of power from China may therefore be helpful in some local areas near the border, possibly to provide power for enterprises in which Chinese firms have invested, but imports from China do not contribute much to overall DPRK electricity needs.

- We have assumed, based on reports of the continuing erosion of the transmission and distribution (T&D) grid, that T&D losses were 20 percent higher in 2000 through 2009 than in 1996, totaling over 27 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, with overall net emergency losses totaling 9.4 percent in 2000, and a slightly lower 9 percent in 2005 through 2009, reflecting some improvements in power plant maintenance (or, alternatively, the abandonment of units with worse-than-average losses).

3.6. Presentation of Estimated Year 2000, 2005, 2008, and 2009 DPRK Energy Balances, and Discussion of Results

In this section we present our estimated DPRK energy balances for 2000 and 2005. 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 (including, not incidentally, considerations related to the 6-Party Talks ongoing as of March 2007). As with our 1990 and 1996 balances, these pictures of the DPRK energy sector in 2000 through 2009 were 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 balances as internally consistent as possible. Although the balances are 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 that reviewers of this document can provide. Additional results of our estimates of year 2000 through year 2009 energy supply and demand in the DPRK can be found in Attachments 1 and 2 to this Report.

3.6.1. Supply and demand for energy in the DPRK in 2000, 2005, 2008, and 2009

Tables 3-1a through 3-1d present summary versions of our estimated 2000, 2005, 2008, and 2009 energy balances for the DPRK. More detailed versions of these balances are presented as Tables 3-2a through d, and detailed balances that focus on the supply of and demand for refined petroleum products are shown as Tables 3-3a through d. Figures 3-5a through 3-5d show the supply of energy by fuel in the DPRK in 2000, 2005, 2008, and 2009, respectively. Here the largest difference between 1996 and 2000 is a pronounced (and growing) increase in the fraction of the total DPRK energy budget supplied by wood and biomass (18 percent of supplies in 1996 vs. 28 percent in 2000, a slightly smaller 25 percent in 2005, rising to 32 and 31 percent in 2008 and 2009, respectively), with corresponding decreases in the fractions of the budget accounted for by other fuels, particularly coal and coal products.

Figures 3-6a through d show the breakdown of overall energy use by sector in 2000 through 2009. These figures show a continuation of the trend of 1990 to 1996, in that the residential sector uses an even larger share (over 40 percent in each year) of the overall energy budget, while the industrial sector share of total energy use shrinks to less than a third of the total. This change is the combined result of continued reduction in fuel demand in the industrial sector, slowly rising use of wood and other biomass fuels in the residential and other sectors, 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. Figures 3-7a through d show the patterns of final fuels demand by fuel. Figures 3-8a through d and 3-9a through d show the patterns of demand for coal and for oil products in the years 2000, 2005, 2008, and 2009.

Table 3-1a: 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	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	338	18	40	38	166	-	-	(0)	599
Domestic Production	337	1	-	38	154	-		-	529
Imports	10	17	42	-	12	-		-	81
Exports	9	-	3	-	0	-		0	12
Stock Changes	-	-	(1)	-	-	-		-	(1)
ENERGY TRANSF.	(53)	(18)	(0)	(38)	(6)	2	3	31	(79)
Electricity Generation	(31)	-	(17)	(38)	-	-	2	48	(35)
Petroleum Refining	-	(18)	18	-	-	-		(0)	(0)
Coal Prod./Prep.	(16)	-	-	-	-	-		(2)	(18)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(1)		(0)				1		(1)
Own Use	-	-	(1)	-	-	-		(2)	(3)
Losses	(4)	-	-	-	-	-	(1)	(13)	(17)
FUELS FOR FINAL CONS.	285	-	40	-	160	2	3	31	520
ENERGY DEMAND	285	-	40	-	160	2	3	31	520
INDUSTRIAL	148	-	12	-	1	-	-	13	173
TRANSPORT	-	-	9	-	1	-	-	3	12
RESIDENTIAL	95	-	2	-	122	2	2	3	225
AGRICULTURAL	4	-	1	-	20	-	-	1	26
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	21	-	11	-	7	-	-	7	47
PUBLIC/COMML	16	-	0	-	3	-	1	3	23
NON-SPECIFIED			-	-					-
NON-ENERGY	1		4		6				11
Elect. Gen. (Gr. TWhe)*	2.64	-	0.15	10.47	-	-		-	13.26

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

Table 3-1b: Summary Estimated Supply/Demand Balance for the DPRK in 2005

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	391	24	23	44	186	-	-	(0)	668
Domestic Production	436	1	-	44	174	-		-	655
Imports	36	22	23	-	12	-		0	93
Exports	80	-	0	-	0	-		0	80
Stock Changes	-	-	(0)	-	-	-		-	(0)
ENERGY TRANSF.	(112)	(24)	13	(43)	(6)	2	4	38	(127)
Electricity Generation	(84)	-	(9)	(43)	-	-	4	60	(72)
Petroleum Refining	-	(24)	24	-	-	-		(0)	(0)
Coal Prod./Prep.	(21)	-	-	-	-	-		(3)	(24)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				2		(0)
Own Use	-	-	(1)	-	-	-		(4)	(5)
Losses	(5)	-	-	-	-	-	(1)	(15)	(22)
FUELS FOR FINAL CONS.	279	-	37	1	180	2	4	38	541
ENERGY DEMAND	279	-	37	-	180	2	4	38	539
INDUSTRIAL	151	-	8	-	1	-	-	15	175
TRANSPORT	-	-	12	-	1	-	-	4	16
RESIDENTIAL	85	-	2	-	135	2	2	4	230
AGRICULTURAL	5	-	1	-	24	-	-	1	32
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	20	-	11	-	8	-	-	9	47
PUBLIC/COMML	17	-	0	-	5	-	1	5	29
NON-SPECIFIED			-	-					-
NON-ENERGY	2		1		6				8
Elect. Gen. (Gr. TWhe)	5.15	-	0.17	11.15	-	-		-	16.47

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

Table 3-1c: Summary Estimated Supply/Demand Balance for the DPRK in 2008

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	370	24	29	43	206	-	-	1	672
Domestic Production	425	1	-	43	194	-		-	662
Imports	12	23	29	-	12	-		2	77
Exports	66	-	0	-	-	-		1	67
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(103)	(24)	7	(43)	(6)	2	4	39	(123)
Electricity Generation	(76)	-	(15)	(43)	-	-	4	62	(68)
Petroleum Refining	-	(24)	24	-	-	-		(0)	(0)
Coal Prod./Prep.	(20)	-	-	-	-	-		(3)	(23)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				1		(1)
Own Use	-	-	(1)	-	-	-		(3)	(5)
Losses	(5)	-	-	-	-	-	(1)	(16)	(22)
FUELS FOR FINAL CONS.	267	-	36	-	200	2	4	40	549
ENERGY DEMAND	267	-	36	-	200	2	4	40	549
INDUSTRIAL	148	-	7	-	1	-	-	15	172
TRANSPORT	-	-	13	-	1	-	-	4	18
RESIDENTIAL	74	-	2	-	153	2	3	5	239
AGRICULTURAL	5	-	1	-	25	-	-	1	33
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	20	-	10	-	8	-	-	9	47
PUBLIC/COMML	19	-	0	-	6	-	2	5	31
NON-SPECIFIED			-	-					-
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	5.12	-	0.21	11.83	-	-		-	17.15

Table 3-1d: Summary Estimated Supply/Demand Balance for the DPRK in 2009

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	356	23	12	43	207	-	-	1	642
Domestic Production	446	1	-	43	195	-		-	685
Imports	4	22	12	-	12	-		2	51
Exports	93	-	0	-	-	-		0	94
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(91)	(23)	17	(43)	(6)	2	4	36	(104)
Electricity Generation	(63)	-	(5)	(43)	-	-	4	57	(49)
Petroleum Refining	-	(23)	23	-	-	-		(0)	(0)
Coal Prod./Prep.	(21)	-	-	-	-	-		(3)	(24)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				1		(1)
Own Use	-	-	(1)	-	-	-		(3)	(4)
Losses	(5)	-	-	-	-	-	(1)	(15)	(22)
FUELS FOR FINAL CONS.	265	-	29	-	201	2	4	37	538
ENERGY DEMAND	265	-	29	-	201	2	4	37	538
INDUSTRIAL	144	-	5	-	1	-	-	14	165
TRANSPORT	-	-	10	-	1	-	-	4	15
RESIDENTIAL	76	-	2	-	156	2	3	4	242
AGRICULTURAL	5	-	1	-	24	-	-	1	32
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	20	-	9	-	8	-	-	8	45
PUBLIC/COMML	19	-	0	-	6	-	1	5	31
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	3.73	-	0.20	11.87	-	-		-	15.80

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

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	337,701	17,857	40,011	37,705	165,746	-	-	(82)	598,939
Domestic Production	336,565	1,278		37,705	153,735				529,283
Imports	10,454	16,579	41,777		12,012			-	80,822
Exports	9,318		3,010		1			82	12,411
Inputs to International Marine Bunkers									-
Stock Changes			(1,245)						(1,245)
ENERGY TRANSFORMATION	(52,526)	(17,857)	(156)	(37,705)	(6,061)	1,818	2,645	30,848	(78,993)
Electricity Generation	(31,316)		(16,555)	(37,705)			2,451	47,746	(35,379)
Petroleum Refining		(17,857)	17,857					(105)	(105)
Coal Production/Preparation	(16,112)							(2,182)	(18,294)
Charcoal Production					(6,061)	1,818			(4,243)
Coke Production									-
District Heat Production	(978)		(402)				855		(524)
Other Transformation									-
Own Use			(1,056)					(1,903)	(2,959)
Losses	(4,121)						(661)	(12,708)	(17,490)
FUELS FOR FINAL CONSUMPTION	285,175	-	39,855	-	159,685	1,818	2,645	30,767	519,946
ENERGY DEMAND	285,169	-	39,852	-	159,683	1,818	2,645	30,768	519,936
INDUSTRIAL SECTOR	147,882	-	11,792	-	1,130	-		12,618	173,422
Iron and Steel	67,382							3,609	70,991
Cement	19,067		7,052					1,503	27,623
Fertilizers	2,070		343					1,629	4,042
Other Chemicals	2,325		-					1,373	3,699
Pulp and Paper	836				836			194	1,865
Other Metals	4,924							857	5,780
Other Minerals	869		3,478					137	4,484
Textiles	6,100							518	6,618
Building Materials	21,383							65	21,448
Non-specified Industry	22,926		920		294			2,732	26,873
TRANSPORT SECTOR	-	-	8,665	-	504	-	-	3,237	12,405
Road			6,795		504				7,299
Rail	-		585					3,237	3,821
Water	-		476						476
Air			809						809
Non-Specified			-					-	-
RESIDENTIAL SECTOR	95,055	-	2,207	-	121,601	1,818	1,826	2,744	225,251
Urban	73,246		2,058		19,021	1,117	1,826	2,421	99,690
Rural	21,808		149		102,580	701		323	125,561
AGRICULTURAL SECTOR	3,845	-	1,251	-	19,943	-	-	1,296	26,335
Field Operations			655					680	1,335
Processing/Other	3,845		596		19,943			615	25,000
FISHERIES SECTOR	423	-	828	-	-	-	-	196	1,447
Large Ships	-		668						668
Collectives/Processing/Other	423		161					196	779
MILITARY SECTOR	21,307	-	10,908	-	7,379	-	-	7,420	47,015
Trucks and other Transport			4,187						4,187
Armaments			148						148
Air Force			1,367						1,367
Naval Forces			5,122						5,122
Military Manufacturing	399		-					21	421
Buildings and Other	20,908		85		7,379			7,399	35,771
PUBLIC/COMMERCIAL SECTORS	15,629		78		3,126		820	3,258	22,911
NON-SPECIFIED/OTHER SECTORS			-				-		-
NON-ENERGY USE	1,029		4,121		6,000				11,150
Electricity Gen. (Gross TWhe)*	2.64		0.15	10.47					13.26

Table 3-2b: Detailed Estimated Supply/Demand Balance for the DPRK in 2005

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	391,355	23,547	23,427	44,008	185,798	-	-	(60)	668,074
Domestic Production	435,749	1,278		44,008	173,816				654,851
Imports	35,536	22,270	23,405		12,001			265	93,477
Exports	79,931		186		19			325	80,461
Inputs to International Marine Bunkers									-
Stock Changes			(207)						(207)
ENERGY TRANSFORMATION	(111,976)	(23,547)	13,353	(44,008)	(6,121)	1,836	4,276	37,657	(128,531)
Electricity Generation	(83,890)		(8,736)	(42,575)			3,719	59,592	(71,891)
Petroleum Refining		(23,547)	23,547					(139)	(139)
Coal Production/Preparation	(20,860)							(2,825)	(23,685)
Charcoal Production					(6,121)	1,836			(4,284)
Coke Production									-
District Heat Production	(1,892)		(79)	(1,433)			1,695		(1,709)
Other Transformation									-
Own Use			(1,380)					(3,508)	(4,888)
Losses	(5,335)						(1,137)	(15,463)	(21,935)
FUELS FOR FINAL CONSUMPTION	279,378	-	36,779	-	179,677	1,836	4,276	37,597	539,544
ENERGY DEMAND	279,377	-	36,780	-	179,677	1,836	4,276	37,596	539,543
INDUSTRIAL SECTOR	150,534	-	8,329	-	1,083	-		14,660	174,607
Iron and Steel	52,717							2,824	55,541
Cement	23,878		3,256					1,561	28,695
Fertilizers	3,010		512					2,370	5,892
Other Chemicals	2,265							1,338	3,602
Pulp and Paper	814				814			188	1,816
Other Metals	15,940							2,773	18,713
Other Minerals	3,528		3,528					222	7,278
Textiles	6,582							559	7,142
Building Materials	20,825							64	20,889
Non-specified Industry	20,975		1,033		269			2,762	25,039
TRANSPORT SECTOR	-	-	11,869	-	876	-	-	3,587	16,332
Road			9,653		876				10,529
Rail	-		896					3,587	4,484
Water	-		526						526
Air			793						793
Non-Specified			-					-	-
RESIDENTIAL SECTOR	84,886	-	2,221	-	134,550	1,836	2,439	3,887	229,819
Urban	67,806		2,075		24,739	1,132	2,439	3,399	101,591
Rural	17,079		146		109,810	704		488	128,228
AGRICULTURAL SECTOR	4,931	-	1,351	-	24,070	-	-	1,431	31,784
Field Operations			707					590	1,297
Processing/Other	4,931		644		24,070			842	30,487
FISHERIES SECTOR	453	-	924	-	-	-	-	210	1,586
Large Ships	-		751						751
Collectives/Processing/Other	453		173					210	836
MILITARY SECTOR	19,614	-	11,221	-	7,871	-	-	8,746	47,453
Trucks and other Transport			3,641						3,641
Armaments			129						129
Air Force			2,039						2,039
Naval Forces			5,326						5,326
Military Manufacturing	399		-					21	421
Buildings and Other	19,215		85		7,871			8,725	35,896
PUBLIC/COMMERCIAL SECTORS	17,423		174		5,227		1,364	5,074	29,262
NON-SPECIFIED/OTHER SECTORS			-				473		473
NON-ENERGY USE	1,536		690		6,000				8,226
Electricity Gen. (Gross TWhe)*	5.15		0.17	11.15					16.47

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

Table 3-2c: Detailed Estimated Supply/Demand Balance for the DPRK in 2008

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	370,238	23,792	28,868	42,575	205,678	-	-	1,058	672,209
Domestic Production	424,584	1,278		42,575	193,678				662,115
Imports	11,533	22,514	29,136		12,000			1,575	76,757
Exports	65,879		267					517	66,663
Inputs to International Marine Bunkers									-
Stock Changes			-						-
ENERGY TRANSFORMATION	(102,860)	(23,792)	6,686	(42,575)	(5,873)	1,762	4,331	39,119	(123,201)
Electricity Generation	(75,804)		(15,471)	(42,575)			4,383	61,617	(67,850)
Petroleum Refining		(23,792)	23,792					(140)	(140)
Coal Production/Preparation	(20,325)							(2,753)	(23,078)
Charcoal Production					(5,873)	1,762			(4,111)
Coke Production									-
District Heat Production	(1,533)		(241)				1,100		(674)
Other Transformation									-
Own Use			(1,394)					(3,493)	(4,887)
Losses	(5,198)						(1,151)	(16,112)	(22,461)
FUELS FOR FINAL CONSUMPTION	267,378	-	35,554	-	199,806	1,762	4,331	40,177	549,008
ENERGY DEMAND	267,374	-	35,553	-	199,806	1,762	4,331	40,177	549,003
INDUSTRIAL SECTOR	147,751	-	7,494	-	1,005	-		15,478	171,727
Iron and Steel	51,776							2,773	54,549
Cement	23,452		3,198					1,533	28,183
Fertilizers	2,872		498					2,261	5,632
Other Chemicals	2,095							1,237	3,332
Pulp and Paper	753				753			174	1,680
Other Metals	16,177							2,814	18,991
Other Minerals	4,108		3,099					227	7,434
Textiles	6,465							549	7,014
Building Materials	20,453							62	20,516
Non-specified Industry	19,600		699		252			3,846	24,396
TRANSPORT SECTOR	-	-	12,590	-	899	-	-	4,185	17,674
Road			10,807		899				11,706
Rail	-		516					4,185	4,702
Water	-		414						414
Air			853						853
Non-Specified			-					-	-
RESIDENTIAL SECTOR	74,302	-	2,086	-	153,322	1,762	2,824	4,670	238,965
Urban	61,212		1,902		34,093	1,089	2,824	4,058	105,178
Rural	13,090		184		119,228	673		613	133,787
AGRICULTURAL SECTOR	5,147	-	1,251	-	25,126	-	-	1,355	32,879
Field Operations			655					476	1,131
Processing/Other	5,147		596		25,126			879	31,748
FISHERIES SECTOR	453	-	921	-	-	-	-	210	1,584
Large Ships	-		751						751
Collectives/Processing/Other	453		171					210	833
MILITARY SECTOR	19,614	-	10,257	-	7,871	-	-	8,886	46,628
Trucks and other Transport			3,338						3,338
Armaments			101						101
Air Force			2,144						2,144
Naval Forces			4,589						4,589
Military Manufacturing	399		-					21	421
Buildings and Other	19,215		85		7,871			8,865	36,036
PUBLIC/COMMERCIAL SECTORS	18,614		289		5,584		1,508	5,392	31,386
NON-SPECIFIED/OTHER SECTORS							-		-
NON-ENERGY USE	1,493		666		6,000				8,159
Electricity Gen. (Gross TWhe)	5.12		0.21	11.83					17.15

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

Table 3-2d: Detailed Estimated Supply/Demand Balance for the DPRK in 2009

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	356,087	23,418	11,551	42,719	207,034	-	-	1,101	641,910
Domestic Production	445,808	1,278		42,719	195,034				684,839
Imports	3,718	22,140	11,674		12,000			1,565	51,098
Exports	93,440		123					464	94,027
Inputs to International Marine Bunkers									-
Stock Changes			-						-
ENERGY TRANSFORMATION	(91,081)	(23,418)	17,198	(42,719)	(5,972)	1,792	3,998	36,138	(104,065)
Electricity Generation	(62,549)		(4,807)	(42,719)			3,961	56,784	(49,330)
Petroleum Refining		(23,418)	23,418					(138)	(138)
Coal Production/Preparation	(21,341)							(2,890)	(24,231)
Charcoal Production					(5,972)	1,792			(4,180)
Coke Production									-
District Heat Production	(1,733)		(41)				1,100		(674)
Other Transformation									-
Own Use			(1,372)					(2,598)	(3,970)
Losses	(5,458)						(1,063)	(15,020)	(21,541)
FUELS FOR FINAL CONSUMPTION	265,005	-	28,749	-	201,062	1,792	3,998	37,239	537,845
ENERGY DEMAND	265,002	-	28,749	-	201,060	1,791	3,998	37,239	537,840
INDUSTRIAL SECTOR	144,468	-	4,882	-	931	-		14,281	164,562
Iron and Steel	51,776							2,773	54,549
Cement	24,216		1,601					1,485	27,302
Fertilizers	1,903		330					1,498	3,730
Other Chemicals	1,972							1,164	3,136
Pulp and Paper	709				709			164	1,581
Other Metals	16,177							2,814	18,991
Other Minerals	4,843		2,364					227	7,434
Textiles	5,818							494	6,313
Building Materials	19,772							60	19,832
Non-specified Industry	17,283		588		222			3,600	21,693
TRANSPORT SECTOR	-	-	9,690	-	627	-	-	4,240	14,557
Road			8,098		627				8,725
Rail	-		448					4,240	4,688
Water	-		351						351
Air			793						793
Non-Specified			-					-	-
RESIDENTIAL SECTOR	75,642	-	1,718	-	155,758	1,791	2,635	4,401	241,943
Urban	62,349		1,571		34,685	1,108	2,635	3,826	106,174
Rural	13,292		146		121,072	683		575	135,769
AGRICULTURAL SECTOR	4,956	-	1,153	-	24,193	-	-	1,300	31,602
Field Operations			629					454	1,082
Processing/Other	4,956		525		24,193			846	30,520
FISHERIES SECTOR	396	-	820	-	-	-	-	183	1,400
Large Ships	-		670						670
Collectives/Processing/Other	396		150					183	730
MILITARY SECTOR	19,614	-	9,265	-	7,871	-	-	8,007	44,756
Trucks and other Transport			3,338						3,338
Armaments			101						101
Air Force			1,807						1,807
Naval Forces			3,934						3,934
Military Manufacturing	399		-					21	421
Buildings and Other	19,215		85		7,871			7,985	35,156
PUBLIC/COMMERCIAL SECTORS	18,937		362		5,681		1,363	4,828	31,171
NON-SPECIFIED/OTHER SECTORS							-		-
NON-ENERGY USE	989		859		6,000				7,847
Electricity Gen. (Gross TWhe)	3.73		0.20	11.87					15.80

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

Table 3-3a: 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	17,857	4,791	8,221	20,809	951	5,240	-	57,868
Domestic Production	1,278							1,278
Imports	16,579	4,791	8,221	22,391	951	5,424		58,356
Exports				2,827		183		3,010
Inputs to International Marine Bunkers								-
Stock Changes		-		(1,245)	-			(1,245)
ENERGY TRANSFORMATION	(17,857)	3,401	3,630	(9,534)	734	946	667	(18,013)
Electricity Generation				(15,783)		(771)		(16,555)
Petroleum Refining	(17,857)	3,401	3,630	6,651	734	2,774	667	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(402)				(402)
Other Transformation								-
Own Use						(1,056)		(1,056)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	8,193	11,851	11,274	1,685	6,186	667	39,855
ENERGY DEMAND	-	8,193	11,852	11,271	1,685	6,185	667	39,852
INDUSTRIAL SECTOR	-	-	633	10,885	-	274	-	11,792
Iron and Steel								-
Cement				7,052				7,052
Fertilizers				69		274		343
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				3,478				3,478
Textiles								-
Building Materials								
Non-specified Industry			633	286				920
TRANSPORT SECTOR	-	3,452	4,166	238	364	-	445	8,665
Road		3,452	3,344					6,795
Rail			585					585
Water			238	238				476
Air					364		445	809
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	458	1,750	-	2,207
Urban					373	1,686		2,058
Rural					85	64		149
AGRICULTURAL SECTOR	-	-	1,251	-	-	-	-	1,251
Field Operations			655					655
Processing/Other			596					596
FISHERIES SECTOR	-	-	710	118	-	-	-	828
Large Ships			634	33				668
Collectives/Processing/Other			76	85				161
MILITARY SECTOR	-	4,742	5,091	30	824	-	222	10,908
Trucks and other Transport		4,118	69					4,187
Armaments		25	122					148
Air Force		321			824		222	1,367
Naval Forces		277	4,815	30				5,122
Military Manufacturing								-
Buildings and Other			85					85
PUBLIC/COMMERCIAL SECTORS					39	39		78
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						4,121		4,121

Table 3-3b: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK in 2005

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	23,547	2,238	12,741	5,302	2,031	1,115	-	46,974
Domestic Production	1,278							1,278
Imports	22,270	2,238	12,741	5,094	2,031	1,301		45,675
Exports				-		186		186
Inputs to International Marine Bunkers								-
Stock Changes				(207)				(207)
ENERGY TRANSFORMATION	(23,547)	4,899	3,423	2,195	965	1,409	461	(10,195)
Electricity Generation			(1,362)	(6,483)		(891)		(8,736)
Petroleum Refining	(23,547)	4,899	4,785	8,757	965	3,680	461	(0)
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(79)				(79)
Other Transformation								-
Own Use						(1,380)		(1,380)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	7,137	16,164	7,497	2,996	2,524	461	36,779
ENERGY DEMAND	-	7,137	16,163	7,498	2,997	2,524	461	36,780
INDUSTRIAL SECTOR	-	-	844	7,076	-	410	-	8,329
Iron and Steel								-
Cement				3,256				3,256
Fertilizers				102		410		512
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				3,528				3,528
Textiles								-
Building Materials								
Non-specified Industry			844	189				1,033
TRANSPORT SECTOR	-	2,900	7,913	263	602	-	191	11,869
Road		2,900	6,754					9,653
Rail			896					896
Water			263	263				526
Air					602		191	793
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	927	1,294	-	2,221
Urban					828	1,247		2,075
Rural					100	47		146
AGRICULTURAL SECTOR	-	-	1,351	-	-	-	-	1,351
Field Operations			707					707
Collectives/Processing/Other			644					644
FISHERIES SECTOR	-	-	796	128	-	-	-	924
Large Ships			713	38				751
Processing/Other			82	91				173
MILITARY SECTOR	-	4,238	5,259	31	1,423	-	270	11,221
Trucks and other Transport		3,581	60					3,641
Armaments		22	107					129
Air Force		346			1,423		270	2,039
Naval Forces		288	5,007	31				5,326
Military Manufacturing								-
Buildings and Other			85					85
PUBLIC/COMMERCIAL SECTORS					44	131		174
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						690		690

Table 3-3c: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK in 2008

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	23,792	5,109	8,236	13,220	2,050	254	-	52,660
Domestic Production	1,278							1,278
Imports	22,514	5,109	8,236	13,220	2,184	387		51,649
Exports				0	133	133		267
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(23,792)	4,956	4,235	(6,265)	975	2,325	460	(17,106)
Electricity Generation			(599)	(14,872)		-		(15,471)
Petroleum Refining	(23,792)	4,956	4,834	8,848	975	3,719	460	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(241)				(241)
Other Transformation								-
Own Use						(1,394)		(1,394)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	10,064	12,471	6,955	3,025	2,579	460	35,554
ENERGY DEMAND	-	10,064	12,470	6,954	3,026	2,580	460	35,553
INDUSTRIAL SECTOR	-	-	503	6,592	-	398	-	7,494
Iron and Steel								-
Cement				3,198				3,198
Fertilizers				100		398		498
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				3,099				3,099
Textiles								-
Building Materials								
Non-specified Industry			503	196				699
TRANSPORT SECTOR	-	6,145	5,384	207	668	-	185	12,590
Road		6,145	4,661					10,807
Rail			516					516
Water			207	207				414
Air					668		185	853
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	797	1,289	-	2,086
Urban					697	1,205		1,902
Rural					100	84		184
AGRICULTURAL SECTOR	-	-	1,251	-	-	-	-	1,251
Field Operations			655					655
Processing/Other			596					596
FISHERIES SECTOR	-	-	793	128	-	-	-	921
Large Ships			713	38				751
Collectives/Processing/Other			80	91				171
MILITARY SECTOR	-	3,919	4,537	27	1,498	-	275	10,257
Trucks and other Transport		3,283	55					3,338
Armaments		17	84					101
Air Force		371			1,498		275	2,144
Naval Forces		248	4,314	27				4,589
Military Manufacturing								-
Buildings and Other			85					85
PUBLIC/COMMERCIAL SECTORS					62	226		289
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						666		666

Table 3-3d: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK in 2009

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	23,418	3,585	5,966	281	1,522	196	-	34,969
Domestic Production	1,278							1,278
Imports	22,140	3,585	5,966	281	1,522	319		33,814
Exports		-	-	-		123		123
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(23,418)	4,864	4,377	4,243	960	2,287	466	(6,220)
Electricity Generation			(381)	(4,426)		-		(4,807)
Petroleum Refining	(23,418)	4,864	4,759	8,709	960	3,660	466	(0)
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(41)				(41)
Other Transformation								-
Own Use						(1,372)		(1,372)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	8,449	10,343	4,524	2,482	2,483	466	28,749
ENERGY DEMAND	-	8,449	10,342	4,526	2,482	2,483	466	28,749
INDUSTRIAL SECTOR	-	-	403	4,216	-	264	-	4,882
Iron and Steel								-
Cement				1,601				1,601
Fertilizers				66		264		330
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				2,364				2,364
Textiles								-
Building Materials								
Non-specified Industry			403	185				588
TRANSPORT SECTOR	-	4,566	4,156	175	602	-	191	9,690
Road		4,566	3,532					8,098
Rail			448					448
Water			175	175				351
Air					602		191	793
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	655	1,062	-	1,718
Urban					576	996		1,571
Rural					79	67		146
AGRICULTURAL SECTOR	-	-	1,153	-	-	-	-	1,153
Field Operations			629					629
Processing/Other			525					525
FISHERIES SECTOR	-	-	708	113	-	-	-	820
Large Ships			637	33				670
Collectives/Processing/Other			71	79				150
MILITARY SECTOR	-	3,884	3,922	22	1,161	-	275	9,265
Trucks and other Transport		3,283	55					3,338
Armaments		17	84					101
Air Force		371			1,161		275	1,807
Naval Forces		213	3,698	22				3,934
Military Manufacturing								-
Buildings and Other			85					85
PUBLIC/COMMERCIAL SECTORS					63	298		362
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						859		859

Figure 3-5a:

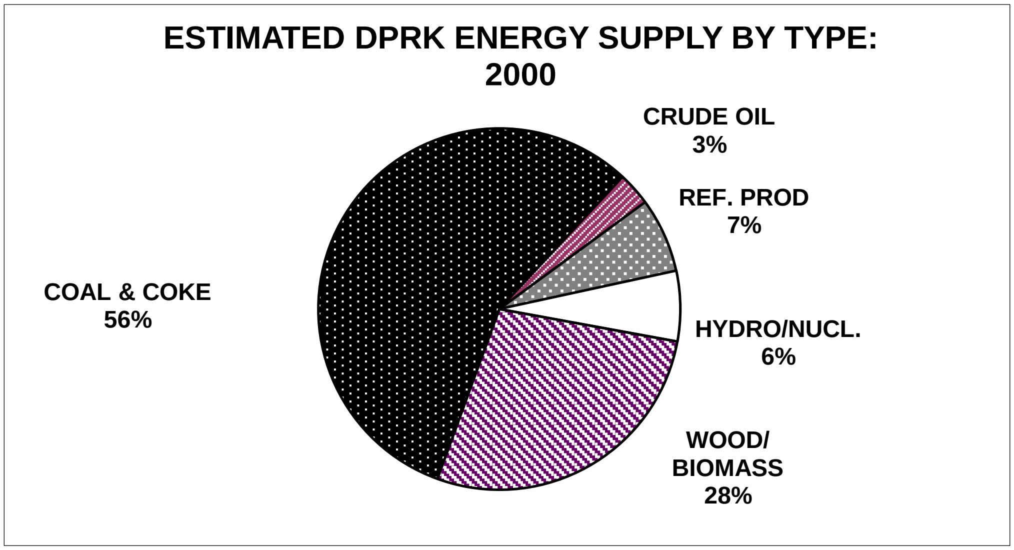


Figure 3-5b:

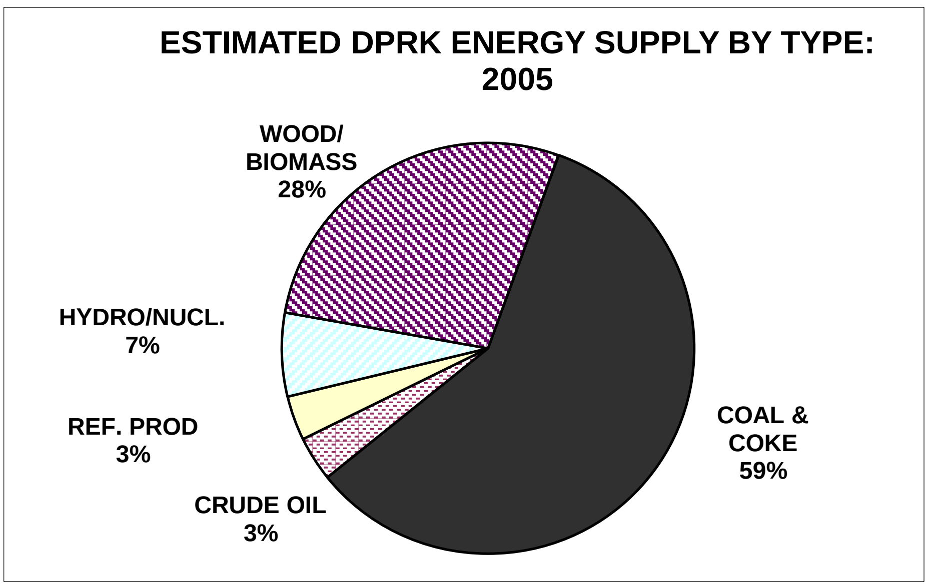


Figure 3-5c:

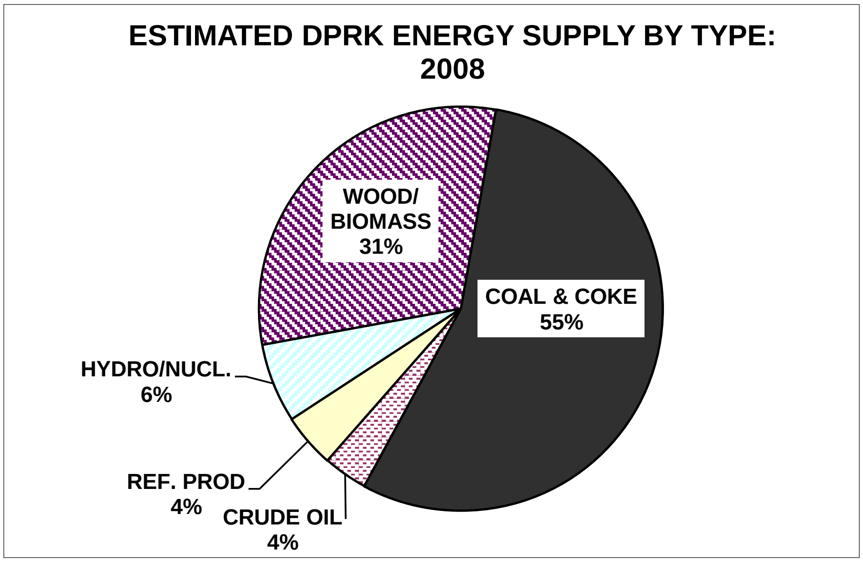


Figure 3-5d:

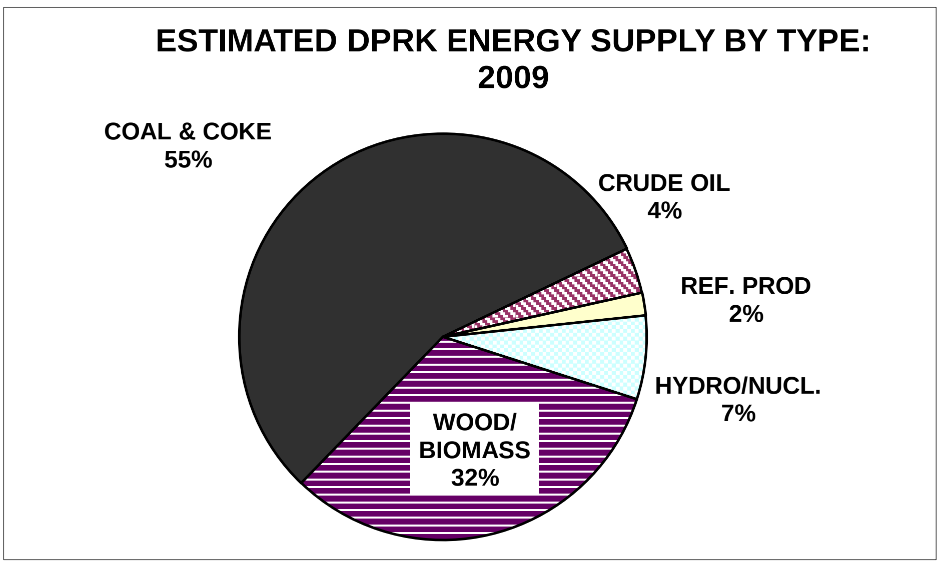


Figure 3-6a:

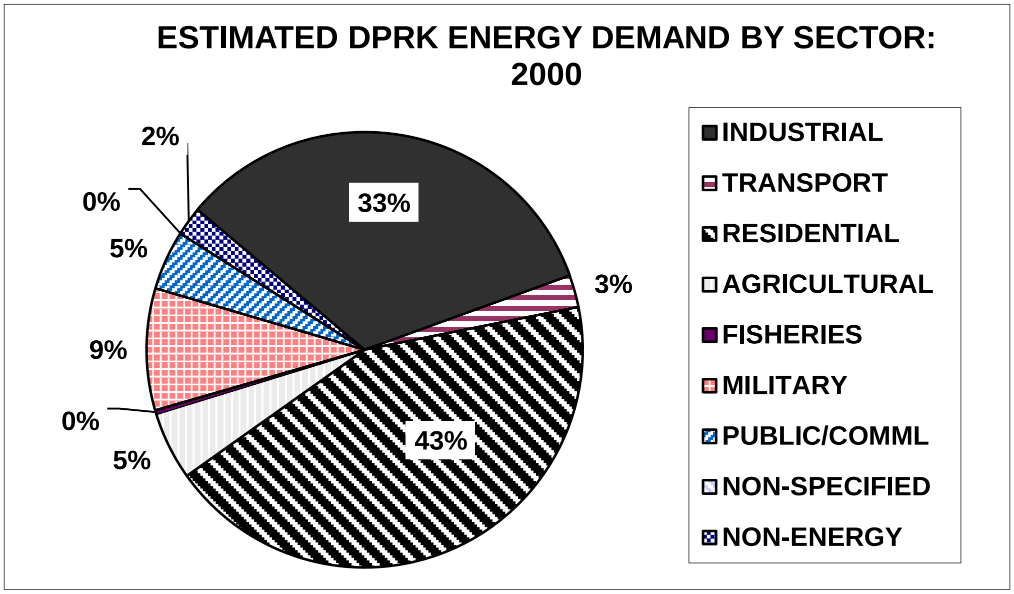


Figure 3-6b:

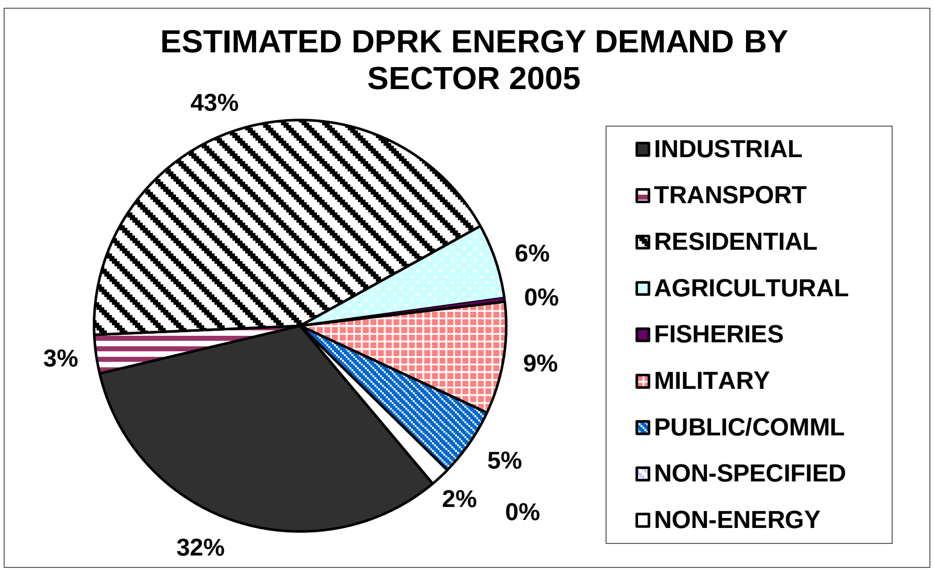


Figure 3-6c:

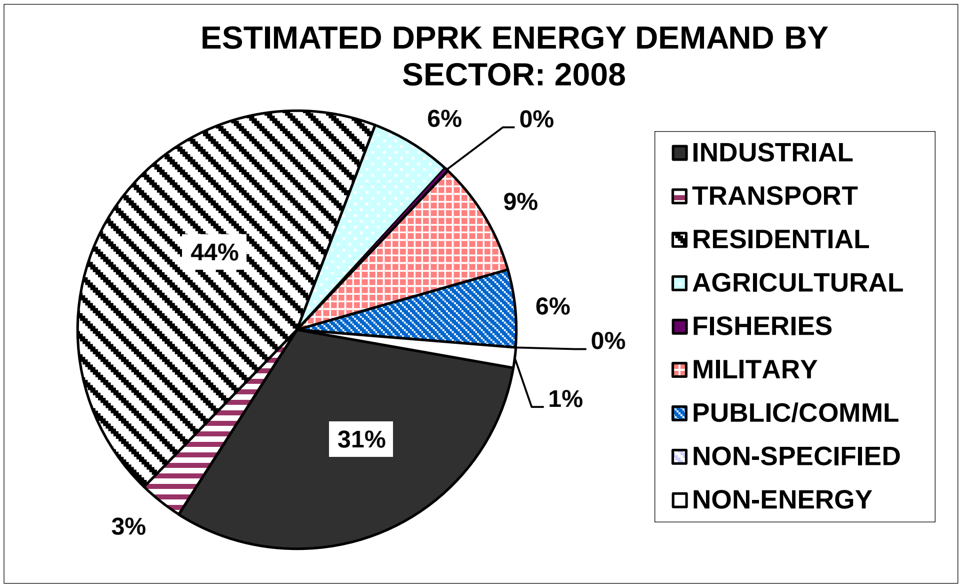


Figure 3-6d:

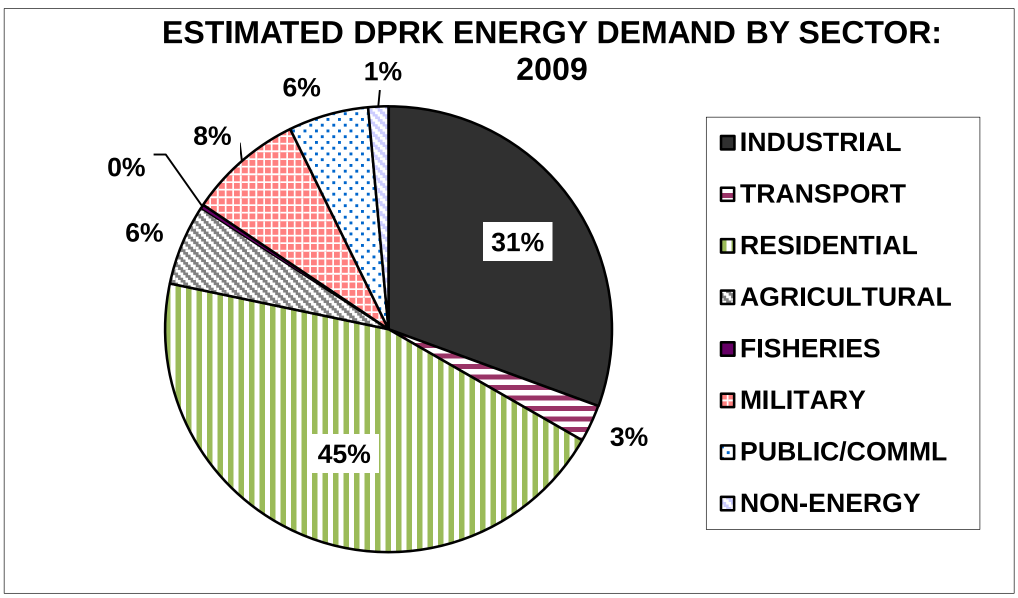


Figure 3-7a:

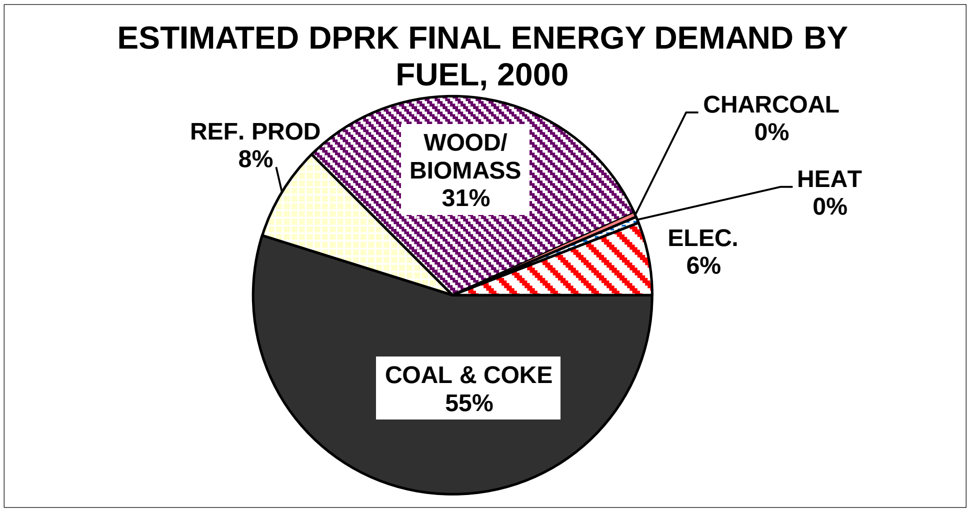


Figure 3-7b:

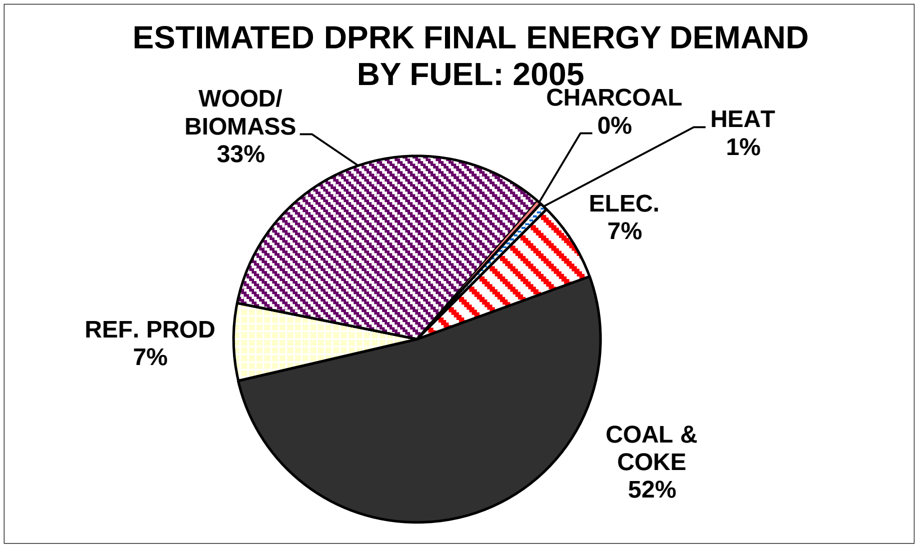


Figure 3-7c:

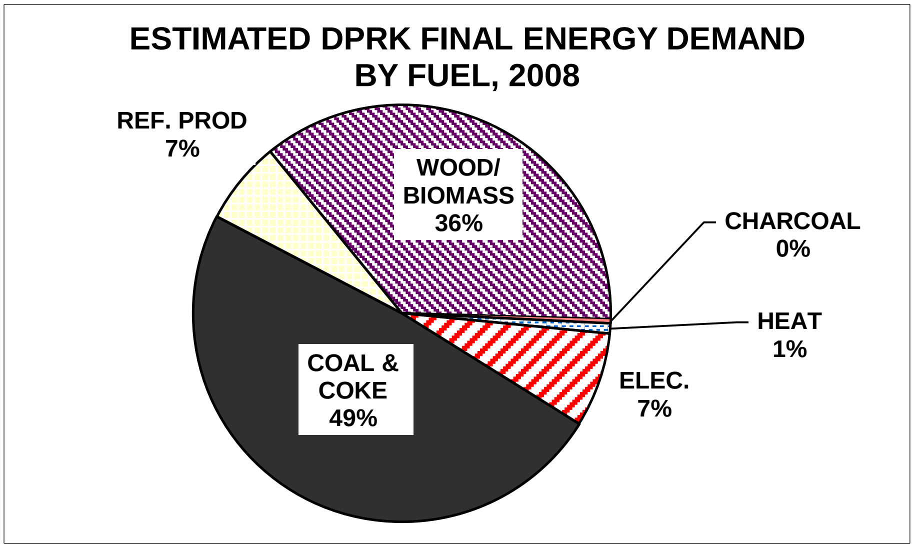


Figure 3-7d:

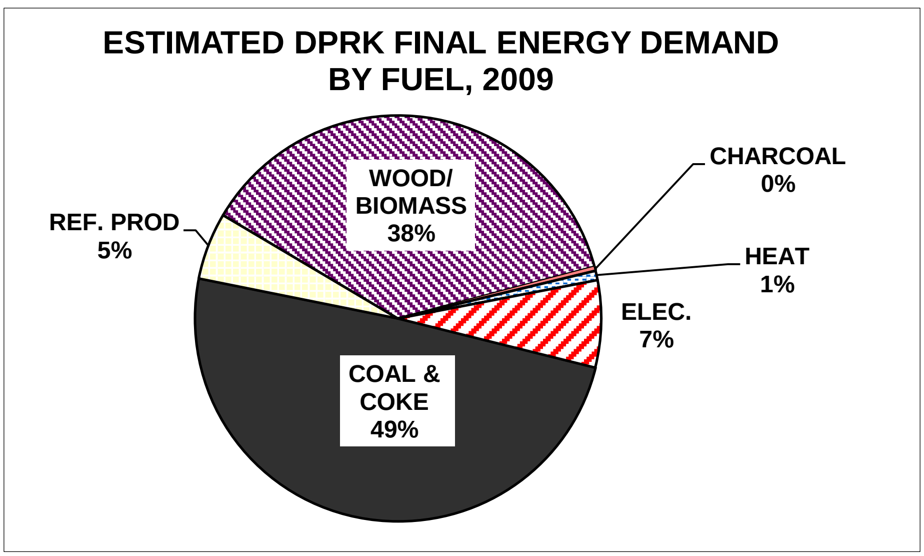
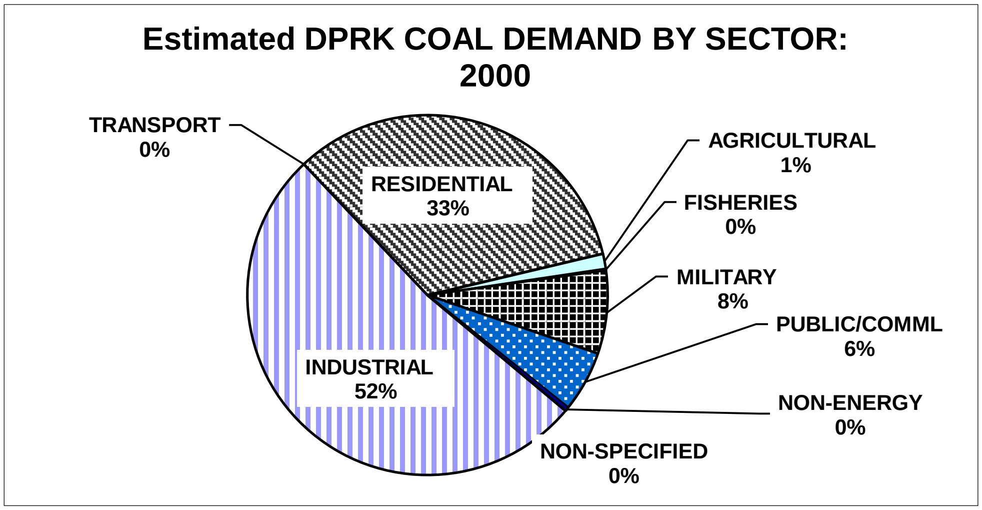


Figure 3-8a:



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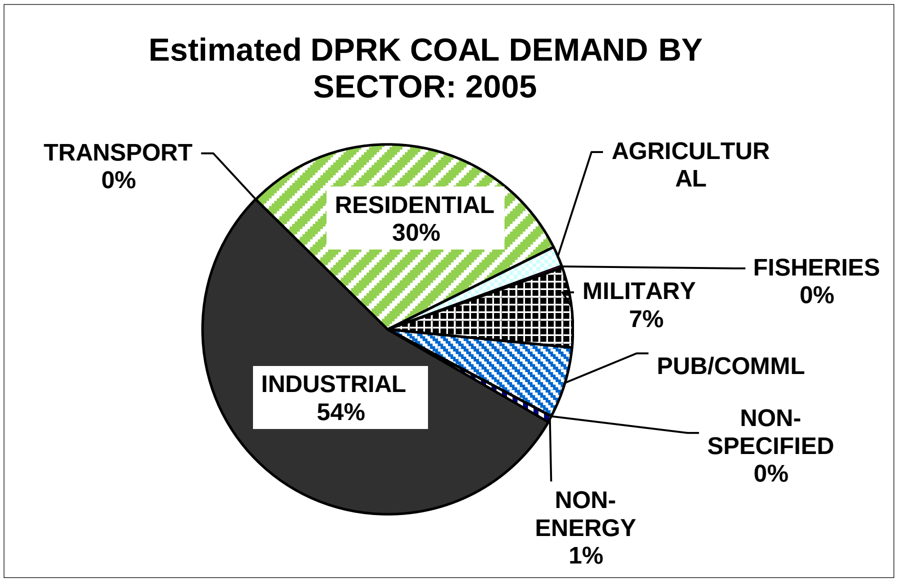

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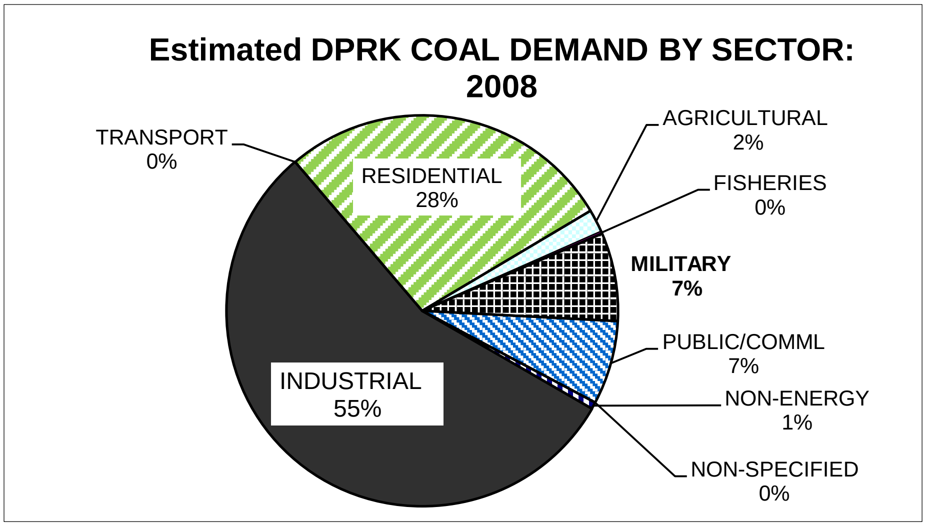

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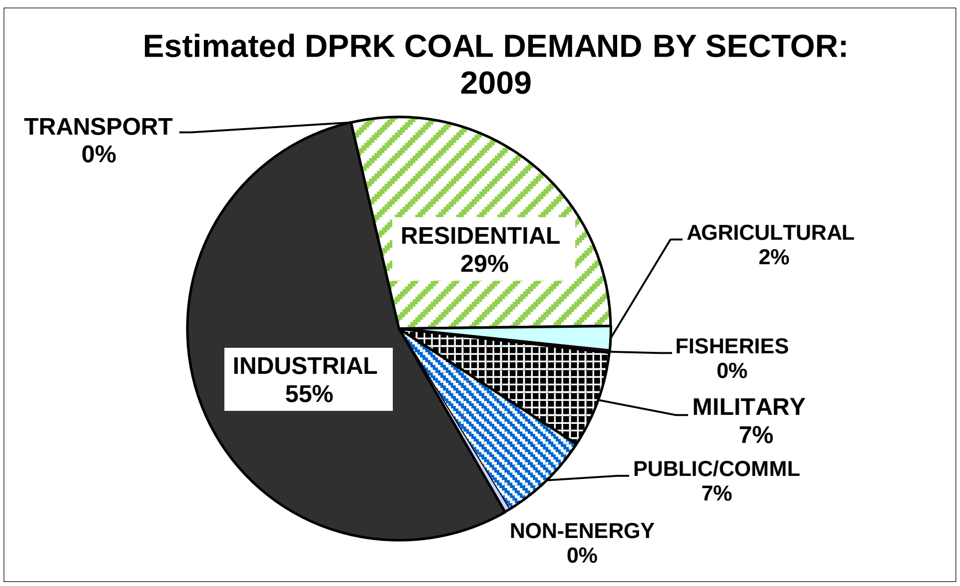


Figure 3-9a:

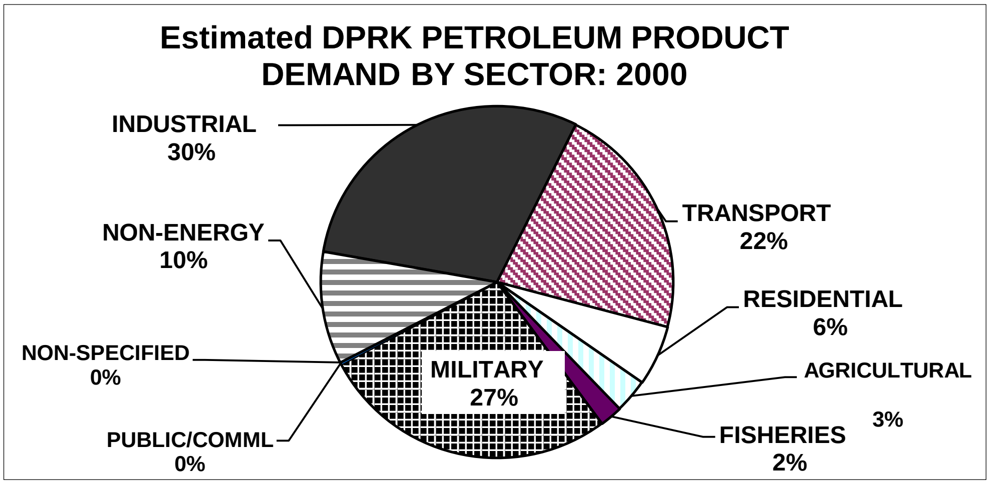


Figure 3-9b:

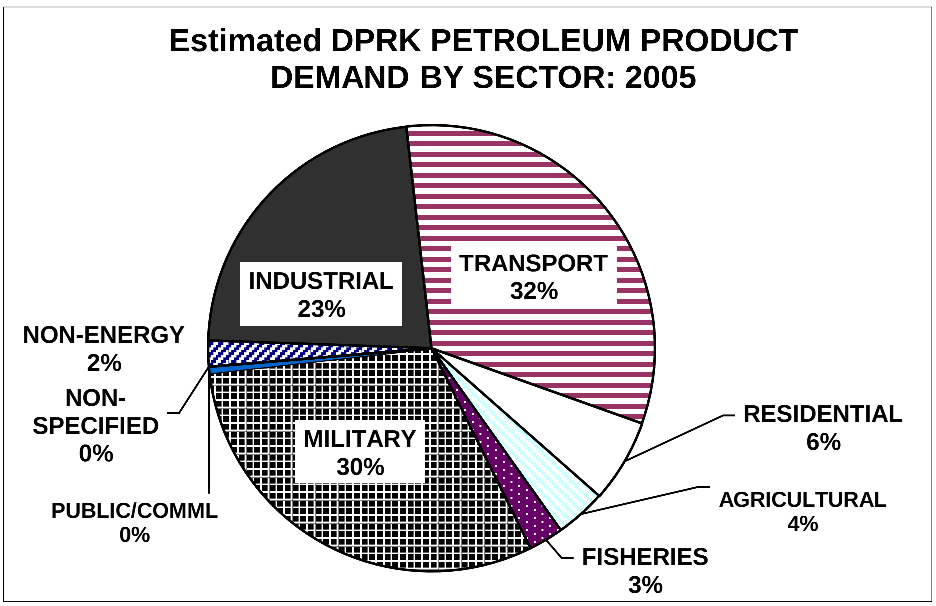


Figure 3-9c:

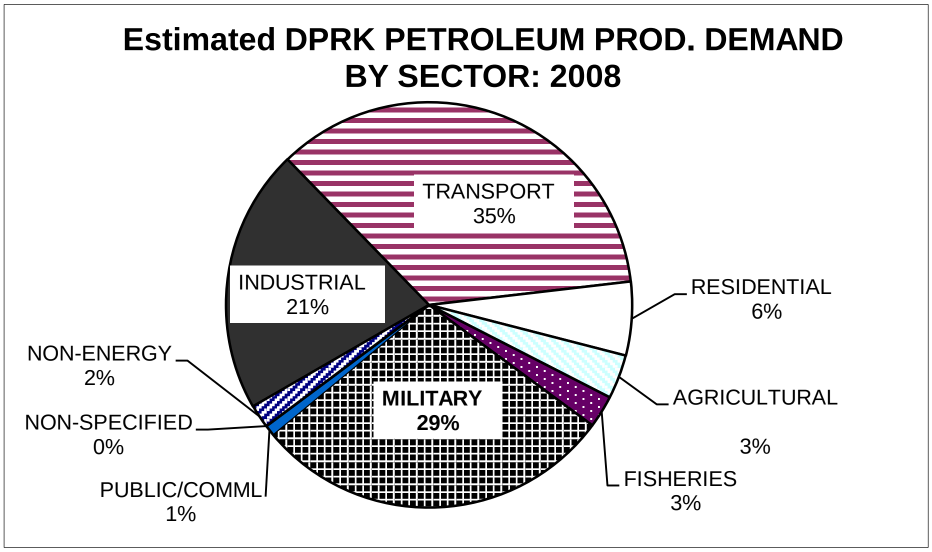


Figure 3-9d:

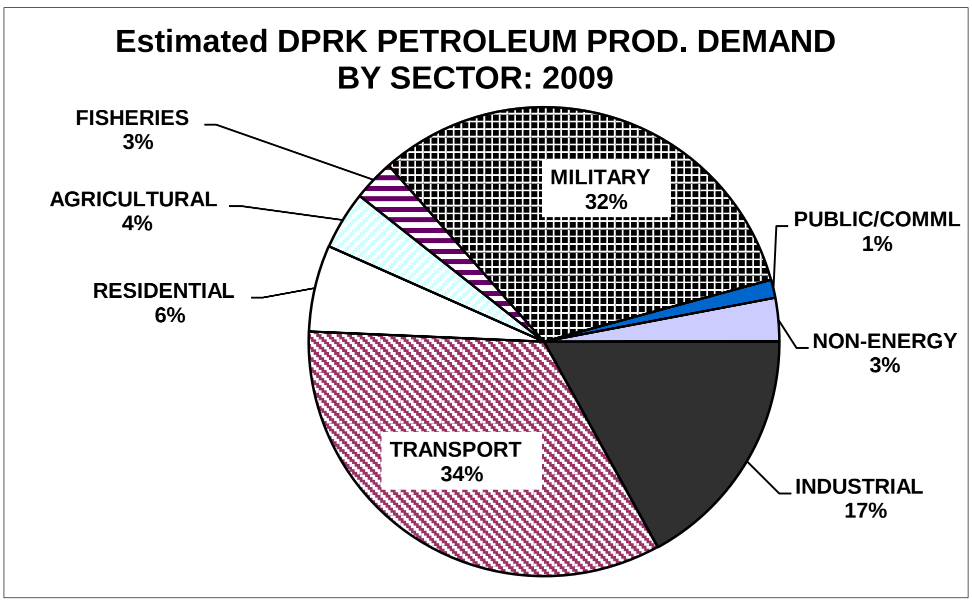


Table 3-4 shows the structure of demand for three key oil product categories—diesel oil, gasoline, and kerosene/jet fuel—in 1990, 1996, 2000, 2005, 2008, and 2009. Of these three categories, gasoline use decreased by the largest percentage between 1996 and 2000. Kerosene use increased in the residential sector between 2000 and 2005 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), but fell in later years. Even more than in 1996, 2000 and 2005 gasoline use was dominated by the Military sector, though the military share of gasoline use decreased in 2008 due to higher estimated gasoline availability for transport, rising again in 2009. By way of comparison, the estimated 2005 diesel fuel use in agriculture shown in

Table 3-4, about 1350 TJ or 31,000 tonnes of fuel, was about 22 percent of international estimates of the DPRK's national fuel needs for agriculture as estimated by the United Nations Development Programme and UN Food and Agriculture Organization[140]. Our estimates of fuel use in the DPRK agricultural sector in 2008 and 2009 are even lower. Table 3-5 summarizes heavy fuel oil demand in 1990 through 2009[184]. HFO use since 1996 has tended to rise and fall with changes in availability from KEDO and, in more recent years, from supplies promised during the Six-Party Talks agreements. In general, in years when more HFO was available, our estimate is that most of the additional HFO (beyond the quantities normally imported and produced in the DPRK's refinery from Chinese crude) has gone to supplement coal for electricity and heat generation, though some additional use for industrial purposes is also possible.

[184] Note that the units on Tables 3-4 and 3-5 differ by a factor of 1000.

Table 3-4: Demand for Selected Non-HFO Refined Petroleum Products by Sector—1990, 1996, 2000, 2005, 2008, and 2009

	DIESEL OIL					
SECTOR	1990	1996	2000	2005	2008	2009
INDUSTRIAL	3,050	671	633	844	503	403
TRANSPORT	12,926	4,999	4,166	7,913	5,384	4,156
RESIDENTIAL	-	-	-	-	-	-
AGRICULTURAL	5,005	1,502	1,251	1,351	1,251	1,153
FISHERIES	2,777	856	710	796	793	708
MILITARY	6,859	5,248	5,091	5,259	4,537	3,922
NON-SPECIFIED/OTHER	1,700	-	-	-	-	-
TOTAL	32,607	13,276	11,852	16,163	12,470	10,342
INDUSTRIAL	9%	5%	5%	5%	4%	4%
TRANSPORT	40%	38%	35%	49%	43%	40%
RESIDENTIAL	0%	0%	0%	0%	0%	0%
AGRICULTURAL	15%	11%	11%	8%	10%	11%
FISHERIES	9%	6%	6%	5%	6%	7%
MILITARY	21%	40%	43%	33%	36%	38%
NON-SPECIFIED/OTHER	5%	0%	0%	0%	0%	0%
TOTAL	100%	100%	100%	100%	100%	100%

	GASOLINE					
SECTOR	1990	1996	2000	2005	2008	2009
INDUSTRIAL	-	-	-	-	-	-
TRANSPORT	23,220	10,376	3,452	2,900	6,145	4,566
RESIDENTIAL	-	-	-	-	-	-
AGRICULTURAL	-	-	-	-	-	-
FISHERIES	-	-	-	-	-	-
MILITARY	7,386	6,352	4,742	4,238	3,919	3,884
TOTAL	30,606	16,728	8,193	7,137	10,064	8,449
INDUSTRIAL	-	-	-	-	-	-
TRANSPORT	76%	62%	42%	41%	61%	54%
RESIDENTIAL	0%	0%	0%	0%	0%	0%
AGRICULTURAL	0%	0%	0%	0%	0%	0%
FISHERIES	0%	0%	0%	0%	0%	0%
MILITARY	24%	38%	58%	59%	39%	46%
TOTAL	100%	100%	100%	100%	100%	100%

	KEROSENE/JET FUEL					
SECTOR	1990	1996	2000	2005	2008	2009
INDUSTRIAL	-	-	-	-	-	-
TRANSPORT	399	320	364	602	668	602
RESIDENTIAL	4,473	553	458	927	797	655
AGRICULTURAL	-	-	-	-	-	-
FISHERIES	-	-	-	-	-	-
MILITARY	1,798	1,199	824	1,423	1,498	1,161
TOTAL	6,670	2,071	1,646	2,953	2,963	2,419
INDUSTRIAL	-	-	-	-	-	-
TRANSPORT	6%	15%	22%	20%	23%	25%
RESIDENTIAL	67%	27%	28%	31%	27%	27%
AGRICULTURAL	0%	0%	0%	0%	0%	0%
FISHERIES	0%	0%	0%	0%	0%	0%
MILITARY	27%	58%	50%	48%	51%	48%
TOTAL	100%	100%	100%	100%	100%	100%

Table 3-5: Demand for and Supply of Heavy Fuel Oil—1990 through 2009

HFO Demand Summary: Petajoules (PJ)

	YEAR					
CONSUMER	**1990**	**1996**	**2000**	**2005**	**2008**	**2009**
OIL-ELECT.	15.6	11.7	2.6	3.0	3.0	3.0
COAL-ELECT	6.3	13.7	13.2	3.5	11.9	1.5
INDUSTRY	21.8	7.1	10.9	7.1	6.6	4.2
SHIPS	1.0	0.4	0.4	0.4	0.36	0.31
STORAGE	-	6.4	(0.03)	(0.01)	-	-
TOTAL	**44.8**	**39.4**	**27.0**	**14.0**	**21.8**	**9.0**
OIL-ELECT.	35%	30%	10%	21%	14%	33%
COAL-ELECT	14%	35%	49%	25%	55%	16%
INDUSTRY	49%	18%	40%	51%	30%	47%
SHIPS	2%	1%	1%	3%	2%	3%
STORAGE	0%	16%	0%	0%	0%	0%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
HFO Supply Summary						
KEDO/Six Party Talks	-	20.7	16.4	-	12.6	-
Net Non-KEDO Imports	6.2	4.1	3.2	5.1	0.6	0.3
Domestic Refining	38.6	14.8	6.7	8.8	8.8	8.7
TOTAL	**44.8**	**39.6**	**26.2**	**13.9**	**22.1**	**9.0**

3.6.2. Supply and demand for electricity in 2000 through 2009

Table 3-6 and Figure 3-10 show the estimated structure of electricity supply in the DPRK in 1990/1996 (for comparison) and in 2000 through 2009, 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 these figures display 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[185]) and 1996 (22.8 TWh), and fell still further (by our estimate) by 2000, to 13.3 TWh, then increased somewhat since, to 16.5 TWh in 2005. Through 2009, by our estimates, total electricity output changed varied relatively little from year to year, with estimated output of 17.2 TWh in 2008, dropping to 15.8 TWh in 2009. The estimate for 2000 is considerably lower than previous estimates by other groups[186], 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 3-10 are the significant drop in hydroelectric output as a result of damage to hydroelectric impoundments (and perhaps generating equipment) from

[185] One terawatt-hour is equal to 3600 terajoules, 3.6 million gigajoules, or one billion kilowatt-hours (kWh).

[186] 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.

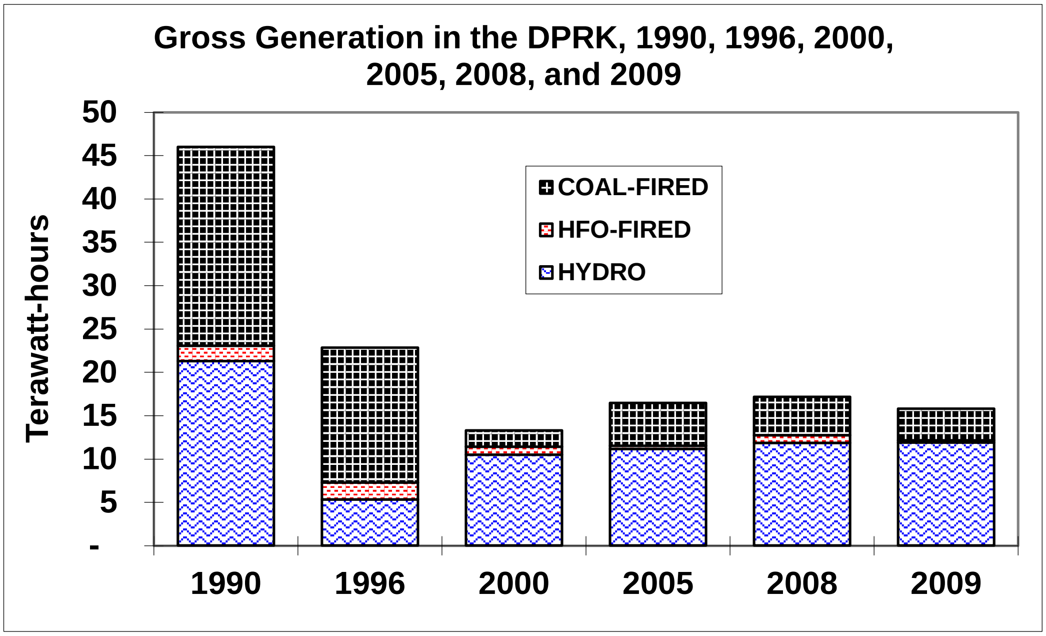
the floods of 1995 and 1996, and a considerable drop in thermal plant output between 1996 and 2000[187].

Table 3-6:

Supply Summary for Electricity: Terawatt-hours of Gross Generation

GENERATION	YEAR					
	1990	1996	2000	2005	2008	2009
HYDRO	21.3	5.3	10.5	11.1	11.8	11.9
HFO-FIRED	1.8	1.9	0.9	0.4	0.9	0.3
COAL-FIRED	22.9	15.6	1.9	4.9	4.4	3.6
TOTAL	46	22.8	13.3	16.5	17.2	15.8
HYDRO	46%	23%	79%	68%	69%	75%
HFO-FIRED	4%	8%	7%	2%	5%	2%
COAL-FIRED	50%	68%	14%	30%	26%	23%
TOTAL	100%	100%	100%	100%	100%	100%

Figure 3-10: Estimated Sources of Electricity Supply: 1990 through 2009



The estimated structure of demand for electricity is shown in Figure 3-11 for the six balance years. The fractions of demand by sector are shown in Figure 3-12a through d for 2000 through 2009. 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

[187] 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.

availability of electricity in many areas) and shares used by agriculture (for example, irrigation and crop processing, a national priority) and the military increasing. After 2000, by our estimates, the sectoral shares of electricity change only modestly from year to year.

Figure 3-11: DPRK Electricity Use by Sector: 1990 through 2009

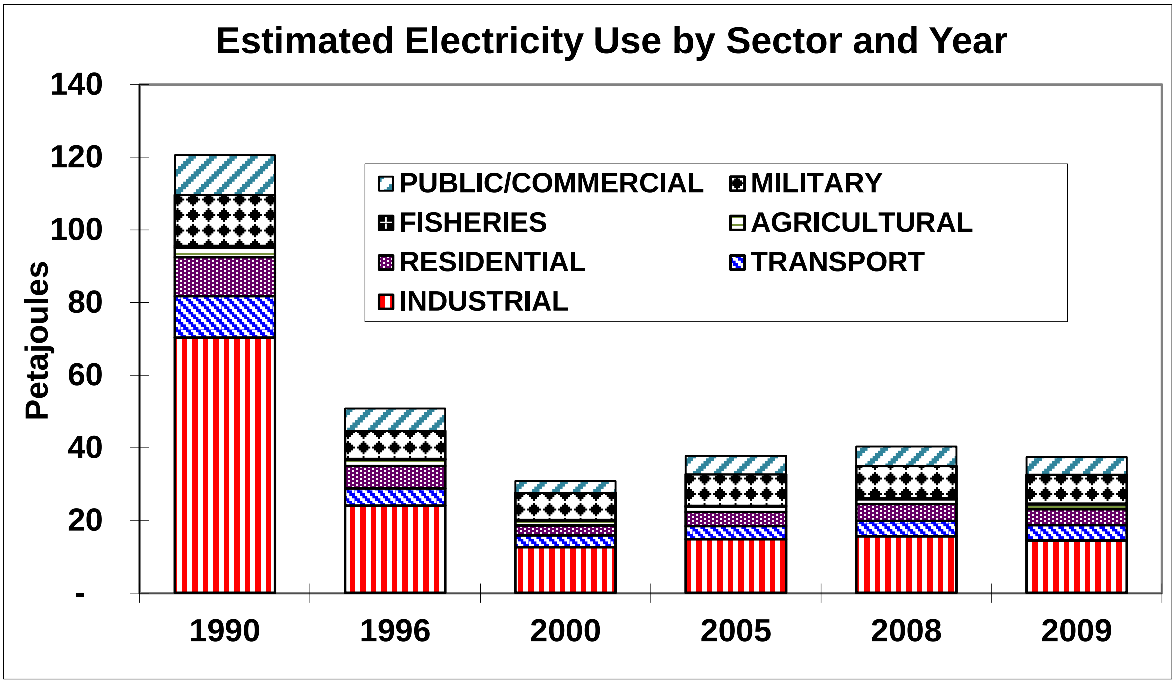


Figure 3-12a:

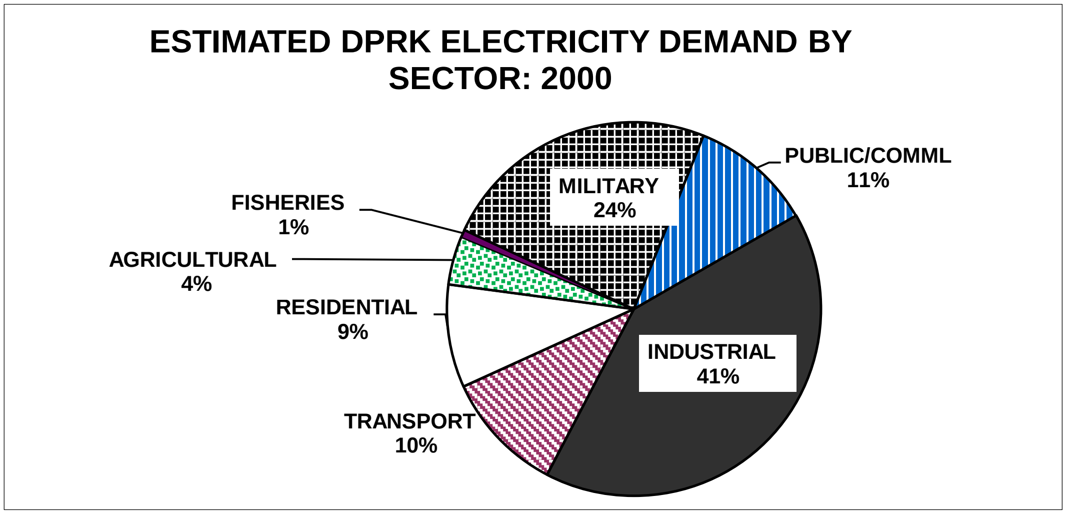


Figure 3-12b:

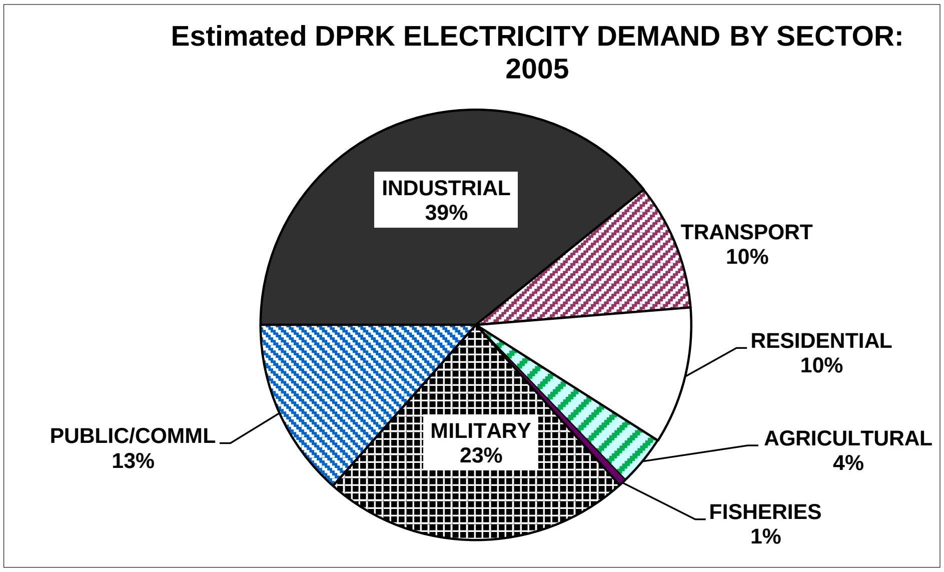


Figure 3-12c:

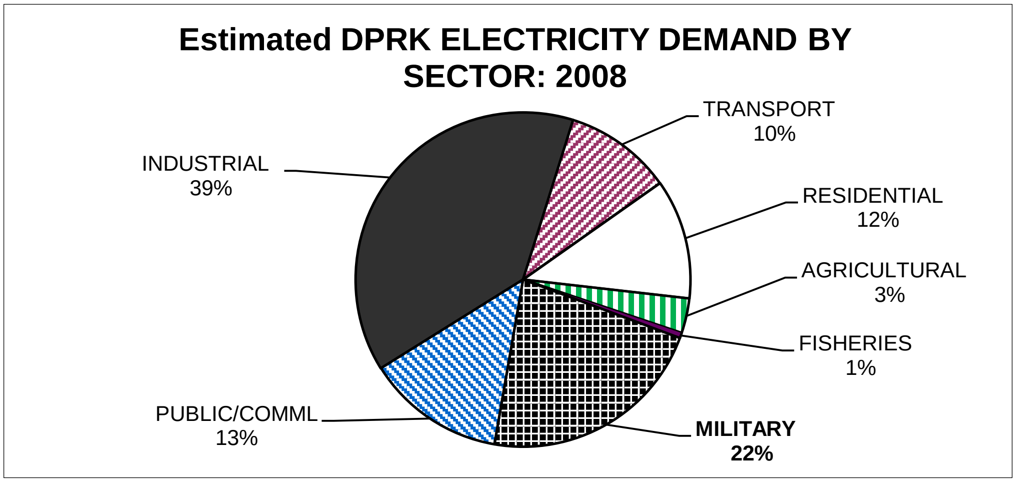
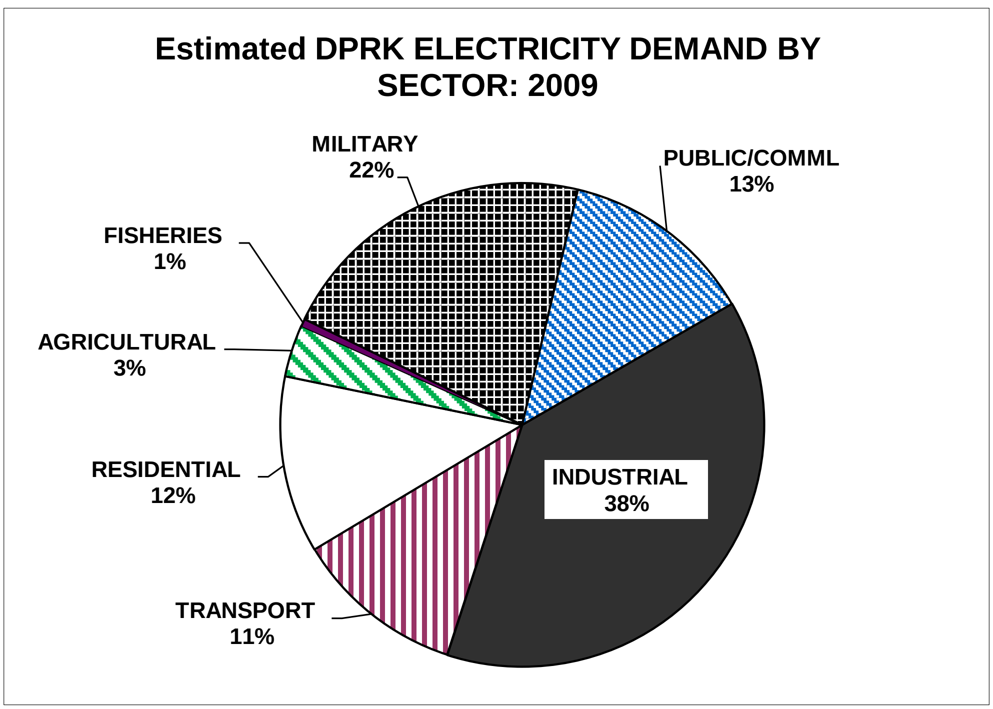


Figure 3-12d:



4. The DPRK's Energy Resources for Fueling Redevelopment

4.1. Introduction

As with virtually any country, the key resource that the DPRK possesses to drive the redevelopment of its economy is its people. The political and other developments of the last two decades, and their effect on the DPRK economy, however, mean that the availability of dedicated workers alone will not be sufficient to assure significant economic progress in the DPRK, even assuming an improvement in the DPRK's relations with neighboring countries and the world community.

In the short and medium term, the DPRK's mineral resource endowment will likely be drawn on to provide the major source of income to fuel economic growth. As the economy improves, energy resources, but from domestic supplies and from exports, will need to be tapped in greater quantities. Coal has for more than a century been the most important fossil fuel resource for the DPRK. Oil and gas, though substantially untapped, are said to be found in the DPRK's onshore and offshore territories. Wood and other biomass contribute, as noted above, a considerable portion of the DPRK's estimated energy supplies, but forest health (and, relatedly, soil conservation) has become a major concern in the DPRK in recent years. Additional renewable resources—solar, tidal, and wind energy—are available. Finally, the relatively low efficiency with which energy is currently used in most applications in the DPRK means that there is a significant resource of energy efficiency to be tapped as the DPRK economy improves—and tapping that resource has important ramifications for the amount of fuels ultimately needed in the DPRK. In the Chapter that follows, we briefly review the status of the DPRK's estimated supplies of each of these potential "resources for fueling development".

4.2. Fossil Fuels

Coal has historically been the DPRK's only significant domestic fossil fuel resource, and the DPRK has, by all accounts, substantial coal reserves. Recent production of oil in the DPRK has been rumored, albeit at a small scale, following many years of exploration with a variety of partners. Geologic structures bearing gas have also been identified in DPPRK territory.

4.2.1. Coal

The DPRK has abundant coal resources, including deposits of anthracite coal and lignite, or "brown" coal. It substantially lacks, however, bituminous coal, which is the most common coal used worldwide as an input to coke production for steelmaking, and as a power plant fuel. Coal quality in the DPRK seems to be quite variable, with reported energy contents for different DPRK coals ranging from a very low 1000 and 2300 kilocalories (kcals) per kilogram for "low grade coal" (lignite and anthracite, respectively)[141] to a relatively high 6150 kcal/kg for high-grade anthracite coal[142]. The DPRK's total coal resource or reserves have been variously estimated at levels ranging from 600 million tonnes ("proven coal reserves", and "recoverable coal reserves", as noted in international compendia of energy statistics[143]) to resources ("coal deposits") of nearly 15 billion tonnes[188]. The latter estimate is included in a fairly detailed description of coal (and other mineral) resource in the DPRK published through a Korean-language website in China[144]. Information from the latter source includes the following:

> "Coal in the DPRK is generally divided into two kinds - anthracite and lignite. The major producing area of anthracite is North and South P'yo'ngan Provinces and lignite is mainly distributed in North and South Hamgyo'ng Provinces. In terms of area, the four major coalfields are in the northern part of South P'yo'ngan Province, southern part of South P'yo'ngan Province, and northern part of North Hamgyo'ng Province, and southern part of South Hamgyo'ng Province respectively.
>
> "Of the about 100 central-level [chungang-ku'p] coal mines in the DPRK, 70 are anthracitic coal mines and 30 are lignite ones. There are about 500 local-level small- and medium-sized coal mines.
>
> "The conjoined areas in the southern part of South P'yo'ngan Province surrounding Pyongyang, 80 km east and west of [Pyongyang], are very rich in coal deposit. Coal mines that can be representative include Samsindong in Taeso'ng District, Sadong District, Ryongso'ng District, Hu'ngnyo'ng District in Kangdong County, Kangso' County, So'ngch'o'n County, and Onch'o'n County.
>
> "Anthracitic coal in the northern part of South P'yo'ngan Province is distributed in an area 668 square km wide. Major coal mines are To'kch'o'n, Hyo'ngbong, and Chenam in the City of To'kch'o'n; Choyang, Kaech'o'n, Pongch'o'n, Yo'mjo'n, Wo'lli, Sillim; Songnam and Hyo'ndong in Pukch'ang County; Sinch'ang, Ch'o'nso'ng, and Yo'ngdae in U'nsan County; Musandae and Chiktong in Sunch'o'n County; and Ryongdu'ng, Ryongmun, and Ryongch'o'l in Kujang County, North P'yo'ngan Province.
>
> "Wuguang Group, one of the five leading Chinese Coal Mining Enterprises, has obtained mining rights to Ryongdu'ng Coal Mine.
>
> "In North Hamgyo'ng Province, Pukpu Coalfield (north of Aoji-ri), Nambu Coalfield (south of Ch'o'ngjin), and Anju Coalfield in South P'yo'ngan Province have the richest coal deposit.
>
> "Among the coal mines in the Pukpu Coalfield, the largest are Aoji in U'ndo'k County and Obong and Hoeryo'ng in the City of Musan. Anju Coal Mine has seven 25 meter-thick ore beds. Lignite coal with caloric value of over 5,300 kilocalorie [kcal/kg] is mainly being produced in this coal mine. It is the largest coal mine in the DPRK, producing 7 million tonnes a year.
>
> "The DPRK is confirmed to have coal deposit of 14.74 billion tonnes. Of them, 11.74 billion tonnes is anthracitic coal and 3 billion tonnes of lignite coal."

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[188] For example, an article in MSN Encarta, "North Korea", (available as http://encarta.msn.com/encyclopedia_761555092_2/North_Korea.html), states "Most estimates suggest that North Korea's vast anthracite coal reserves exceed 10 billion tons." The Federation of American Scientists, in a web page entitled "other industry" and available as http://www.fas.org/nuke/guide/dprk/target/industry.htm, lists, estimated anthracite coal reserves of 1.8 billion tonnes.

As noted elsewhere in this Report, the DPRK has since 2004 exported between 2 and 4 million tonnes of coal annually to China in exchange for strategic materials needed by North Korea or for US dollars (or other hard currencies)[189]. For example, coal produced in the Pyong-An Regional Mines has been exported to Tien-jin, Dalian and Ching-dao Cities in China from Nam-po port in the Western DPRK.

It has been reported that the Anju coalfield has produced coking coal (high heat content coal used as coking coal), which was exported to China in 2008. South Korean research papers on the topic, however, have so far denied the existence of coking-quality coal production at Anju. Annual nationwide coal production was reported by ROK soures as 38.3 million tonnes in 1989, but production of coal declined sharply after 1990 such that annual coal production was 18.6 million tonnes in 1999[190]. Estimated nationalwide coal production capacity, however, is said to have been 53.50 million tonnes in 1986.

With regard to coal quality, DPRK-produced anthracite coal from the Duck-Chon coal mine is reported by Chinese importing authorities and shipping business sources to have the following characteristics. Coal of this type has recently been exported to Chinese thermal power plants in Tien-jin and Dai-lian. This coal is of much better quality from a caloric value standpoint than normal coal produced by the DPRK.

Coal Specifications:

- Caloric value: 6,480 kcal/kg (min.)
- Fixed Carbon: 80.3% (max.)
- Ash contents: 12.2% (max.)
- Volatile material: 6.1% (max.)
- Sulfur: 0.2% (max.)
- Moisture (max): 6.0% (max.)
- Size: 0-30 mm (100%. min.)

Urgent Problems in the DPRK Coal Industry

There are currently several urgent problems that the DPRK coal industry must overcome. First, the depth of mining at existing sites which means that the expense and difficulty of draining underground water has increased, and the operational effectiveness of the mines has decreased, on average. Second, a lack of power, transport equipment, mining technology and funding has held down production. Third, there is a lack of attention to mine development, as opposed to enforcement of impractical plans to promote coal production in the short term when new general

[189] Most of the remainder of this discussion of the DPRK coal sector is adapted from a report prepared for Nautilus by Edward Yoon, Status and Future of the North Korean Minerals Sector, dated January 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf.
[190] Korea Mineral Improvment Corporation Report, “Deposits of Mineral resource in DPRK and trading between South and North Koreas”, 2005.

managers or Labor party executive are sent to oversee the mines**.** Fourth, deterioration of mining equipment and equipment parts, as well as lack of mine support posts, limits production. Fifth, a high rate of industrial accidents and the lack of new investments in the coal mining industry reduces output. And sixth, that lack of electricity for mine operation is a cause of lack of power production due to the fact that most power plants rely on coal supplied by coal mines as energy sources, resulting in a vicious circle connecting the problems of lack of power and the energy sources used to produce power in the DPRK.

Assuming future coal output on the order of 20 to 50 million tonnes annually, coal reserves would appear to be adequate for at least 20 years, and probably on the order of 100 years, of consumption[191].

4.2.2. Oil and Gas

Whether or not oil in commercial quantities has actually been produced from wells either on- or offshore in DPRK territory is somewhat unclear. As noted above (see section 3.5.8), one media source listed production of 300,000 tonnes of crude oil per year starting in approximately 2000, but a number of experts consulted in preparing this Report cast doubt on that estimate, though at least one expert (as of 2006) offered his opinion that ongoing oil production at some level occurs in the DPRK.

The amount of oil resource present in DPRK territories is uncertain. Explorations of potential oil-bearing structures—both onshore and offshore—in the DPRK have occurred intermittently for years. Within the past several years, the DPRK has negotiated and/or reached agreements on exploration of its potential oil resource areas with the ROK's Korean National Oil Company, with the private firm Aminex Plc., of the United Kingdom, and with the Chinese Government[145] [192]. Several sources suggest that an oil resource of about 12 billion barrels lies in the Korea West Sea in the area near Anju, in the DPRK[146]. The map shown in Figure 4-1 indicates several possible or probable oil-bearing areas in the DPRK or in its waters[193]. Figure 4-2 provides a photo of an oil rig, provided by Romania, which was reportedly used by the DPRK to prospect for oil in the Tumen River area in the late 1990s[194].

[191] This assumes that the DPRK will continue to use domestic coal. If its economy develops, and with the global implications of coal use on climate change, as well as the relative economics of coal production in other nations the DPRK might trade with (the United States and Australia, for example), this is not a given.

[192] Selig S. Harrison, in "Quiet Struggle in the East China Sea", (Current History, September 2002, page 271) identifies several other oil exploration arrangements made between the DPRK and mostly small western companies before 2000.

[193] Map from The People's Korea, 2 December 1998, "DPRK has 12 Mil. (sic) Barrels of Oil Reserves in Western Sea: Expert", available as http://www.hartford-hwp.com/archives/55a/161.html. Note that this map provides confusing references to oil units. The correct unit for the oil estimates by "zone" appears to be million tonnes of oil (summing to a total of 155 million tonnes, which would be on the order of 1.2 billion barrels.

[194] Photo from presentation by SOVEREIGN VENTURES PTE LTD, Hydrocarbon Potential of Cenozoic Basins In the Tuman River Area of North Korea (DPRK), prepared by Dr. Robert Mummery, dated 7/6/2002, and available at http://sv-oil.com/oil/cspg/Sub.asp?TitleID=0 and http://sv-oil.com/oil/cspg/images/CSPG_presentation.pdf.

Figure 4-1: Location of Potential DPRK Oil Resources

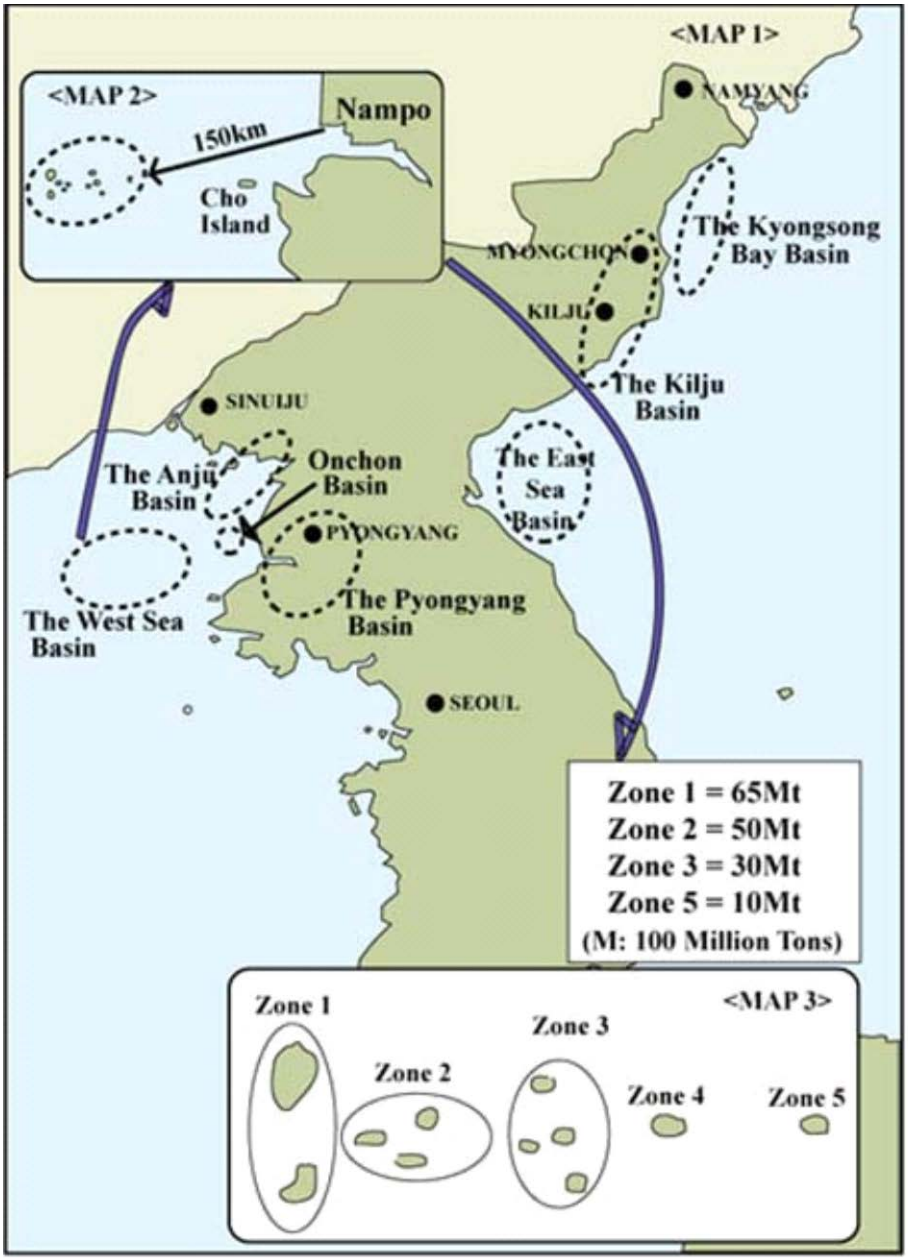
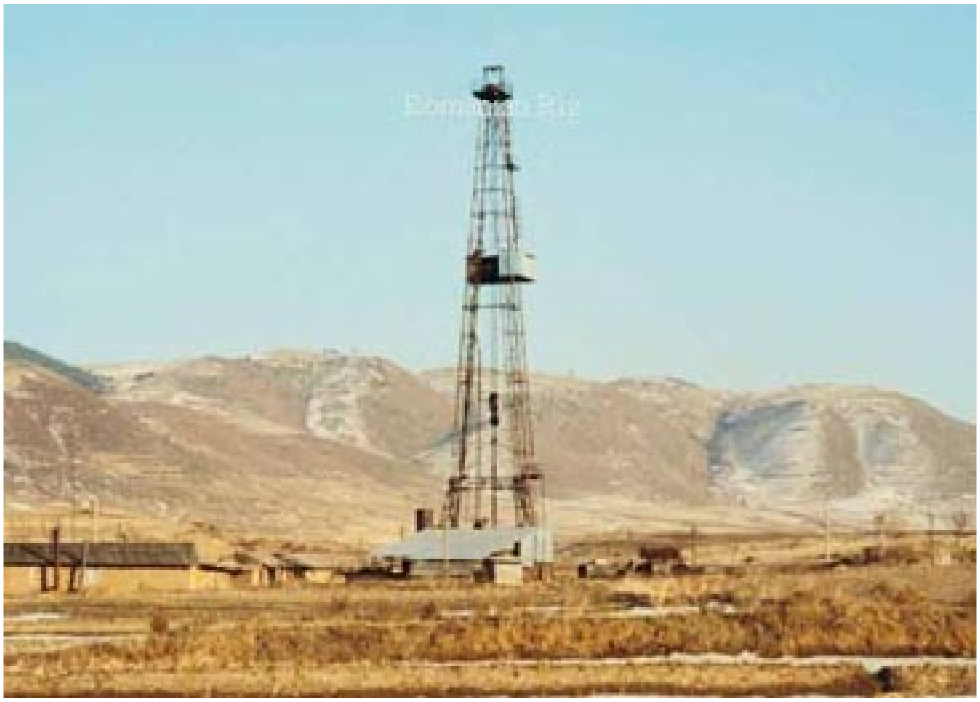


Figure 4-2: Oil Rig, Provided by Romania, in use in the Tumen River Area of the DPRK



A document from a Korean-oriented, Japan-based website includes the following reference to a long-term DPRK program of research into oil resources in its territory[147]:

> "In its report released in late 1997, the ministry [Ministry of Petroleum Industry], after 30 years of geological study and test borings in both offshore and onshore parts of the country, concluded that there exist seven oil-bearing basins. The report suggests that the West Sea Bay Basin alone contains billions of barrels of oil."

The accuracy of this estimate, as with any other assessment of DPRK oil resources, is difficult for outsiders to determine, but the proximity of the purported oil-bearing areas to similar nearby structures in, for example, China's territorial waters[195] do suggest that the presence of oil is likely, though the quantities are uncertain[196]. Still, oil extraction in onshore and offshore areas of the DPRK is likely to be an attractive target for investment as (and when) the redevelopment of the DPRK energy sector gets underway.

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[195] A report on DPRK oil explorations (Selig S. Harrison, Asia Program Special Report No. 106, December, 2002, "Toward Oil and Gas Cooperation in Northeast Asia: New Opportunities for Reducing Dependence on the Middle East", The Woodrow Wilson International Center for Scholars), includes the following: "[The DPRK and the oil firms with which is had partnered] hopes for major discoveries on the geological linkages connecting its seabed concessions with the nearby Bo Hai Gulf, where China has already found oil. There are proved recoverable reserves of 450 million barrels in Bo Hai."

[196] Several available reports and articles summarize the DPRK's oil sector activities over the years. See for example, NORTH KOREA AND SEABED PETROLEUM, by Keun Wook Paik. Royal Institute of International Affairs (undated, but probably about 2005), available as http://www.wilsoncenter.org/topics/docs/Keun_Wook_Paik.pdf. The document Energy Scenarios for the DPRK – Report of the Working Group Convened by the United Nations: Phase I, published by the University for Peace, New York, and dated 2005 (available as http://biblioteca.upeace.org/pdf/Energy Scenarios for the DPRK 2005.pdf) includes a summary of some of the DPRK's oil exploration efforts and joint ventures with exploration firms.

In a report prepared for Nautilus[197], Edward Yoon includes the following descriptions of what is known about oil production, resources, and exploration activity, some of which overlaps with the information provided above:

> "Ascertaining the truth as to whether or not North Korea has petroleum deposits has not only been one of the critical issues in the geological exploration community in the DPRK, but also is a factor for central economy planning authorities. In fact, North Korean geologists and foreign engineers have found oil deposits during East Sea seabed area exploration (near Tong-Chon, Kang-won) and in West seabed area exploration (near Nam-Po) in 1985 (Private source). North Korean authorities have established a self-reliance policy for oil exploration and production since the 1960s. The DPRK set up an Oil Exploration Institute in Sook-Chon (near the West Sea) in 1968, with advanced exploration equipment imported from Russia and Sweden, in order to accelerate oil exploration within the West seabed area. In 1978, North Korea signed an agreement with China on oil exploration, under which the DPRK would receive support in the form of Chinese technology and equipment (oil drilling machines and oil prospecting ships) in the Bal-Hae-man area (the Yellow Sea) (Chinese documents, Private source, 2010).
>
> "In addition, North Korea sent experts in oil exploration to Russia in 1991 in order to gain expertise and experience from Caspian Seabed oil exploration activities. The North Korean Physical Exploration Department drilled 13 exploratory holes in the East seabed and West seabed with assistance from Sweden engineers, and found significant results in 1993. As a consequence, 350 barrels of oil were produced in 1998 at the "406" location, located 66 km from Cho-Do Island of Pyong-An province in the West Sea. Also, 450 barrels of oil were produced from an exploration well at the Nam-Po offshore drilling point, also in 1998. The Canadian oil exploring company Cantexa reported that the oil deposit in the 406 drilling area could hold 5 - 40 billion barrels (Korea Marine Institute, www.kordi.re.kr). The Microleptonics Research Laboratory of the Russian Exploration Institute has reported that massive oil deposits have been found in the West seabed and Yellow seabed (ITAR NEWs, 4/9/1999). Analysis of oil samples from these explorations revealed specific gravity of 0.854-0.887, paraffin content of 8-9%, hydrocarbon content of 70-80%, and asphaltic content of 0.2-1%, suggesting that these finds are commercially valuable oil deposits (ibid, and Private source).
>
> "The latest activities related to oil exploitation in the DPRK in partnership with overseas investors include an agreement between KOREX and KOEC (Korean Oil Exploration Company) on a PSC (production sharing contract) in the East-sea, based on a report by Channel Asia News, 2 June, 2006. KOREX was established as a subsidiary of the Irish company Aminex and the North Korean firm Cho-sun Energy (as a 50:50 shared company)."

Reports of the extent of natural gas resource in the DPRK are less numerous than those of oil reserves, and likely just as speculative. A 2002 report reads as follows[148]:

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[197] Edward Yoon, Status and Future of the North Korean Minerals Sector, dated January 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf.

"'Sovereign Ventures,' a Singaporean petroleum exploration company, announced on August 28 that it found in the DPRK reserves of at least 28.3 billion cubic meters of natural gas and 50 million barrels of petroleum. The locations are in Hoeryong and Onsong in North Hamgyong Province. The Singaporean venture stressed that the discovery is particularly significant since the survey covered only a third of the exploration zone with an area of 6,000 square kilometers."

A late 2002 presentation by the company involved in the exploration, Sovereign Ventures, echoed the above, noting[149] [198]:

"It is unlikely that a 'Giant' oilfield will be found in the Tuman (Tumen) area of North Korea. However significant potential exists for gas reserves in excess of 1 TCF [trillion cubic feet] and smaller oil pools".

A reported gas find in the Korea East Sea in ROK waters may increase the probability that gas will be found offshore of the DPRK as well[150].

4.3. Wood and Other Biomass

The DPRK's forest resource base as of about 1990 has been estimated at somewhat less than 9 million hectares out of a total national territory of about 12 million hectares. This estimate appears to include some "unstocked forests". Table 4-1 presents a forest lands and forest stocks summary derived from a UNEP (United Nations Environment Programme) document[151] [199]. Anecdotal evidence, time series photos, consideration (as discussed in previous chapters) of the increasing rate of use of wood fuels in recent years to compensate for short supplies of commercial fuels, and remote sensing data all point toward a considerable decline in DPRK forest area and forest stocks over the past two decades. As with (many) other aspects of the DPRK, different sources disagree on the attributes of the DPRK's forest stocks, how they have been changing, and how they are used.

4.3.1. Forest area and forest types

As shown in Table 4-2, based on the DPRK's "State of the Environment" report, as published by UNEP, the DPRK's forests are about 42 percent coniferous forests, 35 percent deciduous/hardwood species (referred to as "latifoliate" in the table), and 23 percent mixed conifer and deciduous forests. Pine species dominate the coniferous forests, and oaks dominate the deciduous species. A somewhat different picture of the forests, at least as of 1996, is described by Professor Seung-Ho Lee of the Remote Sensing Laboratory of the Korea (ROK) Forest Research Institute (KFRI). Based on UN FAO statistics, he estimates that about 20 percent of forests were conifers, 63 percent were hardwoods, and the rest were mixed forests

[198] It is unclear what the status of Sovereign Ventures' oil and explorations in the DPRK is currently. The most recent item apparently available on the company's website (http://sv-oil.com/oil/News/default.asp, "Reuters, September 08, 2003 INTERVIEW-Politics stall Singapore firm's N. Korea oil plans"), appears to underline the difficulties of working in the DPRK energy sector in recent years.

[199] Note that the shaded row and column in this table are calculated based on data in the original source table (Table 3.1 in the report DPR KOREA: STATE OF THE ENVIRONMENT 2003, published by the United Nations Environment Programme). The year to which the data in the table correspond is not explicitly described in the source document, but the total forest value is the same as provided in the UN FAO Forest Resource Assessment for 1990. Text in the source document indicates that the units for wood stocks shown in Table 4-4 may in fact be incorrect—it is possible that the units should be cubic meters of wood per hectare, not tonnes per hectare.

(Table 4-3 and Figure 4-3)[152]. Table 4-4 presents another estimate for the forest area of the DPRK during the 1990s, this estimate for 1997 (in comparison with 1970 stocks), and presented by province and municipality[200]. Table 4-5 presents estimates for the distribution of wood stocks by type of tree[201].

Table 4-1: Estimated Summary of Forest Areas and Stocks in the DPRK as of 1990

Classification	**Area (1000 hectares)**	Biomass stock (ton/hectare)	Implied stock (million tonnes)
TOTAL Forested land	**8,201**	**62.3**	510.92
Forest of timber industry	5,440	74.55	405.55
Economic forest	1,436	48.3	69.36
Firewood forest	196	40.95	8.03
Protected forest	1,129	66.15	74.68
Non-timber forest land	436	3.15	1.37
Unforested area	383	-	-
Grass field	170	18	3.06
Total of Above	**9,190**	**61.16**	**562**

[200] Table 4-4 was adapted from "Table 1" in a MS Word document entitled Current Status of Forest and Agricultural Land in North Korea, authored by Park Dong kyun, Secretary General, Northeast Asian Forest Forum, Korea. The document is undated, but apparently from around the year 2000. Document downloaded via Google on 7/19/2012, apparently originally from the website http://english.kfem.or.kr/international/symposium, although direct access to that website did not seem to be available. Some of the headings in Table 4-4 have been corrected or elaborated, relative to the table in the original source, and the note following the table was added for clarity.

[201] From presentation by Professor Lee--same source as for Table 4-3 and Figure 4-3. Data for Table 4-3 originally from UN FAO Forest Resource Assessment.

Table 4-2: Species Composition of DPRK Forests as of (approximately) 1990[153]

Classification	Ratio (percent)
Compositions by species of forest land	100
Coniferous forest	41.9
Latifoliate forest	35.6
Mixed forest	22.5
Coniferous forest	
Pinus	37.8
Larch	33.8
Pinus koraiensis	11.9
Kind of Deodar	14.8
3 needle-leaf Pinus	1.7
Latifoliate forest	
Oak	52.4
Lime	6.4
White birch	6.3
Acacia	3.2

Table 4-3: Alternative Estimate of Species Composition of DPRK Forests (as of 1996)

Forest Type		Area (1,000 ha)	Ratio (%)
Total		**8,445.5**	**100**
Conifers	**Subtotal**	**1,675.5**	**19.8**
	Conifers	**955.1**	**11.3**
	Alpine Con.	**720.4**	**8.5**
Hardwoods	**Subtotal**	**5,331.9**	**63.2**
	Hardwood	**4,415.3**	**52.3**
	Oaks	**916.6**	**10.9**
Mixed wood		**1,438.1**	**17.0**

Table 4-4: Estimate of Forested Land in 1997 by Province, with Change from 1970

Province (Do)	Forest Land in 1997 (ha)			Forest Land in 1970 (ha)	Change from 1970
	Man-made	Natural	Total		Area (ha)
Pyongyang-si	7,118	93,061	100,179	-	-
Nampo-si	3,368	16,767	20,095	-	-
Pyongyang-S*	90,180	575,249	665,429	918,632	-132,929
Pyongyang-N	91,387	579,683	671,070	928,406	-257,336
Chagang	208,413	859,045	1,067,458	1,514,766	-447,308
Gaesung-si	20,287	33,007	53,294	-	-
Hwanghae-S*	80,956	150,432	231,388	420,225	-135,543
Hwanghae-N	90,071	309,447	399,518	586,360	-186,842
Gangwon	103,369	619,250	722,619	889,313	-166,694
Hamgyong-S	207,097	1,076,007	1,283,104	1,612,493	-329,389
Hamgyong-N	166,793	1,045,984	1,212,777	1,485,447	-272,670
Yanggang	141,046	983,974	1,125,020	1,417,040	-292,020
Total	1,219,025	6,341,906	7,551,931	9,772,682	-2,220,751

* Note: Totals for Pyongyang-S and Hwanghae-S in the “Forest Land in 1970” and “Change from 1970” columns apparently include data for Pyongyang-si plus Nampo-si and Gaesung-si (that is, the municipalities of Pyongyang, Nampo, and Gaesung), respectively.

Figure 4-3: Map of Forest Types in the DPRK

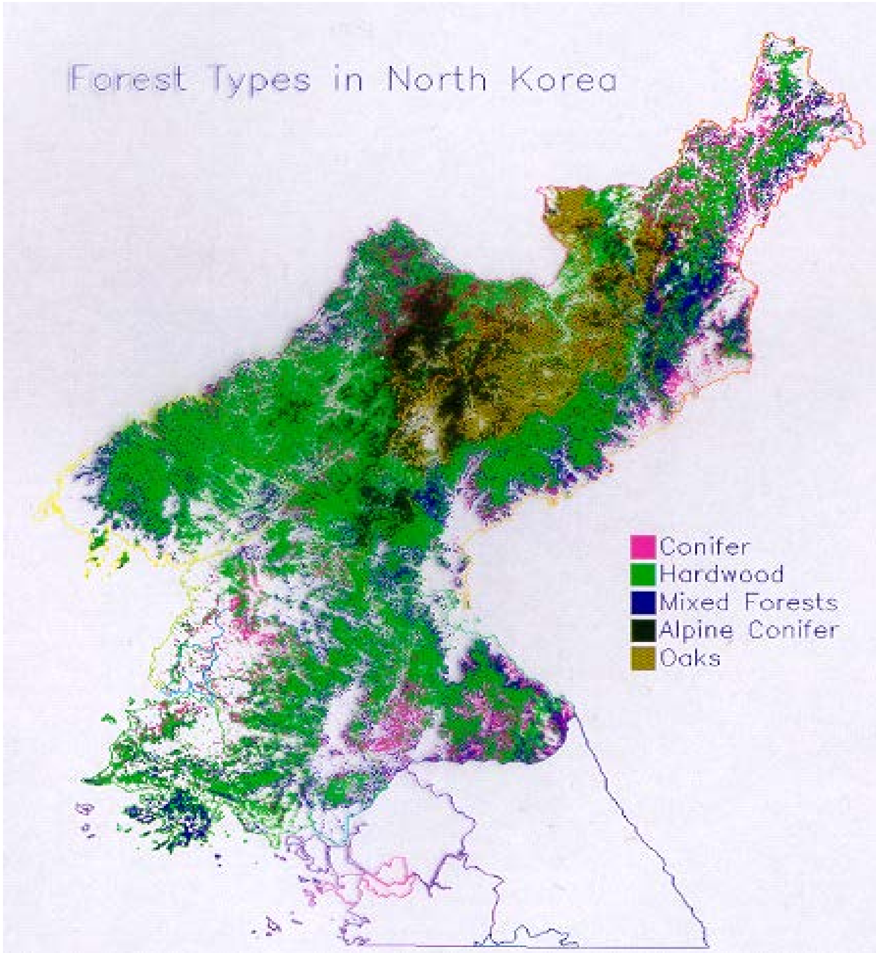


Table 4-5: Estimated Wood Stocks by Type in DPRK Forests (as of 1996)

		Growing Stock (1,000 m^3)	Ratio (%)	Volume per ha (m^3/ha)
Total		**342,864**	**100**	**40.6**
Conifers	**Subtotal**	**86,402**	**25.2**	**51.6**
	Conifers	**46,703**	**13.6**	**48.9**
	Alpine Conifers	**39,699**	**11.6**	**55.1**
Hardwood	**Subtotal**	**205,443**	**59.9**	**38.5**
	Hardwood	**163,879**	**47.8**	**37.1**
	Oaks	**41,564**	**12.1**	**45.3**
Mixed wood		**51,019**	**14.9**	**35.5**

Another source of information on DPRK forests, a set of reports by Keith Openshaw, dated 1994, suggests that the nominal DPRK forest area in 1993 was about 9 million hectares, but that only 7.8 million hectares were "in practice" forested. He applies an average standing volume for DPRK forests of 40 cubic meters per hectare, based on forests in surrounding countries, to estimate wood stocks[154]. This source suggests that softwoods make up 45 percent of total DPRK stocks, and hardwoods 55 percent.

4.3.2. Wood stocks

Despite different assumptions about the composition of DPRK forests, the sources cited above appear to converge on a reasonably consistent set of estimates for stocks of wood in the DPRK. Correcting the table from the UNEP document for what appears to be an error in units suggests a wood volume of about 370 million cubic meters in 1990. Openshaw's average standing volume estimate, depending upon whether the stock average is applied to the DPRK area forested "in practice" or the nominally forested area, yields estimated 1993 stocks of between about 310 and 360 million cubic meters. Table 4-4 yields a growing stock measurement of about 340 million cubic meters as of 1996. Using two different estimates of average cubic meters of wood per tonne, Professor Lee calculates 1996 DPRK wood stocks of between 251 and 293 million tonnes of total above-ground biomass. We use the former estimate—which is based on an average wood density that seems more reasonable for the tree species present in the DPRK, as one input in the estimation of the time series of DPRK wood resources presented below.

4.3.3. The DPRK wood resource over time

The ultimate question to be answered by an investigation into wood resources is the extent to which existing rates of resource use are sustainable. To address this question, we used Professor Lee's summary of data obtained from remote sensing techniques to estimate a trend in total DPRK forest area, and used those estimates with estimates of DPRK forest stocks to derive the amount of wood annually available in the DPRK.

Table 4-5 presents data from two "snapshots" of an area within the DPRK, derived from remote sensing images taken by the Landsat (1999) and Quickbird (2004) satellite systems. Figure 4-4 shows maps created from the two sets of data. Though this table represents only one small area of the DPRK, over only a five-year period, there is a clear increase in the amount of unstocked forest and denuded forest over the period between analyses[155]. Figure 4-6 shows false-color satellite images of an area of the DPRK, taken in 1981 and 1993, showing that "approximately 10,000 ha [of forest area] has been converted into farmland in Daeheungdan-gun County (near Yangkang and North Hamgyong Province)" in the DPRK over the 12-year period[202].

A series of satellite analyses of the extent of DPRK forest cover were summarized by Professor Lee as follows: 9.77 Mha in 1970 (DPRK source), 8.97 Mha in 1987 (FAO source), 8.45 Mha in 1994 (KFRI Satellite Image Analysis), 7.53 Mha in 1997 (DPRK from UNDP Round Table Meeting) and 7.53 Mha in 1999 (KFRI Satellite Image Analysis). An additional time-series of DPRK forest area from the UN FAO Global Forest Resource Assessment 2005

[202] Quote and satellite photos for Figure 4-6 from presentation by Professor Lee Seung-ho, as referenced above.

(FRA 2005) [156] shows a trend from 8.20 to 6.82 to 6.19 Mha in 1990, 2000, and 2005, respectively.

Table 4-5: Land-type Data from Remote Sensing Studies of an Area of the DPRK, 1999 and 2004

CLASS	Landsat TM (1999)		Quickbird (2004)	
	AREA (ha)	Ratio (%)	AREA (ha)	Ratio (%)
Total	**35920.44**	**100**	**28594.72**	**100**
Stocked Forest	**8344.08**	**23.23**	**5124.91**	**17.93**
Unstocked Forest	**4345.11**	**12.09**	**7791.51**	**27.25**
Converted Farmland	**4186.44**	**11.65**	**2470.97**	**8.65**
Denuded Forest	**753.93**	**2.10**	**3754.73**	**13.13**
Rocky Area	**-**	**-**	**1828.37**	**6.39**
Paddy	**2834.64**	**7.89**	**4574.85**	**16.00**
Cropland	**11574.18**	**32.22**	**2921.62**	**10.22**
Others	**3882.06**	**10.81**	**127.76**	**0.45**

Figure 4-4: Land-type Maps Created from Satellite Images of the Kaesong Area in the DPRK, 1999 and 2004

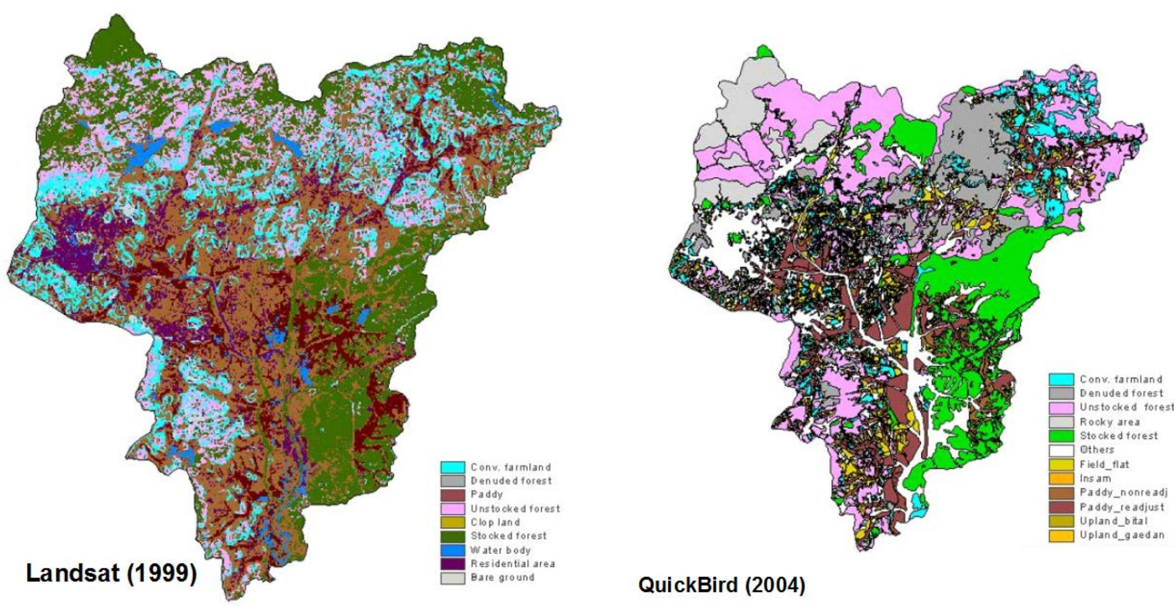
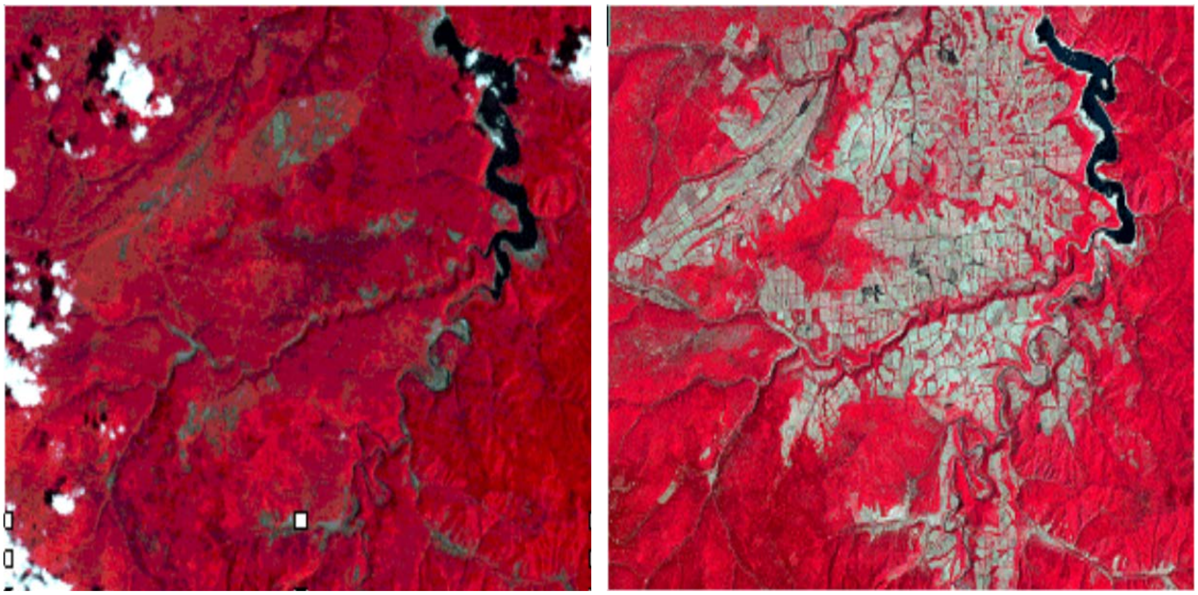


Figure 4-5: Landsat Images of an Area in the DPRK taken in 1981 (left) and 1993 (right)



Based on growth rates for forests in areas of the ROK that have forests similar to the types of forests found in the DPRK, and using data from three sources, Professor Lee calculates a weighted-average annual growth rate of 3.06 %, which implies an annual production from growing tree stocks in the DPRK of 7.68 million tonnes per year in 1996. Note that this figure includes all above-ground biomass, some of which (small twigs and leaves, for example) would likely not be used as fuel, and likely some of which would be lost during harvesting. Prof. Lee cites ratios of total above-ground biomass to tree stem volume ranging from 1.22 (for hardwoods) to 1.29 (for conifers). This implies that leaf and twig biomass might be on the order of 5 to 15 percent of total above-ground biomass.

From the forest area data above, the decline in the area of forest lands in the DPRK averaged 1.45% per year from 1987 to 1999, using the multi-survey timeline cited by Prof. Lee; average rates of forest decline using the FRA 2005 estimates were and 1.83% per year from1990 to 2000, and 1.93% per year from 2000 to 2010.

Based roughly on the information above, we make the following estimate of forest area, wood stocks, and wood production over time through 2010.

Key Assumptions and intermediate results:

- Estimate of forest area in 1990: 8.20 Million ha (DPRK State of Environment Report, 2003, and UN FAO FRA)
- Change in extent of forest lands, 1990 to 2000: -1.64% per year (average of rates estimated above).
- Change in extent of forest lands, 2000 to 2010: -1.80% per year (not quite as low as FRA estimate).
- Growing wood stocks on forest lands, 1996: 251million tonnes (estimate above by Prof. Lee)

- Average annual growth on stocked forest lands: 3.06% per year (estimate above by Prof. Lee)
- Average growth per ha on forest lands: 0.94 te/ha-yr, based on estimates above.
- Total degraded forest lands as of about 1997: 1.6317 Million ha (from Prof. Lee presentation, slide 34; including "denuded forest", "unstocked forest", and "converted farmland", of which the latter is 59% of the total.
- Average fraction of annual stocked-forest growth per hectare in degraded forests: 20% (placeholder estimate).

The results of this analysis are presented in Table 4-6 and Figure 4-6. Overall forest lands are estimated to have decreased by over 30 percent between 1990 and 2010, with a similar decrease in the amount of annual growth in growing stocks[203]. The total annually available woody biomass decreases from over 13 million tonnes in 1990 to just under 10 million tonnes in 2010, but of those totals, about 4 to 4.5 million tonnes annually was biomass from forest areas cleared for one purpose or another. This suggests that by 2010 some 40 percent, at least, of DPRK biomass use was unsustainable—that is, cut from forest stocks, not from annual forest growth. Our estimate for total wood use in the DPRK in 2009 is 8.4 million tonnes. This is already most of what we calculate is the total woody biomass available from annual growth plus wood from cleared lands, but this simple comparison does not take into account the following factors:

- The estimate of total woody biomass available includes twigs and leaves, most of which would likely not be used for fuelwood (or industrial roundwood).
- There will be some harvest losses (wood left behind in the forests or fields).
- Much of the annual increment of forest growth may be in rugged terrain inaccessible for use by people.
- Not all forest clearing results in complete land conversion, meaning that the wood harvest from land clearing may be overstated.
- Both the estimated average wood stocks and the average growth rate of DPRK forests may be overstated.

Taken in combination, these factors, together with our estimates, suggest that the DPRK populace is indeed using the bulk of the nation's available supply of wood as fuel and for other uses, and underscores the observations by visitors and satellites alike of a dwindling resource base. The DPRK government has undertaken massive reforestation projects, with mixed results, but clearly reforestation and related forest and soils conservation activities constitute an area where international assistance and capacity building will be both useful and a crucial step toward environmental sustainability in the DPRK.

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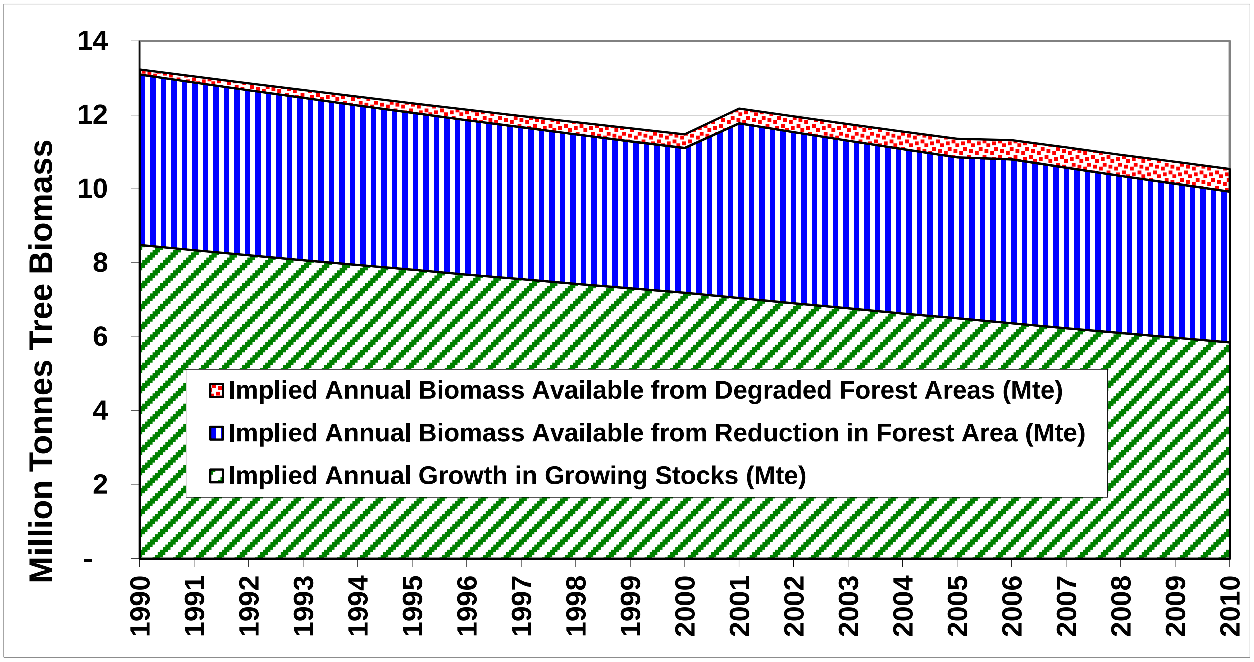
[203] The Forestry Department of the Food and Agriculture Organization (FAO) of the United Nations, in its Global Forest Resources Assessment 2010, Country Report, The Democratic People's Republic of Korea, dated 2010, and available as http://www.fao.org/docrep/013/al489E/al489e.pdf, presents a variety of data on the DPRK forest sector, but little of the information appears to have been updated since the 1990s. FAO does present, based on extrapolation of forest trends in the 1990s, an estimate of forest area in 2010 that is nearly the same (5.67 million ha) as our estimate for that year (which was also prepared largely by extrapolation).

Table 4-6: Estimate of Annual DPRK Woody Biomass Production, 1990 to 2010

Year	Mha Forest Lands	Growing Stocks (million te)	Implied Annual Growth in Growing Stocks (Mte)	Implied Annual Biomass Available from Reduction in Forest Area (Mte)	Implied Annual Woody Biomass Available from Forest Lands and Clearing (Mte)	Estimated Degraded Forest Lands (Mha)	Implied Annual Biomass Available from Degraded Forest Areas (Mte)	Implied Annual Woody Biomass Available from all Stocked and Degraded Forests (Mte)
1990	8.20	277	8.48	4.61	13.09	0.74	0.14	13.23
1991	8.07	273	8.34	4.54	12.88	0.87	0.16	13.04
1992	7.93	268	8.20	4.46	12.67	1.00	0.19	12.85
1993	7.80	264	8.07	4.39	12.46	1.13	0.21	12.67
1994	7.68	259	7.94	4.32	12.25	1.26	0.24	12.49
1995	7.55	255	7.81	4.25	12.05	1.39	0.26	12.31
1996	7.43	251	7.68	4.18	11.86	1.51	0.28	12.14
1997	7.31	247	7.55	4.11	11.66	1.6317	0.31	11.97
1998	7.19	243	7.43	4.04	11.47	1.75	0.33	11.80
1999	7.07	239	7.31	3.97	11.28	1.87	0.35	11.63
2000	6.95	235	7.19	3.91	11.10	1.98	0.37	11.47
2001	6.81	230	7.05	4.72	11.77	2.12	0.40	12.17
2002	6.68	226	6.90	4.63	11.53	2.26	0.42	11.96
2003	6.54	221	6.77	4.54	11.30	2.40	0.45	11.75
2004	6.41	217	6.63	4.44	11.07	2.53	0.47	11.55
2005	6.28	212	6.50	4.35	10.85	2.66	0.50	11.35
2006	6.15	208	6.36	4.43	10.79	2.79	0.52	11.32
2007	6.02	204	6.23	4.34	10.57	2.92	0.55	11.11
2008	5.90	199	6.10	4.25	10.35	3.04	0.57	10.92
2009	5.77	195	5.97	4.16	10.13	3.16	0.59	10.72
2010	5.65	191	5.85	4.07	9.92	3.29	0.62	10.54

Values in non-shaded cells are estimates from sources as indicated above. Values in shaded cells are estimates that are calculated based on estimates from literature sources and other inputs.

Figure 4-6: Estimated Trend in Sources and Amount of Woody Biomass Availability in the DPRK, 1990 to 2010



4.3.4. Other biomass

Crop wastes constitute the other major source of biomass for fuel in the DPRK. As of this writing, we have no detailed estimate of the DPRK's crop waste resource. A very rough estimate can be prepared for the major crops of rice and maize as follows. For rice, about one unit of straw is typically produced per unit of grain. The year 2004/2005 rice harvest was estimated at about 1.5 million tonnes, meaning that available rice straw would also have been about 1.5 million tonnes (though in fact some or much of this straw should be used as a soil amendment)[157]. The UN FAO has estimated somewhat higher rice production in 2004/2005, at about 2.2 to 2.4 million tonnes, with similar output in 2009 and 2010 (and about 3 million tonnes in 2008)[204]. Maize production was been estimated at about 1.7 million tonnes of grain in 2004/2005, and about the same (as estimated by UN FAO—see previous footnote) in 2009 and 2010, though 2008 harvests were somewhat lower, at about 1.4 million tonnes. The amount of maize crop residues per unit grain seems to vary depending on the source of information, but most estimates seem to be in the range of 1 to 1.5 tonnes of residues (stalks, husks, and cobs) per tonne of grain. Using a value of 1.3 for this parameter suggests that maize residue production in 2005 was approximately 2.2 million tonnes. Residues from other crops, including other grains, potatoes, and orchard crops, are likely in the range of 0.5 to 1 million tonnes, meaning that overall crop residue availability was about 4 to 5.5 million tonnes annually. Our estimate for non-wood biomass use for fuel in the DPRK in 2009 is within this range, at about 4.2 million tonnes, which suggests, if both supply and demand estimates are close to accurate, that the vast bulk of crop residues are used for fuel in the DPRK and/or (probably and) other biomass fuels,

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[204] See Figure 1 in UN FAO, Special Report, FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea, dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.htm.

such as grasses and other non-tree biomass, are harvested for fuel use. In either case, the lack of residues returned to the soil, and the use of non-wood vegetation for fuel, suggest an ongoing pattern of soil fertility decline, and spell trouble for soil conservation.

As the DPRK livestock population is relatively low relative to other countries with similar population, animal manure presently is unlikely to represent a sizable resource. Based on UN FAO statistics, the DPRK in 2005 had slightly under 600,000 cattle (a very few dairy cows, with most of the rest classified as "Oxen"), 3.2 million pigs, 21 million chickens, 5.5 million ducks, 2.75 million goats, and about 170,000 sheep. Using rough estimates of 2.2 kg volatile solids (dry organic matter) per head of cattle per day, 0.3 kg per pig per day, 0.010 kg per chicken, and 0.024 kg per duck per day suggests that the DPRK's current resource of biomass in livestock manures was about 1 million tonnes per year in 2005[205]. More recent statistics suggest somewhat lower livestock numbers. The Yonhap News Agency quoted **(**in 2011**)** the World Organization for Animal Health (OIE) as saying that "North Korea has 577,000 heads of cattle, 2.2 million pigs and 3.5 million goats"[206]. The lower number of pigs in the 2011 estimate suggests that the total available livestock manure would probably fall to closer to 900,000 tonnes by 2009/2010.

4.4. Other Renewable Resources

Other renewable energy resources in the DPRK include hydraulic power, wind energy, solar energy, tidal power, and geothermal energy.

A number of sources suggest that the DPRK's hydraulic resource is sufficient to provide about 10 GWe of hydroelectric generation. This is consistent with what we have been told in workshop presentations by delegations from the DPRK:

> "The hydraulic generating capacity of DPRK is now over 4 million kW – but this figure only accounts for 30% of the total available resources." And "DPRK has hydraulic energy resources of 10 million kW with a favorable development condition and high effectiveness of investment."[207]

Many, but not all, of the sites for large hydroelectric facilities have been built upon, but many sites for small and medium hydro dams remain. In addition, it has been reported that some of the DPRK hydroelectric plants—some of which were built before the Korean War, have efficiencies (electrical energy output as a fraction of energy available in falling water) that are around 60 percent, suggesting that significant additional electricity could be generated at these existing sites once plants are upgraded to modern efficiency levels (on the order of 90 percent). Table 4-9 provides one estimate of hydroelectric potential for a number of major rivers in the

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[205] Manure from goals and sheep, which are typically difficult to collect, are not included in this estimate. Animal population estimates are from UN Food and Agriculture Organization FAOSTAT, available as http://faostat.fao.org/site/568/default.aspx. Estimates of manure production per animal are derived from data in Rural Energy Production: Biogas Plant, a Sustainable Source of Energy for Cooperative Farms, by Arthur Wellinger, dated December 12, 2003, and published by ADRA (Adventist Development and Relief Agency International) and Nova Energie. This report provides case studies of the application of manure-fed biogas digesters in the DPRK.

[206] Yonhap news article from included in a 2011-4-20 post on North Korea Economy Watch, "Agricultural Statistics" archive, available as http://www.nkeconwatch.com/category/statistics/agriculture-statistics/.

[207] DPRK Delegation, "THE POTENTIAL IMPACT OF THE INTER-STATE ELECTRIC TIES IN NORTH EAST ASIA ON ENVIRONMENT," September 31, 2003. Paper presented at Nautilus Institute's 3rd Workshop on Grid Interconnections, held in Vladivostok, Russia, September 30 to October 3, 2003. Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/K_DPRK_2_PPR.pdf.

DPRK. The total of the estimates shown is the equivalent of approximately 9,200 average MW of power[208].

Table 4-9: Estimate of Hydraulic Resources in the DPRK[209]

Name	GWh	(%)
Amrok River	39,635.00	47.9
Tumen River	8,134.61	9.5
Taedon River	7,508.17	9.1
Chongchon River	4,407.00	5.3
Rimjin River (north)	2,806.10	3.4
Pukhang River (north)	3,422.10	4.1
Resong River	701.34	0.8
Songchon River	1,675.00	2.0
Kumya River	1,617.17	2.0
Tanchonnam River	1,692.40	2.0
Orangchon River	1,451.80	1.8
Kiljunam River	7,670.80	0.9
TOTAL OF ABOVE	80,721.49	88.8

Estimation of the wind resources potential in the DPRK is incomplete, and we have found existing DPRK wind data to be potentially unreliable. Significant DPRK wind resources are said to exist, however, in mountain areas and in coastal areas (including offshore areas). A DPRK delegation to a workshop organized by Nautilus and co-hosts provided an annual wind resource estimate of 1.7 TWh, which corresponds to about 550 MWe of wind power at an assumed capacity factor of about 35 percent (not atypical for wind generators). A presentation by a DPRK delegation at a subsequent Nautilus workshop included the following passage on wind power in the DPRK

> "Most of the western seashore of the country is suitable for installing large size wind turbines. The annual average wind speed is above 4.5 m/s in 18% of the territory and it is expected to have an installed capacity of more than 4,000 megawatts of wind-generated electricity."[158]

Based on our own (Nautilus') experience in installing several small wind generators in a location on the western coast of the DPRK, it seems unlikely that onshore wind resources in that area are quite as good as claimed above, though offshore areas may well prove to have a better wind regime than onshore areas. Until additional and more rigorous wind data collection is completed, the actual DPRK wind resource is uncertain, but it seems likely that the total practical level of wind turbine installations in the DPRK will be in the range of hundreds of megawatts, of which some is likely to be in near-offshore areas or on islands.

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[208] That is, the total shown is the equivalent of 9200 MW of power supplied continuously, year-round. Given that the average capacity factors of DPRK hydroelectric facilities may be 50 percent or less, this implies a total potential "nameplate" hydroelectric potential on the order of 18,000 MW, though not nearly all of this potential can be taken advantage of in practice.

[209] Table from Some Thoughts on DPRK's Natural Geological Conditions and Their Evaluation - On the Distribution and Development of Hydropower Resources and the Electric Industry, by Professor Sagong Jun, Korea University in Japan, Available as http://www1.korea-np.co.jp/pk/112th_issue/99091601.htm. Units in the original source were listed as "1,000,000 kw/h", but it seems likely that the units intended are GWh.

The same DPRK presentation cited above gives the following information about the DPRK solar resource: "Annual average solar irradiation is about 1200 kWh/m^2 and 55~60% of days per year are clear." The DPRK's winters are often relatively clear but cold, and summers are humid, with much of the annual rainfall in the DPRK occurring in the summer months. This weather pattern, and the solar resource data provided, suggest that the DPRK has at best a moderate solar resource, on average. At 1200 kWh/m^2-yr, the DPRK's average insolation is less than that in many cities in the United States (for example, Pittsburgh, Pennsylvania has a similar solar resource[210]), but is greater than the solar resource in most locations in Europe.

Tidal power is a possibility for some coastal areas of the DPRK. The 2004 presentation by DPRK delegates noted above noted: "The west seashore of the DPRK is one of the well-known tidal zone in the world. The average difference between high and low tide is 4~6 m. n Tidal potential capable of the development is estimated at about 19 TWh." Generation of 19 TWh annually suggests installed capacity on the order of 4 to 6 GW. An estimate by a Russian author put the tidal power resource of the DPRK at 4700 MW (4.7 GW)[159]. At least one small tidal power station exists in the DPRK—a 500 kW unit built into the Nampo barrage near the mouth of the Taedong River[211] (see Figure 4-7 and Figure 4-8). The DPRK planned, as of 2004, to build a 2 MW prototype tidal power plant in South Hwanghae province, and to investigate a site for a 20 MW tidal power plant and complete a design for that plant. In 2004, China was reportedly planning to build a 300 MW tidal power facility based on an artificial offshore lagoon approach near the mouth of the Yalu River near the DPRK border, but it is somewhat unclear whether this project has moved forward since[212]. The fact that China was planning such a project, however, probably means that such projects are also possible in nearby DPRK near-shore territory, at least from the point of view of the tidal energy resource.

Geothermal energy is also mentioned as a possible source of both heat and power for the DPRK. At present, we have no information about the extent of the DPRK's geothermal resources, though some potential geothermal sites undoubtedly are present in the DPRK.

[210] See, for example, http://howto.altenergystore.com/Reference-Materials/Solar-Insolation-Data-USA-Cities/a35/.

[211] The authors visited this installation on their 1998 visit to the DPRK. We do not know its current status.

[212] See, for example, K.Steiner-Dicks, Tidal: Asia's Cinderella renewable energy", Tidal Today, dated July 5, 2011, and available as http://social.tidaltoday.com/technology-engineering/tidal-asia%E2%80%99s-cinderella-renewable-energy; and Renewable Energy World.com, "China Endorses 300 MW Ocean Energy Project", dated November 2, 2004, and available as http://www.renewableenergyworld.com/rea/news/article/2004/11/china-endorses-300-mw-ocean-energy-project-17685.

Figure 4-7: Photo of West Sea Barrage, Near Nampo, DPRK[213]

[213] Photo shows locks for ship passage and, in the channel in the center of the photo, spillways and structures where tidal power turbines are installed. Photo downloaded from http://www.llukasz.com/North_Korea_photos/DPRK/West_sea_barrage.JPG.

Figure 4-8: Painting of Kim Il Sung and Kim Jong Il at the Dedication of the West Sea Barrage[214]

4.5. Energy Efficiency

In the 1990 energy balance study (conducted in 1995) described in Chapter 2 of this report, the estimated energy balance was used as a starting point for a indicative—though admittedly very approximate and not at all exhaustive—quantitative analysis of a subset of the energy efficiency and renewable energy options that could be implemented in the DPRK. This analysis was intended to illustrate the significant potential for energy efficiency as a crucial component to energy sector development in the DPRK. Since 1990, based on the observations of the authors and others who have visited the DPRK, there have been relatively few changes in end-use equipment that would substantially affect the overall conclusions of the 1995 study[215]. An energy-efficiency analysis using substantially the same measures included in the 1995 study, but updated to take into account the year 2009 estimated energy consumption, is presented below. Note that the use of the 2009 energy balance as a starting point reduces both the costs and savings from the energy efficiency measures. This may in fact be an artificial reduction, as any economic improvement that also includes an improvement in the availability of electricity and other commercial fuels is likely to increase demand for energy, and thus would increase the

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[214] Photo taken by D. von Hippel at the West Sea Barrage Visitors' Center, near Nampo, DPRK, in October 1998.

[215] For a more complete discussion of the analysis of the energy efficiency opportunities described in this section, as well as a more qualitative discussion of some of the additional opportunities available, see, for example, 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; and D.F. Von Hippel 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.

savings potential (and absolute costs, if not costs relative to the costs of installing new standard devices and equipment) of the measures described below.[216]

4.5.1. Analytical Approach

The general approach used in preparing the analysis of energy efficiency opportunities can be described as follows:

- Use the estimated DPRK energy balance data as a guide to indicate key sectors and subsectors where fuel demand could be significantly reduced by energy efficiency measures.
- Use the energy balance results, together with data from the international energy literature and rough estimates of key parameters to estimate end-use shares for key technologies.
- Use cost and performance data on energy efficiency and renewable energy technologies data from international literature sources to estimate the potential achievable fuel savings available in key subsectors, and the investment costs required to achieve those savings[217]. In many of these cases, the cost and performance data are based on actual Chinese experience obtained during the 1980s.
- Evaluate and aggregate the potential impacts and costs of the energy efficiency and renewable energy technologies quantified, and suggest other key measures that are likely to be broadly applicable in the DPRK.
- Evaluate, briefly, the potential environmental and other impacts of implementing energy efficiency measures.

A full-fledged analysis of the achievable potential for energy efficiency measures requires a host of assumptions about the future. Population growth rates, economic growth rates, and underlying, ongoing structural changes such as changes in the housing stock, shifts in industrial output, and changing patterns of personal consumption (among many others) form the backdrop against which energy efficiency opportunities should be considered. For this analysis, however, the choice has been to let estimates of potential energy sector improvements stand for the achievable savings over the next decade. Reasons for this assumption, in addition to the paucity of reliable data include:

- The relatively static present state of the DPRK economy, suggesting that a complete and immediate turnaround less likely than a slow recovery, and thus that a 10-year analysis based on a current year's data might not be entirely unreasonable.
- Though complete implementation of a particular energy efficiency measure in a subsector is unlikely, the pathways for technology dissemination in North Korea—if there is committed support from national leaders and enabling financial and technical support from the international community—have the potential to allow the rapid implementation of energy efficiency measures.

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[216] Democratic People's Republic of Korea, NATIONAL REPORT on Asian Least Cost GHG Abatement Strategy (ALGAS), Ministry of Land and Environment Protection Pyongyang, DPR of Korea, April, 2000.

[217] In many cases, this analysis has drawn upon the large body of work on energy efficiency programs in the People's Republic of China that has been published by the by the Energy Analysis Program of Lawrence Berkeley National Laboratory (LBNL or LBL) and their Chinese collaborators.

- We believe that our assumptions as to the energy savings achievable from the technologies we address (quantitatively) are more likely to prove to be under- than over-estimated. This belief is informed by the large number of anecdotal reports of extremely high energy intensities in the DPRK, even when compared with early 1980s conditions in China, and with our own (if limited) observations of end-use technologies it the DPRK. Experts with experience in “energy rationalization” projects in the DPRK during the 1990s have estimated potential for energy conservation in the DPRK ranging from 20 to 60 percent of current energy use, providing further evidence that our estimates of potential energy efficiency savings may be conservative. The results of an industrial energy audit program carried out in the DPRK found potential savings of 15 to 60 percent of current consumption, and that a combination “housekeeping” measures, with simple paybacks (time required for the value of energy savings to equal the cost of any initial investment) of less than a year, and process improvements, with paybacks of one to three years, could by themselves result in savings of up to 40 percent of current energy use[160].

4.5.2. Overall Results for Energy Efficiency Measures Evaluated

The following set of energy efficiency and renewable energy measures have been chosen for initial analysis:

- *Electric Utility Coal-Fired Boiler Improvements*: Utility boilers in the DPRK reportedly have minimal (if any) insulation, are poorly operated, suffer from steam tube cracks and other maintenance problems, and are often antiquated. We assumed that a combination of measures that have been applied to industrial boilers in China can be applied to utility boilers in the DPRK at similar costs to obtain similar results. We have assumed that a combination of microcomputer boiler control, insulation of piping, and renovation of boilers can raise the average boiler efficiency (heat energy output divided by fuel energy input) from about 55-60 percent to 75-80 percent, reducing coal consumption by about 30 percent (total improvement in heat delivery to turbines for power generation)[161]. We assumed that these measures are available for about the same cost as similar industrial boiler improvements in China--approximately $6.33 per annual GJ of coal saved (year 2009 US dollars/(GJ/yr))[218] [219]. In fact, economies of scale may make efficiency improvements for utility boilers less costly, per unit of energy saved, than similar measures for the generally smaller industrial boilers.
- *Reduction in "Own Use" at Coal-Fired Electric Utility plants:* We have assumed that the in-station use of electricity at coal-fired power plants is 7.2 percent of gross generation. Based on cost and savings estimates from Sathaye[162], we estimate that own use can be reduced to 4.5 percent at a cost of about $77 per GJ/yr of electricity saved.
- *Reduction in Electricity Transmission and Distribution (T&D) losses:* Official DPRK estimates place transmission and distribution losses of electricity at 16 percent of net generation (electricity leaving the power plant), although, as noted earlier, this figure may well be low. We have assumed, again based on performance and cost data cited by Sathaye, that will be possible through a combination of measures to reduce combined T&D losses to

[218] We have used a conversion rate of 4.755 1990 Chinese Yuan to the 1990 US dollar (Microsoft Encarta, 1994) to convert quoted costs for Chinese energy efficiency investments to $US. As the Yuan was not as of 1990 a floating currency, this assumption may introduce some inaccuracy in converting Chinese costs.

[219] Unless otherwise specified, dollar figures referred to in this description of our energy efficiency analysis refer to year 2005 USD.

10 percent of net generation at an average cost of 48 $/(GJ/yr). T&D improvements would include better system control facilities, improved transformers and substation equipment, the addition of capacitance to the system, and other measures to improve power factors and reduce voltage fluctuations.

- *Reduction in "Emergency Losses" at Coal-Fired Electric Utility plants:* We have assumed, based on anecdotal reports, that emergency losses of power at coal-fired power plants in the DPRK average about 7 percent of gross generation. We assume that these losses can be reduced by 90 percent through the application of measures available at a cost per unit energy saved similar to that for T&D improvements. It may well be, however, that the combination of boiler improvements, T&D improvements, and possibly control system improvements will by themselves reduce or eliminate emergency losses, with little or no additional efficiency investments required.
- *Wind powered Electricity Generation:* Wind power is one of the major renewable resources readily available to the DPRK, though, as noted above, the wind resources in the country remain, to our knowledge, largely unmapped[220]. We have assumed that 500 MW of wind generation capacity (for example, 500 machines per year of 100 kW, or 250 200-kW machines per year) could be installed in the DPRK over the next 10 years (with machines manufactured in the DPRK and/or imported), and that the average installed capital costs of the machines would be about $1500/kW, though costs of wind power in China seems to be somewhat lower, and this estimate may thus be somewhat high. We assumed a relatively low capacity factor of 25 percent for machines installed in the DPRK, yielding an investment cost of $190/(GJ/yr) of electricity generated. Note that this figure does not include fixed or variable operating and maintenance costs, but variable operating and maintenance costs are included in the overall analysis of this option (at $16 per MWh of generation).

Other potential energy efficiency improvements addressing the electricity generation sector that seem promising but which we have been unable to evaluate quantitatively include:

- *Coal Preparation*: Grinding and washing coal to remove ash and sulfur will improve the efficiency of coal combustion in utility boilers. Such preparation will reduce the load of ash in the bottom of boilers and provide a more homogeneous coal particle size, allowing for cleaner and more complete combustion. The environmental benefits of such measures (including reduced particulate and sulfur oxide emissions to the air) could be considerable, and byproducts of coal cleaning (inert material removed from coal, and elemental sulfur) could be used in the building and other industries. In addition, coal preparation, if done near the coal mines, should reduce coal transport costs by increasing the energy content of the coal per unit mass.
- *Expansion of Electricity Metering*: At present there is reportedly very little metering of electricity consumption in the DPRK. Metering the electricity used by industrial facilities, residences, and buildings would not only provide valuable information on the use of electricity in the DPRK, it would also, if coupled with per-unit electricity pricing, provide

[220] An official description of the wind resource in DPRK (document in the author's files, 1993 [EE1]) mentions the Chinese border area and offshore islands as the only likely sites for wind energy development, but it appears from the context of the description that this assessment considered wind-generated electricity to be primarily an off-grid resource. Our assessment that wind is probably an attractive resource for the DPRK is based on the country's rugged topography and strong seasonal (winter/summer) weather patterns.

electricity users with an incentive to use electricity efficiently. It should be noted that the benefits of metering have apparently been taken to heart by DPRK officials, as witnessed by a trend, in recent years, toward the use of pre-paid card-type electricity meters in Pyongyang (see Figure 4-9), and the recent establishment in the DPRK of a factory to produce electricity meters[163].

Figure 4-9: Graphic of Card-style electricity meter in use in Pyongyang[164]

- *Waste Heat Recovery and Cogeneration:* The energy literature on China and the former Soviet Union (for example, Levine and Xueyi[165]) cites examples of industrial boilers and furnaces that have very high exhaust gas temperatures, indicating the availability of a substantial amount of waste heat. Assuming that such situations are also common in North Korea, the waste heat from industrial and other large boilers could be used to generate electricity, though in all probability much of the industrial infrastructure that could support such cogeneration will need to be rebuilt or replaced as the DPRK economy is redeveloped.
- *Gasification-Combined Cycle Electricity Generation/Retrofits:* The efficiency of electricity generation from coal could be increased dramatically in the DPRK by first converting the coal into a gas, combusting the gas in a turbine that turns a generator, and then routing the exhaust gasses from the turbine to a boiler to raise steam for a second cycle of electricity generation. Gasifiers could be added as "front ends" to existing (renovated) coal-fired boilers in the DPRK. The efficiency of gasification-combined cycle plants can be over 40 percent[166], a vast increase from the probable 20 to 25 percent efficiency in existing DPRK plants. There should also be substantial emissions benefits from employing this technology, though it should be noted that the IGCC (integrated gasification combined-cycle) technology is arguably only still at the cusp of commercial deployment as of 2012. Coal preparation may be a prerequisite for implementing this technology in North Korea. Repowering of the

DPRK's oil-fired utility boilers (over 200 MW) to make them combined-cycle plants is also a strong possibility[221].

Industrial Sector Measures

Our quantitative analysis of efficiency and renewable energy measures in the industrial sector of the DPRK includes the following measures:

- *Improvements in Industrial Coal-Fired Boiler and Furnaces:* Like utility boilers, industrial boilers and furnaces in the DPRK reportedly have very low average efficiencies, perhaps as low as 50 percent (or less) for boilers, on average. Using the same set of improvements assumed for utility boilers (see above), we assumed that the average efficiency of boilers themselves could be raised from about 50 percent to about 65 to 70 percent, reducing coal consumption by about 37.5 percent when other boiler-related measures are also applied[167]. We assumed that these measures are available for approximately the same cost as has been estimated in the past for similar industrial boiler improvements in China--approximately $5.80 per GJ/yr saved.

- *Improvements in Industrial Electric Motors:* Electric motors in DPRK may be made domestically, imported from China, or a combination. In any case, the stock of motors in the DPRK is highly likely to be both aging and inefficient. We have attached rough estimates of the fraction of electricity use, by subsector, that is consumed in motors and drives. These estimates vary from as low as 50 percent, for subsectors where we felt electricity was likely to be used intensively in end uses other than motive power (such as electrolytic refining of metals), to as high as 95 percent for subsectors (such as the Cement industry) where we felt that motor-driven applications such as grinding and sizing of cement "clinker" would likely be the dominant use of electricity. As a point of reference, note that 65 percent of the electricity used in the entire Chinese economy has been estimated to be consumed in electric motors.

  Based again on Chinese experience, we have assumed that it will be possible to increase the average motor efficiency from approximately 75 percent to approximately 88 percent[168]. The latter efficiency (which corresponds to higher efficiency new motors produced in China as of 1990—and is considerably lower, in fact, than the current generation of premium motors made in the US, Japan, and Europe—and possibly in China as well) is similar to that for standard new electric motors sold in the US and Japan as of 1990, so efficiency improvements beyond what we have assumed are definitely possible[222]. We have assumed that the cost of this efficiency improvement would be on the order of $59 per GJ/yr of electricity savings.

- *Industrial Lighting Improvements:* We have assumed that lighting accounts for a relatively modest 5 percent of industrial electricity use in the DPRK. Based on the cost and performance of non-residential lighting improvements in industrialized countries, we have estimated that it will be possible to save 50 percent of the industrial lighting electricity used

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[221] Repowering existing 20 to 30 year-old oil-fired boilers to create combined-cycle plants figured prominently in the future plans, for example, of the major electricity utility in Hawaii, as of the mid 1990s.

[222] Note that motor efficiencies vary by size class, with larger motors (for example, 100 to 200 hp or 75 to 150 kW) having efficiencies generally a few percent higher than smaller motors of similar types. The efficiencies presented here can be thought of as rough weighted averages over the stock of electric motors in use.

through a variety of measures (including improved bulbs and ballasts, more efficient fixtures, replacement of incandescent lamps—where they are used—and older fluorescent fixtures with high-efficiency fluorescent lamps, improved daylighting, and lighting controls) at a cost of about $42 per GJ/yr of electricity saved[169].

As in the electricity generation sector, there is a wealth of opportunities for saving energy in the industrial sector that we have not been able to quantitatively evaluate. These include:

- *Industrial Process Improvements:* It is likely that a considerable amount of electricity and coal could be saved by improvements in industrial processes. These opportunities are available in many subsectors. In the DPRK cement industry, for example, the coal consumption per unit output is 6.9 GJ per tonne of "clinker" (raw cement; data from document in authors' files [CE1]). This can be compared with an average coal use of 6.1 GJ/te in China in 1980, 5.2 GJ/te in China in 1992[170], and 3 GJ/te in modern plants in industrialized countries, and implies that coal use in the cement subsectors could be reduced by 12 to more than 50 percent. Similar opportunities exist in the iron and steel, other metals, fertilizer, textiles, and other industrial subsectors. In the important iron and steel subsector, possible process improvements include integrating steel production and forming processes (thus eliminating the need to cool and reheat the steel), continuous casting and forming, electricity generation using top pressure in blast furnaces, use of coal gas for electricity generation, and other technologies[171]. Generic efficiency improvements applicable to many industries include insulating product pipelines, using better refractory materials (special ceramics used as, for example, furnace linings) that last longer and have better insulating properties, using variable-speed drives to reduce the electricity used in electric motors, modifications to reduce friction in piping, valves, and conveyance systems, and using harder, longer lasting materials in cutting and grinding applications.

  Note that process improvements can be geared to not only improving the efficiency of fuel use, but also in reducing materials waste. Improving chemical reactors so that there is less waste of reactants, using better-quality raw materials to improve product yield, and recycling waste materials from production processes and product refining can reduce both waste and energy consumption[223]. Product modifications that result in the reduction of raw material (and thus energy) used per unit of product are also possible[224]. Not coincidentally, these improvements also typically reduce process effluents to the environment.

  Process improvements could also be directed toward the 30 percent of DPRK petroleum demand that is reportedly used in carbide manufacturing. As we at this point know little about how this petroleum is used in carbide manufacture (if the report is in fact correct), it is impossible to say what the prospects for savings are.

  Many DPRK industries use technologies that are on the order of 50 years old. In many cases, simply replacing key industrial machinery with modern equipment will result in considerable

[223] For example, valuable metals such as gold, zinc, and cadmium can be recovered from the flue gases and liquid effluents of metal smelting industries, and sulfuric acid could be recovered from steel and non-ferrous metal plants. The latter modification would not only remove SO_x from flue gases, but would also serve as a source of sulfuric acid for the chemical industry, reducing energy use in that subsector.

[224] As an example of reduction in materials use per unit product (though one unlikely to be directly germane to North Korea at present), by carefully controlling the aluminum rolling and forming process, US manufacturers have been able to markedly reduce the thickness and weight of aluminum cans.

energy savings, as well as improvements in productivity, but will require significant investments.

- *Coal Processing:* As for electricity generation, coal washing and other methods of coal preparation could help to dramatically improve the combustion efficiency of coal-fired boilers and furnaces in the industrial and other sectors. It is likely that coal processing could also improve the efficiency of industrial processes where coal is used as a feedstock--including fertilizer (ammonium) and synthetic fiber manufacture.
- *Construction Industry Modifications:* The massive scale of construction projects in the DPRK, coupled with the use of manual design and construction methods, results in wastage of building material relative to more updated methods. Considerable savings in steel and cement--and thus savings in the energy needed to produce these materials--are possible through the use of improved construction practices[172].

Residential and Public/Commercial/Military Sector Measures

Our quantitative analysis included four efficiency measures for the residential sector:

- *Boiler Improvements:* For small and medium-sized space heating (and possibly water heating, in some instances) boilers of the type found in urban residential and other buildings, we assumed, based roughly on the same sources we used for our industrial boiler measure estimates, that a 15 percent improvement in efficiency (starting from an average boiler efficiency of 50 percent; thus a 23 percent reduction in coal use) is available for approximately $3.3/(GJ/yr) of coal saved. Note that the boiler improvements included here are unlikely to exhaust the opportunities for improving boiler energy efficiency (and delivery of heat to end-users) through equipment upgrades and improved operations and maintenance.
- *Building Envelope Improvements:* We have included two simple building envelope improvement measures in our estimate of possible energy efficiency savings. A combination of A) application of a 30 mm coat of concrete containing perlite--a lightweight mineral with insulating properties--to the inside of the typical concrete slab walls of residential and other buildings, and B) double glazing of windows are together estimated, based on simulations for Chinese buildings, to save 20 percent of heating energy[173]. The costs of these savings are estimated at slightly under $3 per GJ/yr. Note that in applying this measure to coal use in buildings, we have assumed that boiler improvements take place before (or at the same time as) building envelope improvements, that is, the savings fraction for building envelope improvements was applied to the total energy use after boiler efficiency improvements had been factored in.

  The two building envelope improvements above can be considered a minimal simple start to the list of potential measures of this type. Other measures include caulking and weatherstripping to reduce air infiltration, insulation of water and steam piping, improved radiator controls (in fact, visitors to the DPRK report that the only heat control measure available to residents of typical North Korean apartment buildings is the opening and closing of windows and doors), interior and exterior wall and roof insulation, roof coatings, and other improvements. Actual savings from building envelope measures will vary by building type and with the current condition of the buildings, but savings of much more than 20 percent of current energy use are quite possible, at costs possibly not significantly higher than those above. Proposals to undertake pilot building efficiency projects in the DPRK were developed by United Nations agencies in the late 1990s, but have not, to the authors' knowledge, been implemented as of yet. Colleagues from the DPRK that the authors have interacted with have shown a very keen interest in promoting building energy efficiency measures in their country, and understand very well the potential benefits of those measures to the DPRK, but lack the combination of materials, technical know-how, and funding to implement them.

- *Rural Residential Coal Stove/heater Improvements:* We have assumed that the average residential stove/heater can be improved from an average of 30 percent efficiency to 40 percent efficiency, thus saving 25 percent of initial coal use. This is a rough estimate on our part. The estimates that we have found of coal stove efficiency in the DPRK and China range from 20 to 50 percent; 30 percent was cited as an estimate for DPRK by an informed visitor to the country[174]. We have assumed that this efficiency improvement is available for the same cost cited for coal stove improvements in China[175], namely $1.1/(GJ/yr).
- *Electric Motor Improvements in Urban Residential and Non-residential Buildings:* Electric motors are typically used in multi-family apartment buildings and in non-residential buildings for a variety of uses, including ventilation, refrigeration, and water pumping (for heating and potable water), We have assumed that 10 percent of the electricity used in the urban residential subsector, and 30 percent of that used in the Public/Commercial and Military sectors, is used in electric motors. These estimates are admittedly rough guesses at best, but are lower than the fraction of electricity used in motors in similar sectors in many other countries. We have assumed that the average cost and performance of measures that increase the efficiency of these motors is roughly the same as in the industrial sector.
- *Improvements in residential and non-residential lighting:* We have assumed that the fraction of residential electricity used in lighting end-uses is 40 percent. This figure is somewhat higher than lighting electricity fractions quoted for Thailand and the former Soviet Union (28 and 33 percent, respectively), but both of those societies use electricity for end uses—including air conditioning and water heating—that reportedly are little used in DPRK residences. We have assumed that 80 percent of lighting electricity use in residences in DPRK powers incandescent bulbs, that compact fluorescent (CFL) bulbs can save 75 percent of the electricity used by incandescent bulbs (while providing similar or enhanced light output), and that compact fluorescent bulbs can reasonably be substituted for incandescent bulbs for 80 percent (by energy) of lighting uses. Taken together, these three assumptions result in a 48 percent reduction in electricity use in residential lighting. If, as has been suggested, tube-type fluorescent lamps are in wider use than we have assumed, these savings may be somewhat overstated, but a combination of luminaire, lamp ballast, and bulb improvements for tube-type fluorescent lamps can yield savings that are nearly as significant. As an estimate of costs, we have assumed that, as other authors have suggested for China, a factory producing 3 million CFL bulbs per year could be built in North Korea at a cost of $5 million[176]. The cost of conserving electricity by producing and using these bulbs is approximately $59/(GJ/yr). We should note that the lifetime of most CFLs is shortened if they are operated on a grid with fluctuating voltage and low power factors, thus unless CFLs are specifically designed for such conditions, transmission and distribution improvements would probably have to go hand in hand with major introduction of CFLs in the DPRK.

In 2005, we were told by a DPRK delegation to a Nautilus workshop that CFLs had in fact been implemented in residences in the DPRK, using Phillips brand bulbs and also bulbs made in the DPRK. This implementation was reportedly fairly extensive, but we do not have independent feedback on how extensive or effective, on a long-term basis, it will prove to be. We therefore leave this measure in the list of potential improvements for the time being. While in Pyongyang in 2009 one of the authors estimated, based on observation (from outside) of a limited number of residential buildings in the city, that perhaps 40 percent of apartments were using CFLs[225]. As the penetration of CFLs in other cities and in rural areas is likely to be lower than in Pyongyang, we roughly estimate that 20 percent of residential electric lighting was, as of 2009, done with CFLs. Although it is likely that other improvements in residential lighting, at similar cost per unit savings, can be identified to replace the savings ascribed to CFL introduction, any estimate of the potential benefits of lighting efficiency improvements in the DPRK, in a scenario where the DPRK economy is redeveloped, should, realistically, take into account that existing lighting levels in DPRK residences are, on average, very low by the standards of most industrialized nations, and thus as the DPRK economy is rebuilt, residents will probably choose to install much more lighting than is currently (typically one bulb per room) present in most dwelling units.

Our assumption for non-residential buildings is that 50 percent of the electricity consumed is used in lighting. As for industrial lighting, we assume that 50 percent of this amount can be saved by a package of lighting energy efficiency measures, at a cost of about $41 per GJ/yr. Since these costs and savings estimates are based on figures for industrialized countries, our guess is that similar improvement will cost less and save more in the DPRK, particularly if production of quality lighting components can be done with a substantial contribution of domestic (versus imported) labor and materials.

Other possible energy efficiency measures for the residential and non-residential buildings sectors include:

- *Improvements in Electric Appliances:* The fraction of residences in the DPRK with refrigerators is unknown, but likely to be small. What refrigerators are in use in the DPRK—and we found relatively few households with refrigerators in our one-village survey of rural energy use in 1998 and 2000[226]—are likely to be mostly older models imported from Japan or China, or cheaper Chinese models, and thus up to 50 percent less efficient than those manufactured in industrialized countries (or the best refrigerators currently manufactured in China, which has made great improvements in refrigerator efficiency in recent years). Liu et al[177] reported that Chinese refrigerators in the 200-liter size range consumed 365 kWh per year as of approximately 1990, while South Korean models of similar capacity used 240 kWh per year. To the extent that refrigeration is used in buildings other than private residences (for example, in communal kitchen facilities), similar savings may be possible. Improvement of the efficiency of refrigerators manufactured in or available to DPRK could

[225] This extremely rough survey was done simply by looking around the city at the lights visible inside residential buildings at night, observing that apartments lit with CFLs showed a more bluish light than apartments lit by incandescent bulbs, and estimating the fraction of dwellings in which each type of bulb was present.

[226] See, for example, D. von Hippel et al (2001), Rural Energy Survey In Unhari Village, The Democratic People's Republic of Korea (DPRK): Methods, Results, and Implications, Nautilus Institute Special Report dated May 20, 2001, and available as http://nautilus.org/wp-content/uploads/2011/12/Unhari_Survey.pdf.

be increasingly important, as a refrigerator is probably one of the first appliances that households will invest in if economic conditions in North Korea begin to markedly improve.

- A substantial fraction of households in DPRK have either television or radio, or both. Recent improvements in electronics technology that the DPRK does not currently have access to have reduced the hourly energy consumption of these devices markedly, though the aggregate amount of electricity saved by such improvements may be small due to the limited power consumption of radios and small televisions. Other improvements in appliance efficiency in North Korea may well be possible, but their evaluation must await better information on the stock of electricity-using appliances in the household and other sectors. Microwave ovens, for example, accomplish many cooking tasks more efficiently than simple electric resistance burners, but the penetration of the latter in the DPRK residential housing stock is currently unknown (we assume that penetration of microwaves in North Korea is near zero).

- *Improvements in Cooking Efficiency (Non-coal fuels):* Urban households in the DPRK reportedly use charcoal, LPG, and kerosene stoves for cooking in addition to coal stoves. Rural households use wood and other types of biomass for cooking and heating. Efficiency improvements in all of these technologies are possible, though the percentage improvements (and the aggregate amount of fuel savings) are likely considerably higher for devices using solid fuels. Reduction in the use of wood and biomass fuels through the use of more efficient stoves and heaters would help to make wood and biomass available for other applications and/or to reduce harvest pressures on forests.

- *District Heating:* District heating of homes and other buildings using heat from power plants, industrial facilities, and stand-alone central steam plants is apparently practiced in North Korea (as it is throughout Eastern Europe), but the extent to which it is practiced is not entirely clear (but see our estimate in earlier chapters of this Report). Switching to an efficient district heating network from a system of dispersed small boilers and stoves can result in substantial coal savings, and there are quite likely extensive opportunities for improvements to existing district heating systems that can markedly increase the efficiency with which those systems deliver heat (and thus, possibly, increase the number of households that the district heating systems serve, especially when combined with weatherization of residential and commercial/institutional buildings, boiler and other improvements in district heating plants, and other upgrades).

- *Building Shell Improvements in Rural homes:* Potential improvements include caulking and weatherstripping, insulation, and glazing (in some cases, in our limited experience in the DPRK, many windows use plastic or wood coverings, or are cracked, so any reasonable glazing would be an improvement), but any definitive list of measures will have to wait until a better description of the rural housing stock in DPRK is in hand.

- *Use of Biogas:* Biogas—produced via anaerobic fermentation of human night soil, animal manures, and agricultural wastes—could be used as a clean cooking fuel in rural areas, or could contribute to small-scale power production (with cogenerated heat for agricultural processing or other applications)[227]. The biogas production process also has the potential to yield important by-products such as animal bedding, soil amendments, and organic fertilizer, as well as potentially (depending on the state of current waste disposal practices) reducing environmental impacts.

Transport and Other Sector Measures

We have evaluated only one energy efficiency measure in the transport sector in a quantitative manner:

- *Replacement of Medium-duty trucks:* Two and one-half tonne trucks have been the workhorses of the military ground transport fleet in the DPRK, and are reportedly (as well as by the author's observations) widely used in civilian goods (and civilian passenger, as shown in Figure 4-10) transport as well—often with military and civilian cargoes and passengers combined. We have assumed that all of the gasoline used for civilian freight transport by road in the DPRK is used in such trucks, and assuming that the freight transport provided by each vehicle is on the order of 15,000 tonne-km per year, we very roughly estimate that there are about 16,000 civilian 2 1/2 tonne trucks in the DPRK fleet, to go along with about 38,000 military trucks in active service. If the most heavily used two-thirds of these trucks (which we assumed to use 90 percent of the fuel) were replaced with new vehicles similar to the Isuzu FRR (mid-1990s) model, a fuel savings of about 43 percent would result. We have assumed that these vehicles could be manufactured in the DPRK (probably, especially in the first few years, from imported parts, as has been the practice in recent automobile production joint ventures in the DPRK) at a cost of $20,000 each[228]. At this cost, however, replacement of the truck fleet is not likely to be cost-effective. Note, however, that we have assumed that the existing trucks will be replaced whether they are at the end of their useful life or not. If one assumes only an incremental cost for the trucks (the difference between the costs of producing a standard DPRK truck and one similar to the Isuzu model), and/or if one assumed a substantially heavier usage (in te-km/yr) for the new trucks, which is probably reasonable, this measure would appear more cost-effective. Whether these changes would make this measure sufficiently cost-effective to pursue is not possible, with the data at hand, to ascertain.

[227] See, for example, Rural Energy Production: Biogas Plant, a Sustainable Source of Energy for Cooperative Farms, by Arthur Wellinger, dated December 12, 2003, and published by ADRA (Adventist Development and Relief Agency International) and Nova Energie. This report provides case studies of the application of manure-fed biogas digesters in the DPRK.

[228] This figure is based on the fact that the Isuzu truck model cited was available in the US for roughly $30,000 (retail) as of 1995. The cost is probably at least double that in 2007. Assuming A) that a large portion of this cost is dealer profit, profit for Isuzu, import costs and duties, and other non-product costs, and B) such trucks could be built in the DPRK at DPRK labor rates, but with Japanese technology (presumably under license), we have estimated a cost per truck of $20,000 US (2009 dollars). This may still be too high, as the average value of trucks imported to the DPRK from China in 2005 was under $10,000 (though some or many of these units may well have been used).

Figure 4-10: Military Truck in Use by Military Personnel and Civilians near Nampo[178]

Other potential improvements in the transport and other sectors might include:

- *Electric Motor and Drive improvements for Electric Locomotive:* Electrified rail is the backbone of the DPRK transit system. Though we have no data on the efficiency of electric locomotives in North Korea, potential efficiency improvements on the order of those described above for industrial motors seem plausible.
- Substantial improvements in electric rail efficiency may come about simply as a result of transmission and distribution improvements on the electric grid as a whole. Other options for increasing rail efficiency might include updated rail control and scheduling systems, track improvements to reduce friction (and forced halts), and optimizing freight loads.
- *Updating Other Transport Fleets:* Updating the road passenger transport, water transport (including the fishing fleet), and air transport fleets may as much as double their efficiency, but any fuel savings is highly likely to be offset by increased use of these transport modes as they become more efficient and reliable.
- *Biofuels for Transport:* The DPRK government has expressed an interest, in various documents, in increasing self-reliance by replacing petroleum-based transport fuels with liquid fuels derived from biomass. While the GHG and pollutant-reduction benefits of such a program are important, we are reluctant to enthusiastically endorse this idea at present because 1) all DPRK agricultural land appears to be needed and fully employed just to feed people, thus production of motor fuels from agricultural crops such as corn would appear to be ruled out; and 2) there appears to be relatively little extra wood or crop wastes available for use (see discussion of biomass resources above) as cellulosic feedstocks for biofuels

production (via either fermentation or thermal liquefaction). If the biomass resource situation changes in the future, however, biofuels would become a more attractive option.

- *Improving agricultural tractors:* Specific fuel consumption in tractors in China, reported to be 195 grams/hp-hr in the 1980s was some 10 percent greater than for similar tractors in industrialized countries[179]. Tractors in the DPRK are unlikely to be more efficient than the average for these older Chinese units, and are likely to be worse, particularly in recent years, as spare parts and other maintenance supplies have become increasingly difficult to obtain.

- *Reducing fertilizer use:* Fertilizer application in North Korea is reported to be excessive for some crops. On rice, for example, it has been suggested that the typical-practice nitrogen fertilizer application in the DPRK could be reduced by 25 percent[229]. If so, significant reductions in energy use in the energy-intensive ammonia manufacturing industry in DPRK should be possible (and/or an expansion of the amount of crops that could be fertilized from fertilizer produced domestic plus the limited available imports), as well as (probably minor) reductions in the need for tractor fuel for fertilizer application.

Additional details of the process used in estimating the impacts and costs of these measures are provided in studies referenced previously in this paper[180], as well as in the section of Attachment 1 providing printouts of the worksheets used for energy efficiency measure analysis.

Table 4-10 shows the overall results of our evaluation of these measures. It has been assumed that under an aggressive program with both strong leadership commitment inside the DPRK and technical and financial cooperation from other countries, these measures (or some of these measures and others with similar per-unit costs and impacts) could be implemented over the next 10 years[230]. In total (that is, in year 10 of an aggressive program), they annually save approximately 111 Petajoules (one Petajoule, or PJ, is equal to 1000 terajoules or 1 million gigajoules) of coal (about 31 percent of estimated 2009 DPRK coal supplies) at a cost of about $US 620 million (2009 dollars), plus over 19 PJ/yr (about one-third of 2009 generation) of electricity supply (electricity saved plus 500 MW of new wind-powered generation) at a total cost of approximately $1.45 billion. Note that more than half ($750 million) of this total cost for electricity-related measures is for wind power deployment, which accounts for just 21 percent of the total 19 PJ/yr impacts on generation requirements. If the package of measures included were reconfigured to include less wind power but more energy efficiency, the average cost per unit electricity supply impacts could be reduced significantly—illustrating the fact that this illustrative package of measures is NOT by any means cost-optimized. Replacement of the DPRK fleet of 2 1/2 tonne trucks, as it has been modeled, is unlikely to be cost effective with respect to saving energy alone, but would save approximately 2.1 PJ of refined products annually, which is somewhat under 8 percent of total estimated national petroleum use in 2009, and over a quarter of road transport petroleum use, at an investment cost of $720 million.

A key assumption made in estimating the costs and performance of most of the coal- or electricity-saving energy efficiency measures is that the costs and performance of these

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[229] Personal communications with UN agricultural sector expert with experience in DPRK, but note that this assessment probably refers to a time when DPRK fertilizer use was on average much higher than ongoing fertilizer shortages have allowed in recent years.

[230] Note that figures in Table 4-10 have been rounded for presentation, and are likely to be accurate to only one or two significant digits.

measures, when implemented in the DPRK, will be similar to the cost and performance of the measures as experienced in the People's Republic of China during energy efficiency programs carried out there in the late 1980s. It could be argued that the costs of the measures in China might be lower than in the DPRK, due to lower labor rates in China at that time and a larger manufacturing base in China. It could, however, equally be argued that the opportunities for savings with the measures we have evaluated are likely to be greater in the DPRK than they were in China, due to the, on average, older capital stock in the DPRK.

The environmental benefits of measures such as those described above would be substantial. The measures to save coal would avoid the emissions of approximately 51 thousand tonnes of sulfur oxides, 32 thousand tonnes of nitrogen oxides, and 7.9 million tonnes of carbon dioxide. Using the year 2009 ratio of thermal to hydroelectric generation, the electricity-saving measures described above (including the wind power generation) would avoid emissions of another 13 thousand tonnes of sulfur oxides, 8 thousand tonnes of nitrogen oxides, and 2.1 million tonnes of carbon dioxide. These emissions reductions represent 24 to 28 percent of our estimates of total national emissions of each pollutant in 2009.

Together, the energy savings and environmental benefits of these few energy efficiency measures, as evaluated, underscore the very important role that energy efficiency can, and indeed, must play in any DPRK energy sector development/redevelopment effort. By way of comparison, the electricity savings from the limited package of measures described above (excluding wind power systems) amounts to about the same amount of electricity that would be produced by a 400 to 500 MW thermal power plant at approximately the same capital cost, but with no fuel costs, arguably higher reliability, and far fewer environmental impacts. Plus, each individual investment in energy efficiency measures is smaller, and thus arguably more manageable and sustainable, than investments for the larger capital investments (such as power plants) that are avoided by energy-efficiency investments.

Table 4-10: Results of Energy-Efficiency Analyses for the DPRK

MEASURES TO SAVE COAL:

Measure	Estimated Energy Energy Savings Potential, TJ/yr		Total Estimated Investment Cost, $US 2009
Industrial Boiler and Furnace Improvements	41,000		$ 241,200,000
Residential and Public/Commercial/Military Boiler Impr.	22,000		$ 70,500,000
Building Envelope Improvements	15,000		$ 43,300,000
Solar Water Heating	7,000		$ 130,800,000
Domestic Stove/Heater Improvements	5,000		$ 5,300,000
Electric Utility Boiler Improvements	20,000		$ 127,800,000
TOTALS	110,000	TJ/yr	$ 618,800,000
Avoided Losses of Coal During Transport:	1,100	TJ/yr	
TOTAL COAL SUPPLY SAVINGS	111,000	TJ/yr	
Fraction of 2009 Total Coal Supply	31.1%		
Investment required, $ per GJ/yr of Coal Supply Savings			**$ 5.57**
Investment required, $ per tce/yr of Coal Supply Savings			**$ 163**

MEASURES TO SAVE/GENERATE ELECTRICITY:

Measure	Estimated Energy Energy Savings Potential, TJ/yr		Total Estimated Investment Cost, $US 2009
Industrial Motors and Drives	1,380		$ 81,300,000
Motors and Drives in other Sectors	630		$ 37,300,000
Residential Lighting	530		$ 31,100,000
Non-residential Lighting	3,560		$ 149,500,000
Own Use reduction in Power Plants	630		$ 79,200,000
Reduction of Emergency Use in Power Plants	1,090		$ 52,200,000
Transmission and Distribution Improvements	5,630		$ 269,800,000
Wind-powered Electricity Generation	3,940		$ 750,000,000
TOTALS	17,400	TJ/yr	$1,450,200,000
Additional Avoided T&D Losses (based on 2009 Rates)	1,690	TJ/yr	
TOTAL ELECTRICITY SUPPLY SAVINGS/GENERATION	19,090	TJ/yr	
Fraction of 2005 Total Electricity Generation	33.6%		
Investment required, $ per GJ/yr of Electricity Supply Savings/Generation			**$ 75.95**
Investment required, $ per MWh/yr of Electricity Supply Savings/Generation			**$ 273**

MEASURE TO SAVE PETROLEUM PRODUCTS:

Measure	Estimated Energy Energy Savings Potential, TJ/yr		Total Estimated Investment Cost, $US 2009
Improvements in 2 1/2 tonne truck fleet	2,140		$ 717,000,000
Fraction of 2009 Total Refined Products Use	7.4%		
Fract. of 2009 Total Refined Prod. Use in Road Transport	26.4%		
Investment required, $ per GJ/yr of refined products Savings			**$ 335**
Investment required, $ per toe/yr of petroleum products Savings			**$ 14,021**

5. The DPRK's Mineral Resource Base

5.1. Introduction

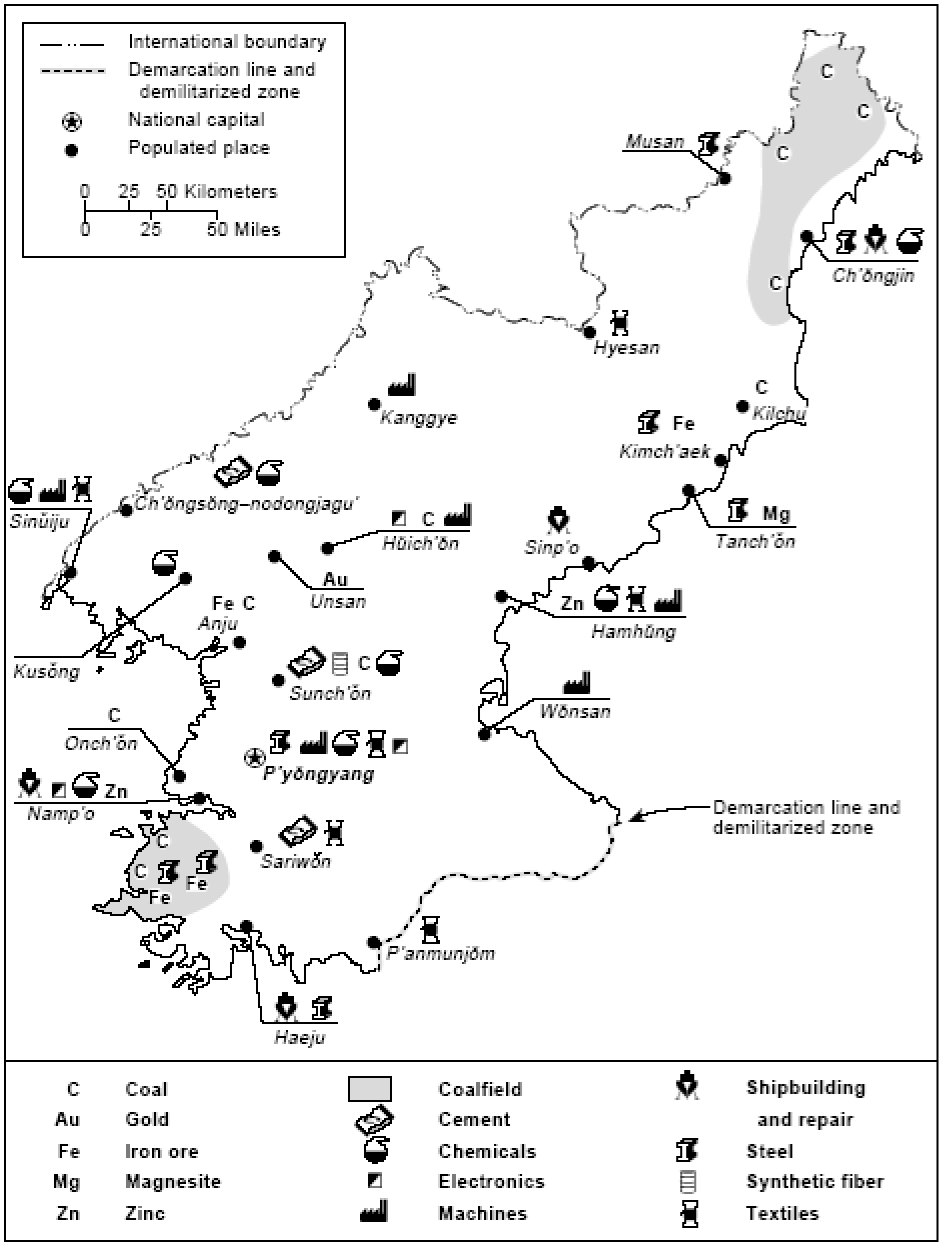
Minerals, including metal ores and non-metallic minerals, constitute a major economic resource for the DPRK. The DPRK has the world's largest known resource of the refractory mineral magnesite, estimated at up to 50 percent of the world's resources. The DPRK has seven minerals, including tungsten, molybdenum, barite, and fluorite, for which the DPRK's resources rank among those of the top ten countries in the world[181]. Minerals and metals represent an important current source of income for the DPRK, and will be an important short-to-medium-term area of investment to spur the redevelopment of the DPRK economy. The DPRK website "DPRKorea-Trade" lists graphite, gold, silver, platinum, palladium tellurium, bismuth, selenium, zinc, talc and granite among the metals and minerals that the DPRK currently seeks to export[182]. Figures 5-1 and 5-2 show selected minerals deposits and industries in the DPRK, with Figure 5-2 focusing on the locations of key reserves. Table 5-1 shows ROK estimates of reserves of a number of metals and minerals in the DPRK and in the ROK, with the estimated value of those reserves. The subsections that follow provide additional information on DPRK resources for iron, other base metals and precious metals, uranium and other heavy metals, and key non-metallic minerals. Also provided are descriptions of the existing minerals-related infrastructure in the DPRK, and key minerals-related government authorities and training organizations in the DPRK. The text, tables, and figures in this Chapter largely draw upon three studies prepared for Nautilus in 2008 and 2010/2011. These studies are:

- A presentation by Choi Kyung Soo of the ROK-based North Korea Resources Institute, titled "The Mineral Resources of North Korea", prepared for the 2010 DPRK Energy and Minerals Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/05.-Choi.pptx

- A presentation by Chung Woo-jin of the Korea Energy Economics Institute (KEEI), dated March 2008, titled "North Korea's Mineral Resources and Inter-Korean Cooperation", and prepared for the 2008 DPRK Energy Experts Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/Chung1.ppt.

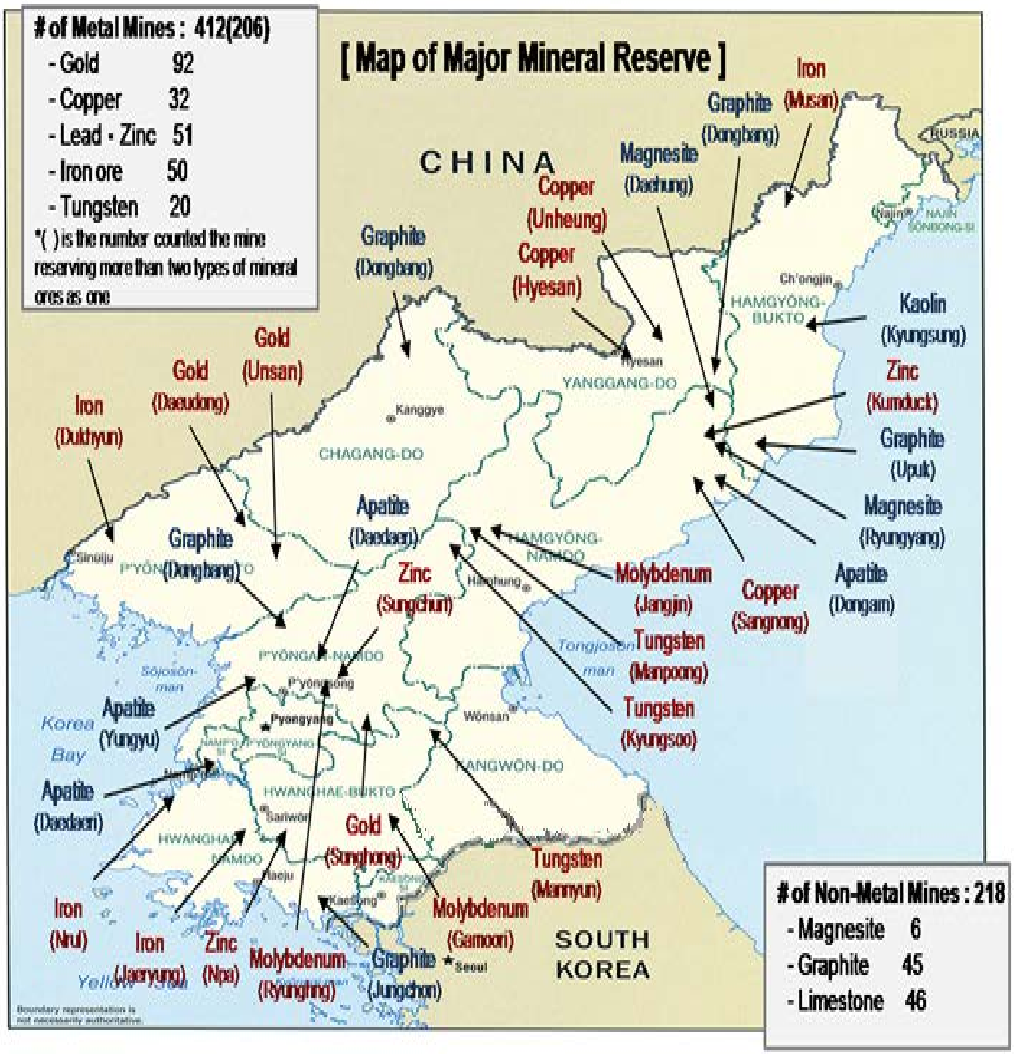
- A report prepared by Edward Yoon entitled Status and Future of the North Korean Minerals Sector, dated January 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf. Slightly edited versions of sections in Mr. Yoon's report are the primary source for the text in sections 5-3 through 5-5 of this Chapter, as well as in other sections, as indicated.

Figure 5-1: Location of Selected Minerals Deposits in the DPRK[231]



[231] Map from Federation of American Scientists web page on "Other Industry" in North Korea, http://www.fas.org/nuke/guide/dprk/target/industry.htm.

Figure 5-2: Location of Selected Minerals Deposits in the DPRK[232]



232 Map from Choi Kyung Soo's 2010 presentation prepared for Nautilus, as referenced above.

Table 5-1: Estimates of Metals and Minerals Reserves in the ROK and DPRK[233]

Mineral Type	Reserves (1,000 ton except as noted)		Potential Value ($ million)	
	South Korea	North Korea	South Korea	North Korea
Gold (Au100)	0.030	1-2	469	23,450
Silver (Ag100)	1.175	3-5	296	1,007.7
Copper (Cu100)	41	2,155	55.1	2,896.1
Lead (Pb100)	305	6,000	117.4	2,309.5
Zinc (Zn100)	440	10-20 (million)	264.8	9,027.3
Iron (Fe50)	19,700	2-4 (billion)	484.9	73,842.6
Tungsten	100	200-300	86.9	217.3
Molybdenum	10	1-3	208.6	41.7
Manganese	123	100-300	20.8	6.5
Nickel	-	10-20	-	3.6
Graphite	1,837	6,000	1,183.4	3,865.2
Limestone	6,547,800	100 (billion)	65,248.6	996,496.5
Kaolin	74,357	2,000	1,143.8	30.8
Talc	5,451	600	545.1	60
Asbestos	511	13	55.2	1.4
Fluorite	345	500	53	76.8
Barite	712	2,100	75.5	222.7
Magnesite	-	3-4 (billion)	-	126,000

Table 5-2 summarizes ROK estimates of mineral resources output from major mines in the DPRK. In this table, production data for North Korean minerals in 1990 have likely been understated, with production somewhat overstated after 1990. A reason for these inaccurate estimates by ROK organizations is that North Korean natural resource production capacity actually reached its highest level in 1990 but declined dramatically through 1999. This decrease in DPRK mining capacity was not well known to ROK analysts. As a result, the numbers in Table 5-2 are inaccurate reflections of true DPRK minerals production. Based on the testimony

[233] Table 5-1 from a presentation by Dr. Chung Woo-jin, entitled "Mineral Resources in DPRK", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available as http://nautilus.org/wp-content/uploads/2012/01/Chung.ppt. The table shown has some minor edits and format differences from the table in Dr. Chung's presentation. A similar table, with generally similar estimates of resources, is available (as Table 2) in the 2011 report by Edward Yoon referenced above.

of former North Korean miners, mining production in the DPRK declined dramatically from the early 1990s (from about 1993-1994) through 1999[234].

Table 5-2: ROK Estimates of Output of Major Metallic Ores in the DPRK[235]

	Gold (tonnes)	Silver (tonnes)	Copper (1,000 tonnes)	Tungsten (ton)	Pb (1,000 tonnes)	Zinc (1,000 tonnes)	Iron ore (1,000 tonnes)
1990	5	50	15	1000	80	230	8430
1992	5	50	16	1000	75	200	5747
1994	5	50	16	900	80	210	4586
1996	4,5	50	16	900	80	210	3440
1998	4.5	50	14	500	70	100	2890
2000	2	40	13	500	60	100	3793
2001	2	40	13	500	60	100	4208
2002	2	40	12	600	60	100	4078
2003	2	20	12	600	60	100	4579
2004	2	20	12	600	12	100	4580
2005	2	20	12	600	13	100	5000
2006	2	20	12	600	13	100	5000

Presentations of what is known about key mines, output trends, and infrastructure for each of several different important types of minerals are provided below in section 5.2, below, followed by a section providing a description of major mining, metals refining, minerals transport, and related infrastructure (section 5.3), a review of the policies, organizations and human resources involved in the DPRK minerals sector (section 5.4), and a presentation of conclusions regarding the DPRK minerals sectors offering potential strategies for overseas investors who might wish to become involved in development of the sector (section 5.5).

[234] Information on reduced DPRK minerals production described here are based on personal observations and interviews conducted by E. Yoon, as described in the 2011 document referenced earlier in this Chapter.
[235] Korea Mineral Improvement Corporation Report, Deposits of Mineral resource in DPRK and trading between South and North Koreas, 2008.

5.2. Mining and Other Infrastructure, Output Trends, and Related Information for Key Types of Minerals

5.2.1. Iron

The DPRK's iron ore reserves are substantial. In addition to the ROK estimates of DPRK reserves, at 2 to 4 billion tonnes, other sources note reserves of 3 billion tonnes[183]. The Korea Mining Corporation (ROK) estimated the overall size of deposits of iron ore in the DPRK at 3.5 – 4.0 billion tonnes (including ores of quality in the 22-50% Fe range) as of 2008. The Musan (or Moo-san) mine, in the DPRK's northeast, is described by one source as "the largest open air [presumably meaning open pit] mine in Asia", and has been a recent target of investment by Chinese mining companies[236]. Major iron ore regions are the Moo-san, Lee-won, Buk-Chong, Hur-chon areas (Ham-Kyung province), and Eun-Ryul, Shin-Won, and Jae-Ryong (in Hwang-Hea province). Details of key mines and factories using iron ore are provided below.

Table 5-3 summarizes the major iron ore mines in the DPRK, including their location, the reported size of their deposits, and the reported grade of their ore bodies, as well as estimates of their output as of 2001. Iron ore production in the DPRK peaked in 1985 (at 9.8 million tonnes, based on ore with Fe content of 65%) but sharply declined to 2.89 million tonnes as of 1998[237].

[236] North Korea Brief No 06-4-8-1, "Digging for Answers in the DPRK Mining Sector: Seeking Solutions for the North Korean Economy", lists reserves for the Musan mine at "7 trillion tons", which we assume is a mistranslation, a mistake in units, or both—probably the proper value is 700 million tons or 7 billion tons.

[237] Source: "DPRK's Industry", Korea Industrial Bank (ROK), 2001.

Table 5-3: Major Iron Ore Mines in the DPRK[238]

Area	Mine name	Location	Deposit	Grade	Others
East	Moo-san	Moo-san, Ham-kyung province	1.5 billion tonnes	25-35 %	8 million tonnes. (30%), 3 million tonnes (60%)
	Lee-Won	Lee-won Ham-Nam, prov.	20 years operation	49%	
	Poong-San	Poong-San Ran-gang prov.	120 million tonnes	45%	
	Hur-Chon	Hur-chon Ham-nam	150 million tonnes	48%	
	Dan-chon	Dan-chon Hamnam	100 million tonnes	45%	
	Jang-Gang	Ja-Gang province	unknown	50%	
West	Eun-Ryul	Hwang-nam province	100 million tonnes	48%	Open mine 1.6 million tonnes
	Jae-Ryung	Hwang-nam province	100 million tonnes	50%	Open mine 500,000 ton
	Chon-Dong	Gae-chon Pyong-Nam province	50 million tonnes	50%	1 million tonnes
	Suh-hae-ri	Eun-Ryul Hwang-Nam province	unknown	55%	Under development
	Hah-Sung	Shin-Won Ham-Nam province	15 million tonnes	45%	Open mine 500,000 ton
	Duck-Hyun	Eui-Joo Pyong-Buk, province	unknown	50%	Iron & copper 500,000 tonnes
	An-Ark	Hwang-nam province	unknown	50%	Newly developed
	Song-rim	Hwang-buk province	unknown	55%	Newly developed
	Hwang-Joo	Hwang-buk province	unknown	55%	Newly developed
	Yon-San	Hwang-buk province	unknown	55%	Newly developed
	Tae-Tan	Hwang-nam province	unknown	55%	Newly developed
	Gae-chon	Pyong-Nam province	17.5 million tonnes	45-55%	Developed 1976

[238] Source: "DPRK's Industry", Korea Industrial Bank (ROK), 2001.

The Moo-san (Musan) Iron Ore Mine

The reserves of the Moo-san mine are estimated at 1.5-2.0 billion tonnes as Magnetite ($FeOFe_2O_3$) containing Fe at 23-30%. Choi (see reference above), describes development of this mine as beginning in 1935, its reserves as 1.73 billion tonnes at an ore grade of 24% Fe. The mine's reserves are considered low-grade ore (average 25%), but as it is a strip mine (an open pit mine), it offers iron ore production at low cost. There are 3-4 mineral veins in the Moo-san mine. The first vein is 400 meters in width, 3,000 meters in length, and 1,000 meters deep. Another 3 veins are known to be similar in structure to the first, but further details on those veins are not available. Starting from an iron content of 28-30%, ore is refined to an iron content of 60%-65% through a dressing (separation of higher grade ore products) procedure in the mine area. Ore produced from an open surface is sent to 6 ore separators in 25-ton and 50-ton heavy trucks (which were mostly imported from Sweden) then, the ore is sent to dressing plants for further refining by gravity separation methods at a location near the ore separator.

Using this refining method above, the 60-65% Fe powdered ore is produced, then sent to the Kim-Chaek Iron-manufacturing plant in Chong-Jin city, 97 km from the Moo-san mine. Transport is via freight train and via a steel pipeline that is 2 meters in diameter. Unlike most regional one-way railway systems in the DPRK, the railway from the mine is a double line so that powdered ore can be carried out without any delay via freight train if the mine produces at its maximum capacity. The total capacity to carry out powdered ore via the railway and pipeline from the Moo-San mine to the Chong-Jin iron manufacturer) was 6 millon tonnes per year[239].

The Moo-San mine's production capacity is 3 million tonnes of 65% powdered ore. The mine produced 9.9 million tonnes of raw ore in 1985, but after that production sharply declined to 2.89 million tonnes, or 30% of production in 1985 production, though iron ore production at the mine has reportedly been slowly increasing between late 2002 and 2009. Choi (see reference above) lists the mine's capacity as 10 million tonnes or ore annually, with ore processing throughput capacity of 7.5 million tonnes/yr using a magnetic separation (wet) processing method. Choi estimates the 2006 output of the mine at 5 million tonnes of ore, and 2 million tonnes of concentrate (Fe 65%), at a recovery rate of 79.5%. The mine is linked to the Seodusu hydroelectric power plant over a 60 kV power line, and draws its water from the Duman (or Tumen) river. It is also linked by railroad to the port at Chengjin, 150 km from the mine site.

The mine has been supplying its production to the Kim-Chaek Iron-Manufacturing Company. This iron-manufacturer's annual production capacity is reportedly 2.17 million tonnes, accounting for about 40% of the DPRK's iron production capacity (5.42 million tonnes)[240]. Kim-Chaek employed 20,000 workers when operating at peak output, and its annual capacity is reported to be 2.4 million tonnes of pig iron, 2 million tonnes of steel, and 1.4 million tonnes of steel materials (rolled steel)[241].

[239] Based on data from Kim, Young Yoon "DPRK's Mineral production systems and future", Korea Reunification Institute, 2007, and personal communications with industry sources.
[240] Based on Korean (ROK) Central Bank report, 2005.
[241] Source, Han GyeRe Newspaper, March 3, 2002. Note that the 2.4 tons of pig iron is probably roughly consistent with the estimate of 2.17 tons of iron output noted above.

Eun-Ryul Mine

This mine extracts iron ore in the form of limonite ($Fe(OH)_n H_2O$) and is located in Eun-Ryul-Gun, Hwang-Hae province. Deposits in this mine are estimated to total 200 million tonnes. Due to their high grade of iron ore (Fe 44%) and the convenience of transporting ore in ships (the Eun-Ryul mine is within 20 kms of Hae-Joo port) the Eun-Ryul mine and the nearby Jae-Ryong mine descibed below are likely possible destinations for overseas' investment funds[242].

Jae-Ryong Mine

This mine is located in Jae-Ryong-Gun, Hwang-Hae province. The mine vein is similar to that in the Eun-Ryul mine. Both mines provide their production to the Hwang-Hae Iron-manufacturer.

Hwang-Hae Iron-Manufacturer

The two mines above provide their production to the Hwang-Hae Iron-manufacturer. This factory's capacity in to produce pig iron is approximately 1.14 million tonnes per year[243]. This iron-manufacturer has more modernized and sophisticated facilities relative to the Kim-Chaek Iron-Manufacturer, but it does not operate continuously due to a shortage of iron ore supplies from the Jae-Ryong and Eun-Ryul mines (Chung, 2007 and private source, 2010).

Hur-Chon iron ore mine

This mine is located in Hur-Chon Gun, Hwam-Kyung Nam province. The deposit is composed of reserves of hematite (Fe_2O_3), and the quality of iron ore is 44% (Kim, 2007 and Private source, 2010).

North Korea has been reluctant to export iron ore, but it has encouraged iron ore manufacturers to export steel or pig iron production to China or South Korea. Table 5-4 provides a summary of the production capacity (in units of ten thousand tonnes per year). Table 5-5 shows the supply chains—sources of ore and electricity—for major iron manufacturers in the DPRK.

[242] Sources of information used to describe this and other mines in this section include Kim, Young Yoon "DPRK's Mineral production systems and future", Korea Reunification Institute, 2007; Chung, Woo-Jin "Strategic Cooperation Plans and Current situation in Development of South and North Korea", Korea Energy Economics Institute, 2007, and personal communications with industry sources.

[243] Korea Mining Improvement Corporation report, "Deposits of Mineral resource in DPRK and trading between South and North Koreas", 2005, p. 9.

Table 5-4: Production Capacity of Major DPRK Iron Manufacturers (10,000 tonnes per year, and fraction of total national capacity)[244]

Name	Iron making (10,000 tonnes)	Steel making (10,000 tonnes)	Rolling (10,000 tonnes)
Kim-Chaek Iron Manufacturer	216.7 (40%)	240 (40%)	147 (36.4%)
Hwang Hae Iron Manufacturer	114.2 (21%)	144.5 (24.1%)	75 (18.6%)
Sung Jin Iron Manufacturer	48 (8.9%)	72.6 (12.1%)	41.5 (10.3%)
Chong Jin steel manufacturer	96 (17.7%)		
4.13 Iron manufacturer	51.6 (9.5%)		
September (Kuwol) Iron manufacturer	9.6 (1.8%)	9 (1.5%)	55 (13.6%)
Others	6 (1.1%)		
Total	542.1	600.2	403.7

[244] Source: "DPRK's Industries", Korea (ROK) Industrial Bank, 2002. These data are consistent with data provide by Dr. Chung Woo-jin in the presentation listed in section 5-1, above.

Table 5-5: Supply chains for Major Iron & Steel Manufacturers in the DPRK

Name	Major Products	Iron Ore	Power Plant	Supplies Products for
Kim-Chaek Iron Manufacturer	pig iron, steels, rolled steel	Moo-san Iron mine	Chong-Jin Thermal power plant	Sung-Jin, Chunrima steel maker
Hwanog-Hae Iron Manufacturer	Pig iron, steels, secondary metal products	Eun-Ryul, Jaer-yong mine	Pyong-Yang Thermal power plant	steel sheet, Rail, shape steel
Chunrima steel Manufacturer	general rolled steel steel rope, secondary steel products	Chon-dong, Gea-chon mines	Pyong-Yang Thermal power plant	construction, building materials
Chong-jin steel manufacturer	secondary steel products alloy steel products structural steel		Chong-Jin Thermal power plant	machinery factories, exporting

5.2.2. Other base metals

Most lead and zinc deposits are found in Ham-Kyung, Pyong-An and Hwang-Hea provinces, and the total and total reserve are approximately 600,000 tonnes (Pb 100%) and 15 - 20 million tonnes (Zn 100%), respectively[245]. ROK estimates, as noted above, place the DPRK's endowments of lead and zinc at 6 and 10-20 million tonnes of metal, respectively. Another source suggests that reserves of these metals are roughly 12 million tonnes each, and are concentrated in the Komdok area of the DPRK's Northeast (South Hamgyong province)[184]. Surveys for a single mine in Komdok mine show about 2.7 million tonnes of lead, 7.9 million tonnes of zinc, and a number of other metals, including precious metals, in the mine's estimated 240 million tonnes of ore[246].

The National total output of lead and zinc are approximately 60,000 tonnes and 100,000 tonnes per year respectively. Most zinc and lead ore are smelted at the Moon-Pyong Refinery (located in Moon-Chon City, Kang-Won province).

Gum-Dock Zinc Mine

This mine is located in Dan-Chon area in Ham-Kyung province[247]. As the largest zinc mine in the DPRK, this mine has rich vein of ore 9 km in extent, and its deposit is estimated at 8 million tonnes (Zn 100%), about half of the DPRK's total deposits. Development of this mine began in

[245] From E. Yoon 2011 report described above.
[246] From document in the author's files. Other metals described as present in ore from this mine include silver, mercury, and cadmium. The mine's ore-handling capacity is described as about 14 million tonnes/yr.
[247] Choi, in the 2010 presentation listed above, described this mine as the "Kyumduck Zinc mine", located in "Hamkyungnam-do, Dancheon, Kyumgol-dong".

1932, and its reserves are estimated at 266 million tonnes of Sphalerite ore at a grade of 4.21% Zn and 0.88% Pb. It is an Underground mine, with a reported production capacity of 10 million tonnes of ore per year, produced with a mining method described by Choi (source as above) as “70% shrinkage, with 30% sub-level stoping”[248], processing the minerals extracted using flotation, with a throughput (capacity) of 10 million tonnes/yr. In 2006, this mine reportedly produced 3.5 million tonnes of ore, yielding 196,000 tonnes of zinc concentrate (Zn 53%), at a recovery rate of 52%, and 31,800 tonnes of lead (Pb 63%) at a recovery rate of 63%. The mine is powered by a link to the 50 MW Hyeuchen hydroelectric power plant, uses water from the Bukdaechen river, and is connected to the Kimcheck port by a 78 km rail line. At the Kimcheck port, the loading capacity for product is about 800,000 tonnes per year. Figure 5-3 provides photos taken from the outside and inside of the Kyumduck Zinc mine.

Figure 5-3: Photos of Kyumduck Zinc Mine[249]

Copper reserves in the DPRK are estimated by ROK experts at about 2.2 million tonnes. The Honchon mine, in Honchon County, South Hamgyong province, is reported to have reserves of about 400,000 tonnes of copper, and the nearby Sangnong mine has reported copper reserves of over 500,000 tonnes[250]. The four major copper refining facilities in the DPRK are listed as Nampo, at 41,400 tonnes/yr, Heungnam, at 4000 tonnes/yr, Wunheung, at 25,000 tonnes/yr, and

[248] According to Wikipedia (http://en.wikipedia.org/wiki/Stoping_%28mining_method%29), The mining technique known as stoping “is the removal of the wanted ore from an underground mine leaving behind an open space known as a stope”.

[249] From presentation by Choi Kyung Soo of the ROK-based North Korea Resources Institute, titled "The Mineral Resources of North Korea", prepared for the 2010 DPRK Energy and Minerals Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/05.-Choi.pptx.

[250] From document in the author’s files. Gold reserves in these two mines combined are listed at about 400 tonnes.

Pyungbuk, at 20, 000 tonnes/yr. These facilities are described as small in scale, by international standards[251].

North Korean authorities have been deliberately reluctant to reveal information about North Korea's copper mines and copper production capacity to outsiders, including China and South Korea, due to the fact that copper has been a significant material for producing military equipment, for including copper cable, bullets, shells and missile-related materials (Private source, 2010). It is not easy to gather data related to copper mines and copper production in North Korea. There are 3 major copper mines in the Northern part of the DPRK: Hur-Chon Copper Mine, Hye-San copper mine and Yong-Heong Copper Mine. These mines are owned by the People's Army Department (PAD), as they provide strategic war industry supplies, and are controlled and operated by the PAD. The information available on these mines is as follows.

Hye-San Youth Copper Mine

This mine is located in the Hye-San region in Ryang-Gang province. The copper ore deposit for this mine is known to be 20 million tonnes, the mine's annual production capacity is 30,000 tonnes (of Copper 30%) and its employees number about 2,500. Copper ore from the mne is processed in a concentrator unit at the mine, and the concentrated ore is carried by freight train to the Dan-Chon metals refinery. There are two copper mines in this region: Gap-San copper mine and Shin-Pa copper mine in Ran-gang province.

Hur-Chon Copper Mine

This mine (likely the same as the "Honchon" mine described above) is located in the Hur-Chon region of Ham-Kyung province. The known copper ore deposit for the mine as 15 million tonnes, and Gold and other rare minerals are also found in the deposit. The annual production capacity of the mine is 20,000 tonnes (Copper 40%) and it employs 5,500 personnel. Copper ore is processed in a concentrator at the mine and is carried by trucks and freight trains to the Dan-Chon refinery.

Yong-Heong Copper Mine

This mine is located in the Yong-Heong region in Ham-gyung province. The known copper ore deposit is 12 million tonnes, and is associated with Gold and rare minerals. The annual production capacity of the mine is 10,000 tonnes (Copper 40%), it employs 1,500 workers. Copper ore is concentrated in concentrator units at the mine, and is carried by trucks and freight trains to the Dan-chon refinery.

The DPRK has aluminum resources sufficient to support exports of one the order of a thousand tonnes per year of ore to China, but we have no further information at present about DPRK reserves of this metal.

5.2.3. Precious and specialty metals

The DPRK has gold reserves estimated at 1000-2000 tonnes, and silver reserves estimated at 3000 to 5000 tonnes. In addition, the DPRK has significant reserves of the strategic minerals tungsten and molybdenum, used in specialty metal alloys, and also offers for sale the

[251] Presentation by Dr. Chung Woo-jin, same source as listed for Table 5-1.

precious metals platinum and palladium (see above). Tungsten output in the years around 2000 was estimated at 500 tonnes/yr[185]. The largest of a reported 51 gold mines in the DPRK is Woonsan, located in the DPRK's Northwest. DPRK gold mines, like many other industrial establishments, lack modern equipment, are relatively small, and in some cases have worked existing seams for some time[252].

Gold ore is typically produced with silver ore and also with copper ore in the DPRK[253]. Gold and silver ore reserves total a few million tonnes of raw ore, according to a Korea Mining Corporation source. Major gold mines in the DPRK are the Soo-An Mine (Soo-an-gun, Hwang Buk province), the Hol-dong mine (Yonsan-gun, Hwang Buk province), the Dae-yoo-dong mine(Dongchang –gun, Pyungbuk province), the Woon-san mine (Woonsan-gun, Pyong-Buk province), the Sung-hong mine (Hoi Chang-gun, Pyongnam province), the Sang-nong mine (Huh-chon-gun, Hamnam province), the Ong-Jin Gold mine (Hwang-Hae province) and the Kum-kang mine (Kumkang-gun, Kangwon province). The total production from these 7 major gold mines has not been officially reported, however it is clear that the annual gold production capacity is approximately 5 tonnes in these major mines, and annual silver production is approximately 40 tonnes. In particular, the annual production capacity of the Woon-San gold mine is about 1.5-1.8 tonnes according to private sources (as of 2010). This mine's capacity is estimated to amount to over 40% of the DPRK's gold production capacity. The Woon-san mine's deposits of gold ore are estimated as 1,500 tonnes alone, which is almost 50% of North Korean gold reserves.

The DPRK has been experiencing a shortage of technology and infrastructure in precious metals mining. For example, the large mines described above generally have 30-40 year-old (or older) production equipment, including some equipment inherited from the 1940s Japanese colonial period. As a result, these mines' production capacity is likely similar to their 1940s era production capacity. DPRK authorities have declared that all gold production in the country should belong to the Labor Party's assets (which are controlled by the "39" Department, which was Kim Jong Il's private assets manager), and as a result no other organization has the authority to deal with and to produce gold in the DPRK. Deeper and deeper strata in the gold mines described above have been worked due to the mines having been operated for more than 50 years, and the increasing depth of pit (tunnel depth) is making it more complicated and difficult to extract gold ore from these mines.

Due to a decline in gold ore production, DPRK authorities contacted, in the years before 2010, Chinese businessmen and Japanese business interests in an attempt to attract funds to invest in those major gold mines. These contacts implied that the Labor Party (39 Department) wishes to produce more gold ore to earn more hard currency to support the newly-announced (as of 2010) military leader, Kim Jong Un.

As of 2010, the investment proposals made to overseas investors by DPRK authorities were reportedly as follows: (1), investors should invest at least 1 million US dollars in cash to produce gold ore (Hol-dong gold mine, Kum-Kang, and Woon-san gold mine), (2), the North Korean government would be the guarantor to protect the investor's funds, and (3), investors

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[252] Presentation by Dr. Chung Woo-jin, same source as listed for Table 4-1.
[253] Text in the remainder of this subsection is derived from material from the 2011 report by E. Yoon, as referenced earlier, and based on a combination of ROK sources and personal contacts, as referenced in the original report.

would have the authority to bring out gold ore from the mine they invested in, and export it to overseas locations for refining into gold metal.

Gold mining regions use trucks and freight trains as major carriers of ore from mines to refineries, with heavily-armed guards to protect shipments against potential theft.

The Man-Nyun Mine produces tungsten and molybdenite. This mine is located in Shin-Pyong –Gun, Hwang-Hae province. Tungsten reserves in this area are approximately 20 million tonnes (WO_3 65%), accounting for half of North Korea's total reserves. There are 10 veins of Tungsten in the deposit, of 3-6 meter width and 1,800 meter length. This mine also produces manganese ore and copper pyrite ore. The mine's ore separator's capacity is 1000 tonnes/day, and the mine produces 500,000 tonnes of ore annually (measured as WO_3 65%). The mine employs 3,500 workers, and has 8 work tunnels to support mining activities.

The DPRK is thought to have substantial reserves of rare-earth minerals, global production of which is now dominated (95 percent) by China, though other nations, including the United States, have produced significant quantities of these minerals in the past. Recent news reports suggest that the ROK's Korea Resources Corp. (KORES) has been in discussions with DPRK officials about developing DPRK rare earth resources[254].

5.2.4. Uranium

Figures on the DPRK's reserves of uranium are difficult to obtain, and their accuracy is unknown. It has been reported that uranium has been mined to supply the DPRK's domestic nuclear industry from mines located in various areas around the country, including Pyongsan, Pakchon, Hongnam, Jusong, Ungki, Sunchon 2, Hamheung, Hekumkang, and Najin[186]. Another source refers to a uranium mine near Hungnam (probably the same as "Hongnam"), where the Japanese built a cyclotron in 1943-44[187]. Two sources suggest that the DPRK's uranium deposits "are estimated at 26 million tonnes"[188] [255]. One of the sources describes these deposits as "high grade ore", so it seems virtually certain that the references are to tonnes of ore, not tonnes of uranium metal (or uranium oxides). Another source states:

> "It has been estimated that, at its peak in the early 1990s, North Korea was able to produce about 300 tonnes of yellow cake [U_3O_8] annually, equal to approximately 30,000 tonnes of uranium ore."[189]

Other analysts of the subject have reported estimates of 3 and 4 million tonnes of "reasonably assured resources", based on older OECD and ROK estimates, respectively. Still another source cites a figure of 4.5 million tonnes of uranium ore, and quote "Russian scientists who have visited North Korea" as saying that the DPRK's "mining and milling capabilities produce 2000 tonnes of natural uranium, per year"[190].

The DPRK is reported to have exported significant amounts of uranium ore over the years, starting in (at least) the 1947-1950 period, with the export of "over 9,000 tonnes of uranium [presumably ore] and an unknown amount of monazite to the USSR", and continuing

[254] See, for example, Wall Street Journal Asia, July 24, 2012, "South, North Korea Discussed Rare Earth Mining", available as http://blogs.wsj.com/korearealtime/2012/07/24/south-north-korea-discussed-rare-earth-mining/.

[255] The DPRK has been highly reluctant to reveal the extent of its deposits of Uranium ore and its annual production capacity to the outside world. This same estimate of reserves (26 million tonnes of ore), however, was provided in information from private sources in China and DPRK business contacts compiled by E.Yoon for the 2011 report described above.

with a reported “$6 billion worth of uranium ore” to the USSR in 1985, “1,500 tonnes of monazite[256] annually” in the 1990s to “China, Japan, Spain, and Hong Kong”[191]. More recently, an advertisement by the DPRK's International Chemical Joint Venture Corporation was published in an English-language DPRK trade journal in 2001 and 2002 advertised ammonium diuranate (ADU), a processed form of yellowcake, for sale on the international market[192]. A report in late 2006 that the DPRK and Russia had been negotiating, apparently since 2002, a deal that would give Russia “exclusive rights” to the DPRK’s uranium deposits “in exchange for Moscow's support at six-party talks aimed at denuclearizing Pyongyang“, suggested that Russia would enrich DPRK uranium for re-export to Vietnam and China as nuclear fuel. The report was dismissed as “rumors” by Russian authorities[193]. Exports from the DPRK to China of 90.54 tonnes of "Uranium, Thorium Ore and Concentrate" were listed in China Customs statistics for the year 2004. The listed value for these shipments, about $22,000 USD, suggests that the exports were of ore, not refined metal. Uranium exports from the DPRK to China are not listed for other years between 1995 and 2005[194].

There are two major Uranium ore mines in the DPRK: the Pyong-San mine, and the Woong-Gi mine, as described below (Private source, 2010).

Pyong-San Uranium Mine

This mine is located in Pyong-San–Gun, Hwang-Hae province and has been operating for 30 years under the control of the People’s Army Department. The deposit in this mine area was estimated at 1.5 million tonnes (as Uranium ore), and the mine’s annual production capacity is 10,000 tonnes (private source). The mine has own separator for concentration of ore. All products are sent to the Nyung-Byun (Yongbyon) Nuclear power station under armed guards. Recently, a new facility for Uranium extraction has been built in the Pyong-Won area.

Woong-gi Uranium Mine

This mine is located in Woong-gi, Ham-Kyung province and has been operating for 35 years under the control of the People’s Army Department. The deposit in this mine area was estimated at 10 million tonnes (as Uranium ore), and its annual production capacity is 19,000 tonnes (Private source). The mine has its own separator for concentration of ore. All products are sent to the Nyung-Byun Nuclear power station under armed guards (Private source, 2010). The mine’s operation has been kept secret from outsiders, and even from North Koreans, due to the fact that output from the mine is known to have been used for nuclear weapon development purposes. As a result, the workers and engineers in the mine have been reportedly restricted to the area within the mine facilities even if they suffered from nuclear radiation-related disease.

Educational Institute for Uranium Mines

In the fields of geological exploration and engineering , the Kim-Chaek Engineering University, the Chong Jing Mining and Metal University, and the Sariwon Geology University have been playing major roles in staffing exploration activities to find additional Uranium ore deposits. Nyung-Byun Physics University and Lee-Gwa University have been playing major roles in the

[256] Monazite is a name for a group of rare earth phosphate minerals, the most common form of which (Monazite-(Ce)) contains Cerium, Lanthanum, Thorium, Neodymium, and Yttrium. Monazite is radioactive, and it seems likely to have been exported in this instance primarily as a source of Thorium, though that is just the authors’ conjecture. A description of Monazite can be found at Amethyst Galleries “THE MINERAL MONAZITE”, http://www.galleries.com/minerals/phosphat/monazite/monazite.htm.

areas of mining and ore separator operation within mines, as well as logistics, for security reasons.

Infrastructure and Facilities for the Mines

Unlike other mining industries in the DPRK, Uranium mines have been targets of heavy investment, and its high grade engineers and skilled workers receive preferential treatment in terms of food, salary and social status. Funds invested in the mines have been used for mining equipments and facilities,. In particular, instead of freight railway shipping of ore, sophisticated trucks, imported from Sweden and Japan, are operating to support production activities.

5.2.5. Non-metallic minerals

A number of key non-metallic minerals are present in the DPRK in significant quantities. Of primary importance is magnesite, for which principal mines are the Namgye mine (Ryanggang province Baegam county), the Danchun mine (South Hamgyung province Danchun city), the Daehung mine (South Hamgyung province Danchun city), the Ryongyang mine (South Hamgyung province Danchun city), and the Saengjang mine (Ryanggang province Unhung county)[195]. Estimates of Magnesite reserves range from the 3-4 billion tonnes cited in Table 5-1 to 6 billion tonnes[196]. North Korea's magnesite reserves are the world's largest. The Ryongyang mine is reported to have reserves of 4 billion tonnes of magnesite ore, and the Daehung mine has reserves of 2.3 billion tonnes; the two mines had estimated production capacity, as of the mid-1990s, of 1.0 and 0.8 million tonnes magnesite per year, respectively[257]. The Danchon Magnesia Clinker Factory is reported to have production capacity of about one million tonnes of magnesia clinker per year, if a combination of heavy oil and coal is used as fuel (output is lower with just coal)[197]. Crude magnesite output in the DPRK has been estimated by several sources at about one million tonnes annually. Magnesite is used to produce magnesia clinker, which is used in making refractory materials (materials to line high-temperature furnaces for the metals industry, for example).

The deposit in the Baekgumsan area is approximately 3.6 billion tonnes and is 7,660 meters length and 7 to 100 meters in depth, and is the site of a major strip mine. North Korean production of Magnesite as of 2005 was estimated at 1 million tonnes of concentrated ore. The Ryong-Yang (Ryongyang) Mine is located in Don-san dong, Danchun city and is a subsidiary of the Dan-Chon Regional Mining Group. The Magnesite ore grade in the mine is 30% MgO, and an alternative the mine's capacity to produce Magnesium ore is reportedly 8 million tonnes per year, which after concentration of the ore (to 55-60% Mg) yields 3 million tonnes of concentrated product. Note that this estimate, from the E. Yoon 2011 study described earlier in this Chapter, appears somewhat at odds with the capacity described above for this mine. Mining operations use two methods, terraced strip mining and underground mining. Heavy trucks operate from inside the mine to transfer points outside of the mine tunnels, and freight trains are

[257] Another source describes three major mines in South Hamgyung Province, one open-pit—with a capacity of 1.3 million tonnes/yr, and two underground, with combined capacity of 1.3 million tonnes/yr ("MAGNESIUM COMPOUNDS", by Deborah A. Kramer, U.S. GEOLOGICAL SURVEY MINERALS YEARBOOK—2003, pages 47.1 – 47.5, available as http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mgcommyb03.pdf). Professor Li Dunqiu describes the DPRK's reserves of magnesite as being 56 percent of the world's total (Nautilus Institute Policy Forum Online 06-70A: August 23rd, 2006, DPRK's Reform and Sino-DPRK Economic Cooperation, available as http://nautilus.org/napsnet/napsnet-policy-forum/dprks-reform-and-sino-dprk-economic-cooperation/).

used as the major carrier to move ore from the mine area. Double railways were built early in the 1990s as infrastructure for this mine. Freight railways operating from the seaside (Dun-chon City) to the mining sites are, however, on steep slopes, and alternative freight methods need to be considered to serve the mine.

A major ore separator was built within the mine in 1988, and the reported capacity of the separator is 8 million tonnes of ore per year.

The Ryongyang mine is operating as a subsidiary of the Korea Magnesia Clinker Industry Group (KMCIG), and this parent company has three mines and three clinker manufacturers with 30,000 employees. In addition, the KMCIG operates four kilns for producing CCM (caustic calcined magnesia) and dead burned magnesia, and its capacity of production is 750,000 tonnes per year.

Choi provides the following information about the Dae-Hyeung (Daehung) Magnesite mine:

- Location : Hamkyungnam-do, Dancheon, DaeHyeung-dong
- History : Redevelopment in 1982
- Reserves : 820 million tonnes
- Ore Grade : MgO 46.77%, SiO_2 0.73%, CaO 0.79%, R_2O_3 0.67%
- Mining method : Open pit and underground (in the winter season)
- Mine production(capacity) : 600,000 t/yr
- 90% open pit, 10% underground.
- Mineral processing : Crushing and screening throughput (capacity): 600,000 t/a
- Production in 2006: About 360,000 tonnes of concentrate at a grade of MgO 46.77%
- Infrastructure: Power station, 50MW, link to Hyeucheun hydroelectric power plant; Railroad, 98km from mine site to Kimcheck port; Kimcheck port, loading capacity about 800,000 tonnes per year.

Figure 5-4 presents photos of the Daehung mine.

Figure 5-4: Photos of Daehung Magnesite Mine[258]

The DPRK possesses significant reserves of graphite (6 million tonnes, as estimated by ROK sources), a form of carbon with a number of industrial uses. A 2006 report from KCNA describes the opening of the Jongchon Natural Graphite Mine, apparently as a joint venture with the ROK[198]. Other important minerals in the DRPK are limestone[259] (with reserves on the order of one hundred billion tonnes), kaolin (used in ceramics), barite, and talc.

5.3. Mining Infrastructure

Infrastructure in mine areas can be classified into 3 categories: 1) transportation facilities including trucks roads and railways, 2) power facilities for mining and related industrial operations, and 3) metal refining industries including refineries and iron manufacturers. Each of these is discussed below.

5.3.1. Transportation Facilities

Railway systems

Most mines are linked with freight railways. Railways are single lines in most areas in the DPRK, although double track railways have been built over the 97 km between Moo-San (iron mine area) and the Choing-Jin refining facilities. Open freight cars have been used for carrying

[258] Photos and information above from presentation by Choi Kyung Soo of the ROK-based North Korea Resources Institute, titled "The Mineral Resources of North Korea", prepared for the 2010 DPRK Energy and Minerals Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/05.-Choi.pptx.

[259] Limestone is the principal raw material for cement, and a building material in its own right.

iron ore and other ore materials. The DPRK's railway system is experiencing deterioration in its technology and operational system. Most locomotives are electric-powered, for example, and thus rely on consistent supplies of electricity. Most mining operations cease when sufficient supplies of electricity, typically generated by thermal power plants, are unavailable. Railroad tracks are mostly so old (built in the 1940s and partially replaced in the 1970s) that fatal accidents have occurred annually. The railway system and its operating conditions should be improved or replaced within 3 years if transporting of products from mines in large quantities is to be sustained. As a result of the generally poor condition of the road system, freight trains have become the major means of transportation for iron ore and coal. Most open cars of freight trains are 60 tonnes capacity for heavyweight cargoes, but some 30 tonnes cars are also used as coal carriers.

Road Transport Systems

With regard to facilities for truck transport of mine products, the North Korean roads system identifies roads linking provinces as 1st Class roads. Second Class roads link counties within a province, and 3rd Class road link towns within a county. Most roads covered in this paper fall into the 2nd or 3rd road Classes. Ore products are sent typically via railway facilities, as previously noted, but some products are not sent via freight trains due to safety or security concerns. Gold and other rare metal ores are therefore carried using heavy trucks, made in the DPRK or imported from Russia, Sweden, and more rarely, China. Thus 2nd, 3rd Class roads should be considered as important infrastructure serving mines. In fact, however, although1st Class roads have been paved with asphalt since the1990s, 2nd Class roads are not paved with asphalt due to a shortage of asphalt, which must typically be imported from China or Russia. Most 3rd Class roads also are not paved with asphalt, so that operation of trucks on those roads entails higher costs for repair, tires and fuel. For instance, trucks operating on unpaved roads have more than 20% higher maintenance, fuel, and tires expenses, according to a DPRK research centre. In recent years, due to a lack of dollars for operation of heavy truck (for tires and oil and truck components/parts), heavy trucks are experiencing inappropriate operation (ibid). On the other hand, China and Russia are keen to participate in road construction projects in the DPRK For example, Russian authorities indicated a wish to participate in a DPRK railway development and improvement construction business, and were willing to invest 200 million dollars, according to an article in the Vladivostok News, 17th July, 2008.

5.3.2. Power Facilities

Major Thermal Power Plants

The connection between power plants and the minerals and coal mining industries is crucial for mining operations in the DPRK. All industries rely on power plants that were built in major cities or major industrial areas. More than 60% of the DPRK's electricity needs for the mining and minerals industries in recent years have been supplied by five major thermal power plants fueled with coal and heavy oil. These are the Chong-Jin and Dan-chon thermal power plants (Ham-Kyung province), the Buk(or Book, or Puk)-Chang and Ham-huong thermal power plants, the Pyong-Yang thermal power plant, the Chong-Cheon Gang thermal power plant, and the Nam-po thermoelectric power plant (Pyong-An province). For example, Chong-Jin power plant supplies electricity to the Moo-San mine and the Kim-Chaek Iron manufacturer group, and the Buk-Chang power plant supplies electricity to the Pyong-An coalfields and to major Pyong-An metals refineries. The annual electricity production capacities of each power plant are sufficient to supply its client companies, but the power plants often fail to produce enough power due to a shortage of coal and heavy oil

5.3.3. Metals/Minerals Refining Facilities

Moon-Pyong Metals/Minerals Refinery

Most of the DPRK's Zinc and Lead ore is smelted at Moon-Pyong Smelting Factory, which is located in Moon-Chon City, Kang-Won province. The annual production capacity of this Smelter is: Pb: 35,000 tonnes, Zinc:110,000 tonnes, Gold: 600 kg, Silver: 40 tonnes, Tin: 115 tonnes, Antimony: 100 tonnes, Cadmium: 450 tonnes, Sulfuric Acid: 240,000 tonnes, and Superphosphate of Lime: 200,000 tonnes.

Nam-Po Metals/Minerals Refinery

The Nam-Po (Nampo) refinery is one of the major gold refineries in the DPRK, but the use of the refinery facilities fpr Gold production is hidden from the public. The capacity of the refinery is Gold, 2 tonnes annually, and Silver 15 tonnes per year. The Refinery at Nam-Po is also quite old, having been built in the 1940s and modified in the 1970s, thus, its infrastructure and production systems are not only inefficient, they are also not environmentally friendly (Kim, 2007, and Private source, 2010). The area where the facilites are located (Nam-po City) is polluted by heavy metal wastes from the refinery, and an unknown number of patients have reported health problems, in particular dental problem and skin diseases.

As one of the largest smelters in the DPRK, the Nam-Po Refinery Group also produce Non-ferrous metal products. The annual production capacity is: electrolytic copper: 414,000 tonnes (99.97%), electronic Zinc: 45,000 tonnes, Tin: 200 tonnes, Gold :500 kg, Copper cable: 10,000 tonnes, Copper cable: 10,000 tonnes, Superphosphate of Lime: 200,000 tonnes.

In order to operate its electric furnaces, the power requierments of this refinery are supplied by the Buk-Chang and Pyong-Yang thermal Power plants, for which the refinery is a major consumer

Heong-Nam Refinery:

This refinery is located in near Ham-Heong City and produces copper, gold, and rare earth materials using mineral ores supplied from the Hye-San and Dan-chon mines.

Hae-Joo Refinery

This is plant us located in Hae-Joo. Its main products are gold, copper, tungsten, and rare earth materials using ore mined in Hwang-Hea province. These facilities have the potential to be used to extract gold and copper for export via Hae-Joo port as a part of a foreign investment.in the DPRK mining sector.

The 7.27 Gold Refinery

A third major gold ore refinery in North Korea is the 7.27 Refinery (Heong-Nam 2 refinery). The 7.27 Refinery is located in Ham-Heong city, and was established in 1983 as a subsidiary of the People's Army Department. Its annual production capacities are gold, 1 ton, and silver 10 tonnes, respectively.

5.3.4. Mining Machinery Manufacturers

Another key category of infrastructure related to the DPRK mining industry is the supply chain for equipment used in mining. Table 5-5 provides information about manufacturers of key mining machinery, and Table 5-6 lists key manufacturers of equipment specific to coal mining and transport.

Table 5-5: Major Mining Machinery Manufacturers in the DPRK

Name	Size	Products	Notes
Nack-Won Machine Manufacturer	Site: 93,000 m^2 employees: 4,500 1st class firm	Oil pressure (hydraulic) excavators	Specialized in Excavator production
Koo-Sung Mining Machinery Manufacturer	Site: 27,000 m^2: employees: 5,000	Drillers, lorries, crushers, pumps	Built in 1957
Dan-chon Mining Machinery manufacturer	Site: 10,000 m^2 employees: 2,000	Lorries, crushers, polishers, pumps	Also called the 4.28 factory
Sariwon Mining Machinery Manufacturer	Site: 43,000 m^2 employees: 2,500	pumps, conveyors, belts, compressors, winches	
Shin-Ui Joo Mining Machinery Manufacturer	Employees: 1,500	High-speed excavators, rock drillers	Also called the 8.9 factory

Table 5-6: Coal Mining Machinery Manufacturers in the DPRK[260]

Province	Name of Manufacturer	Products	Size
Ham-Gyung Buk province	Hei-Ryong Coal mining Machinery Manufacturer	Coal carrier car production, iron supports, compressors, cranes, machinery parts, crushers, comprehensive drillers	29,000 m^2 2,500 employees 1st class company
Ham-Buk Province	Na-Nam Coal-mining machinery Manufacturer	Various coal mining drills, carrier cars, cranes, safety equipment production	1st class enterprise (3,000 employees)
Pyong-Yang City	Pyong-Yang coal mining machinery manufacturer	Supports, hydraulic machinery, hydraulic coal mining machines, pumps, conveyors, rock drills	1st class company 64,000 m^2 35,000 employees
Pyong-An province	Duck-Chon Coal mining machinery Manufacturer	Coal lorries, coal drills, pressure horse winches, belts, reduction gears	1st class firm 50,000 m^2 4,000 employees
Hwang-Hea province	Jae-Ryong coal mining machinery manufacturer	coal lorries, coal drills, pressure hoses winches, belts, reduction gears, air chargers, mine buses	2nd class firm, 1,600 employees, 31,000 m^2

5.3.5. Major Ports and Related Facilities

Key to the export of minerals and mineral products from the DPRK are the port facilities available to handle these materials. Brief summaries of the specifications of the major North Korean ports used to handle minerals and mining products are provided below.

Na-Jin Port:

Na-Jin port is located in the Na-Jin Sun-bong (also known as Rajin-Sonbong) Free Trade area. The port is specialized in importing and exporting bulk oil and mineral ores. Approximately

[260] Original Source: DPRK's Industries, Korea Industry Bank (ROK), 2002 ,

100,000-ton capacity cargo ships can be handled at this port. The port was modernized in 1998 with support from Chinese and Russian enterprises. According to the China News (KBC, Gaung-Zhou, China), KOTRA Report, 2008, the Jangil development district plan has been approved by the Jillin province (China) authorities for development of this port to expand Jilin province's exports to Japan and the USA. Also China is planning to invest more than 10 million dollars to expand a 54 km highway to link Hoon-Choon and Na-Jin city, and will also support construction to expand Na-Jin port to build the port's third and fourth docking areas .

Chong-Jin Eastern & Western Port:

The Chong-Jin Port is one of the 3 major ports in the DPRK and is located in Chon-Jin, Shin-am district and Po-hang district. The port is important for iron ore and iron-related products exports. Approximately.three 100,000-ton cargo ships can be handled by this port at the same time. The port was modernized in 1984 with support by Russian enterprises[261].

Heong-Nam Port

This port is a major port and is located in Ham-Huong City. Mineral products produced in the Hur-Chon and Ham-Nam region are expored via this port. The port is well modernized in 1992. Loading facilities such as dock cranes and warehouses are well prepared for use.

Dan-chon Port

This port is located in Dan-Chon city, and is used for exporting Magnesite ore and Zinc ore to overseas and domestic locations. Its capacity to load goods is 300.000 tonnes/month, expressed as the capacity of the ships that this port can handle.

Nam-Po (Nampo) Port

This port is the largest of the three major ports in the DPRK, and is located in Nam-Po City. The port plays the role of exporting mineral ores and coal produced from Pyong-an coalfields, as well as metallic materials refined in the Nam-Po refinery, to China and South Korea.

Hae-Joo Port

This port is located in Hae-joo, Hwang-Hae province. The port plays a significant role in exporting iron ore and steel produced at the Hwang-Hea Iron manufacturer and the Eun-Ryul and Jae-Ryong Iron mines. Its loading facilities were modernized in 1999 with imported dock cranes from Russia and Japan.

[261] Original sources for information on DPRK ports include Kwon, Hyuk-Soo, Current Situation of DPRK's Coal Mining Sector Korea Resource Institute, 2000, as well as private sources contacted by E. Yoon.

5.4. Policies, Organizations and Human Resources Involved in the DPRK Minerals Sector

Brief summaries are provided below for North Korean mining industry policies and mining-related organizations, as well as the organizations in charge of minerals exploitation in the DPRK, development of technology related to geological exploration, and the educational system for mining and minerals-related occupations.

5.4.1. North Korean Mining Industry Policy and Related Organizations

Mining Policy

The mining industry has been a top priority industry for the DPRK government since the 1970s, exceeding other industries in importance because of its key role in providing sufficient materials and energy sources for the DPRK. For successful development of the mining industry, the DPRK has established three major policies: first, strengthening geological exploration to promote new coal and minerals mine development; second, promoting technological development in the excavating of underground tunnels and in ore collection procedures; and finally, scientific research in digging equipment and exploration. Another major principle in the DPRK mining industry is the self-supporting and self-sufficiency policy. This policy has been interpreted such that most mineral resources produced domestically are to be used for domestic purposes. As a result, the domestic supply rate for minerals resources in the DPRK is very high compared to the DPRK's historical imports of mineral resources. For example, North Korea is 100% self-sufficient in iron ore, pig iron, partially-finished steel products, copper, cement and graphite.

In spite of this self-sufficiency policy, North Korean authorities have since the 1990s been pursuing opportunities for minerals exports to earn hard currency, according to KORTRA (ROK) data. In fact, resource development in DPRK has also been closely related to the needs of North Korea's munitions industry; for example, copper, uranium and iron mines exploitation have been developed substantially to meet military equipment and weaopns needs.

Natural Resource Law in the DPRK

According to this law (Section, 21 of DPRK Published Laws, 2003), the North Korean cabinet is in charge of the exploration, exploitation, and use of minerals, with several organs of consultation involved in the approval of exploration, development and standards for minerals deposit estimation by geologic exploration institutions. Section 40 of the law indicates that an organization or individual company should acquire a permit from a government body when the organiations plans to export precious metals or iron ore overseas, and section 51 indicates that in case of any breach in the law, the company or organization should be punished. Section 46 indicates that any skilled labor or engineer, equipment, materials, or funds related to the mineral exploration industry may not be used for other industrial purposes. In particular, section 17 emphasizes that any existing mine or coal mine cannot be closed (abandoned mine issue) without permission from the government consulting body.

Mining Industry-related Organizations

The DPRK mining industry is essentially under the control of the Labor Party and the Cabinet at the same time, but the Party's power dominates the Cabinet's role in the DPRK. As part of the Geological Exploration Institute system, the DPRK established in 1995 the Central Mineral Resource Institute in Pyong-Sung, which is a scientific city and part of the Pyong-Yang capital city. This Central Institute controls all geological organizations and institutes of the DPRK, including the Ham-Huong and Pyong-Yang Exploration Institutes[262].

DPRK commercial organizations involved in trading and development of mineral resources include the Cho-sun General Mining Trading group, the Chosun Magnesite Clinker trading group, the Myong-Ji group, the Dae-Sung Trading Company, the Chosun Baek-Gumsan Trading Company, and the Chosun Maebong-san Trading Company, as well as others. These organizations are described briefly below.

- Cho-sun General Mining Trading Group

The company is located in Joong District, Pyong-Yang City. Its primary business is to trade nonmetallic minerals. It has 10 subsidiaries in 10 major cities throughout the DRPK, and two branch offices. Zinc, copper-related products, and silver are the major export items handled by the company, in addition to nonmetallic refinery-related equipment and facilities, tin, antimony, aluminum cable and bar, coated wire, and other products.

- Magnesite Clinker Trading Enterprise

Major trading items of this company are magnesite clinker, magnesite ore, magnesite brick and diatomite for export. The company also imports coking coal, chrome steel, mining equipment and machinery.

- Myong-Ji Corporation

This company was called Samchonri Group, but changed its name. Zinc and heating coils are its major export items.

- Cho-Sun DaiJin Trading Company

This company is located in Pyong-Yang and is controlled by the 39 Room (Department) of the Labor Party. Its focus is on trading to obtain hard currency, and it specializes in exporting coal and mineral ore overseas and in importing commodities and electric goods from Hong-Kong, Macau and China for Kim Jong Il's family and others.

- Other Companies

The Chosun-Daesung Group, the Chosun DongHeong Trading Company, the Chosun Baekgumsan Trading Company, and the Chosun Maebong Company are major and exporters raw mineral resources to overseas buyers, and importers of machinery and equipment from overseas[263].

[262] Based on reports from Chosun News, 26 January, 2002, and other sources reviewed by E. Yoon.
[263] Original source cited by E. Yoon, Lee, Hea-Jung Development of Mineral Resources of DPRK, Hyun-Dai [Hyundai] Economic Research Institute, 2008.

5.4.2. Mineral Resource Exploitation System

In cases of independent development of mineral resources, the National Underground Resource Development Committee is in charge of providing permission for mining activities through the Ministry of Gathering Industry and the Ministry of Electricity & Coal Industry. Once permission is granted, an individual mine or company would be able to commence the development process. In this step, foreign investors could be involved in the process by contracting with an individual mine or company. In other words, once overseas investors invest by purchasing facilities and equipment for mining, the investors can bring out of the country a contracted amount of produced ore or refined products, which they can offer for sale.

With regard to mining operations and development, skilled workers and engineers are responsible for management and engineering affairs in mines and minerals-related companies, and military service men and skilled workers are responsible for the required labor. The mineral ores produced would be sold by the independent mining company to overseas buyers for dollars, or to domestic clients.

5.4.3. The DPRK's Geological Technology Development

For minerals exploration, geological technologies have been developed in the DPRK since the 1990s. There are two major issues related to geological exploration. The first is geological technology, and the second is earth physics exploration technology. According to a technical and geological magazine published in the DPRK, there are 10 major technology development issues: (1), new explorathon methods to look deep into the earth's crust, (2), computer controlled drilling under GPS (global positioning system) guidance, (3), development of new earth physical exploration methods for depths up on 2,500 meters, such as 3dimensional elastic wave exploration, (4), satellite-controlled exploration methods development (for coal, gold, geothermal heat, natural gas, and underground water, for example), (5), far-infrared radiation controlled exploration, (6), bio-earth physics exploration, (7), electrical exploration development, (8), tomography technology for finding coal and colored metals (such as gold or copper), and (9), advanced chemical exploration methods development. These technologies are related to Earth Physics exploration methods.

5.4.4. An Analysis of the Educational System for Mining-related Occupations

The DPRK maintains a three-level higher-educational system for mining-related occupations. The first level is central government-controlled universities, the second level is local government-controlled colleges, and the third level is enterprise- or company group-controlled colleges used as occupational skill schools. The Mining and Metals and Nonmetallic engineering-related educational system in North Korea has been well established for development of the industries in comparison with the treatment of these discriplines in the South Korean and Chinese educational systems—for example, there is only one Earth Physics Exploration course in South Korean Universities.

University Curricula

With regard to the curricula and quality of education in fields related to mining and minerals, the technology and equipment used in the Universities are mostly from Russia or China, and more rarely from Japan. In the author's (E. Yoon's) view, the quality of education on these topics in the DPRK is competitive with that offered South Korean students**,** but needs additional support to reach USA or European standards. The situation in each of the three levels of education in mining-related topics is described below.

Universities Controlled by the Central Government

There are five major Universities with courses in the mining and metals, geological exploration, and Earth physics exploration: Kim Il Sung University, Kim-Chaek Engineering University, Chong-Jin Mine and Metal University, Pyong-Sung Coal mining engineering University and Sari-won Geology University.

- **Kim-ll-Sung University** is located in Pyong-Yang. It has 12,000 students, including 600 students in the geology exploration course. The university has three courses, Geology Exploration, Earth Physics Exploration and Earth Chemical Exploration. In order to graduate from the university, students must attend five years of courses including at least one year spent doing a practicum in their field . Students in these courses learn English and Russian (most students learn English since about 2000). Graduates of this university are dispatched by the University to geology-related exploration companies and research institutes throughout the DPRK. The graduates have no opportunity try to find jobs that they favor as individuals, rather they are obliged to follow the orders of authorities because their university have studieswere supported by the government, which paid for their school fees and dormitory costs, including clothes and food. The graduates are classified into three categories: those destined to work as Labor Party officials, those who will work as government cabinet officials (in Ministries, for example), and those who will work as exploration company experts or in research institutes. The classification of the graduates is done by the Education Department of the Central Labor Party. Graduates are granted Bachelor degrees in their mining or minerals course and become official experts of their industry. For example. If a student graduates from the Geology Engineering course in this university, she/he will be entitled as a Geology Expert with a Bachelor's degree of Geology Exploration.
- **Kim-Chaek University** is located in Pyong-Yang. It has 10,000 students including 1,800 students of Geology Exploration, Mining Engineering, Metal and Nonmetallic Engineering courses. The university has six related courses, Geology Exploration, Earth Physics Exploration, Earth Chemical Exploration, Metal and Nonmetallic Engineering and Colored Metal Engineering, Refinery Engineering and Iron engineering, and Material Analytics courses. In order to graduate from the university, students must attend a five-year course including one year at least for practicum. Students at Kim-Chaek also learn English and Russian, with English the language of choice since about 2000. Graduates of this university are dispatched to geology related exploration companies and research institutes, mines, Iron manufacturing companies, and refineries throughout the DPRK. The graduates are classified into three categories by Central Labor Party officials as

described above. If a student graduates from the mining engineering course in this university, she/he will be entitled as a mining engineer with a Bachelor's degree in Mining Engineering.

- **The Chong-Jing Mines and Metals University** is located in Chong-Jin, Ham-gyung province. This university was established in 1959 to support the Moo-san mine, the Kim-Chaek iron manufacturing group, and other coal mines with personnel trained in engineering, management, and exploration work. This university has 6,000 students. There are 20 courses related to mining, iron making and management of refinery companies. A selection of these are as follows. The geological exploration courses are the Underground Water Exploration Course, the Drilling Engineering Course, and the Earth Physics Exploration Course. In Geology Engineering School, mining-related courses are:Mining Engineering, Coal Mining Engineering, the Mine Management Course, and the Mining Analytics Course. With regard to mining mechanical equipment course, there are two courses: Mining Mechanic Engineering, and Coal Mechanic Engineering. In order to graduate from the university, students must fulfill the same requirements listed for the universities above, and are similarly dispatched to geology-related exploration companies and research institutes, mines, iron manufacturing companies and metals refineries throughout the DPRK by decisions made by the Education Department of the Central Labor Party.

- **Sariwon Geology University** is located in Sariwon (Hwang Hae province) to support minerals and coal mining in the province. The University has five exploration courses including Earth Chemical Exploration, Earth Physics Exploration, Drilling, Underwater Exploration, and Analytics. Graduates become geology engineers and are sent to exploration companies and to be university teachers for colleges. Other situations are similar with the universities described above. This university has 3,000 students.

- **Pyong-Sung Coal Mining University** is located in Pyong-Sung city and supports coal mining engineering in Pyongan and Hwang-hae provinces. The University offers 10 major coal mining-related courses, including: Coal Mining Engineering, Coal Exploration, Coal Mining Mechanics and Analytics, and Management courses. Most graduates are dispatched to coal mining and exploration companies as engineers. Other conditions for graduation from theUniversity are similar to those of Chong-Jin Mines and Metals University. This university has 4,000 students.

<u>Colleges Controlled by Local Governments</u>

Each province has a mining engineering college and a exploration engineering college. College students take 3-year courses in their majors. All financial support for school fees, dormitory costs, food, and clothes are provided by the government. Graduating students are dispatched to local mines, coal mines, and exploration companies as junior engineers. Students must finish a university course of two years or more, following their training at the provincial level, if they wish to be engineers in their industry. The dispatching of graduates to their positions is carried out by the local government department for human resources. Each college has 700-800 students in every province. For example, the Dan-chon Exploration College has 800 students and has three courses: Geologic Exploration, Drilling, and Underground Water

Exploration. After graduation from this college, graduates are granted positions as junior engineers and are dispatched to exploration companies in Ham-gyung province. Their wages are typically 70-80% of those of engineers graduating from universities.

Colleges Controlled by Enterprise Groups

The college system controlled by enterprise groups is built upon an educational scheme first established during the 1970s. Large enterprise groups such as the Kim-Chaek Iron manufacturing group or the Moo-san mining group operate colleges called "Factory Colleges". College students study after work from 7 pm to 9 pm twice or three times per week in these colleges to obtain more advanced skills and knowledge. Education in these colleges provides good opportunities for promotion or professional development within the company or organization, but the courses taken in these colleges are not recognized by other companies or organizations. These college's curicula are different than those of other universities and colleges, but are worthwhile students in that they provide applicable work skills for their jobs. For example, if a worker in mining company studies in a factory college, she/he would be granted an increase in job level from 3 to 4, and the nextyear, would receive an increase from level 4 to 5, accompanied by a promotion and an increase in wages. It is estimated that there are 100 "factory colleges" throughout the DPRK, with an estimated current enrollment of more than 100,000 students.

5.5. Conclusions and Strategies for Overseas Investors

5.5.1. The Most Fruitful Areas for Foreign Investment in the DPRK Minerals Sectors

The most fruitful areas for foreign investment in the DPRK minerals sector are as described below.

(1) The iron mines in the Moo-San and Eun-Ryul areas have great potential to produce significant benefits for overseas investors due to the fact that the DPRK's biggest iron manufacturers, the Kim-Chaek and Hwang-Hae corporations, could be used to process iron from those mines, and the steel and pig iron products could be exported to provide return on investment with low costs for transportation.

(2) Gold and copper mines could be beneficial investment projects offering low transportation expenses. In recent years, as described above, DPRK authorities have proposed that overseas funds be provided to invest in Gold mines and Copper mines. In fact, newly explored and developed mines such as the Sang-Nong, Gap-San and Shin-pa copper mines may be great opportunities for overseas investors[199].

(3) Another possible mine for investment is the Dan-Chon Magnesite mine, which could be developed to export product to China and the USA. In this case, it should be possible to cooperate with the authorities for a "win-win" strategic investment. According to private sources (Chinese source, 2010), a DPRK company has made a deal with a Chinese trading company for the export of Caustic calcined Magnesia (MgO 90%, CaO 2.5%, SiO_2 2.5%, Fe_2O 1.05 %, LOI

3.5%, Size; 200 mesh 95%). In this deal, the selling price of the material FOB Heong-Nam port was US$ 88.0 per metric tonne.

(4) Mining of limestone ore is another possible application of overseas investments, coupled with construction of cement factories in the DPRK and export of cement product to China and S. Korea. In addition, with investments in the cement industry, overseas funds could be involved in SOC (State-owned Corporations) in the DPRK, as well as North Korean calcium fertilizer industries, which can provide products key to helping DPRK agriculture to be more productive.

(5) The coal mining industry could be an alternative investment for foreign investors, as the DPRK needs to increase production of coal as a required energy source to drive the country's economic engine. In this industry, exploration and development of new coal mines would bring significant benefits to overseas investors.

(6) Investing in zinc ore mines such as the Gum-dok, Hye-san and Ruck-Yon mines has potential for investors due to the fact that the DPRK has sufficient existing capacity to refine the zinc ore, and thus zinc metal could be exported, providing a good return to investors.

(7) Tungsten mines could be alternative destination for investment due to the high price tungsten fetches in the international market, its low transportation expenses, and huge deposits of tungsten ore exist at the Man-Nyun mine, which is currently being further developed and expanded.

(8) New exploitation of deposits of rare-earth elements such as titanium, indium, and cerium are another area in which the DPRK's natural resources could be developed. Rare–earth element production has in recent years been dominated by Chinese mines, which have accounted for 30% of global deposits, but 97% of global production (Cho-sun news, 22th Oct. 2010). North Korea is known to have reserves of these materials in the Gyung-Sung and Hur-Chon areas. In particular, the Saen-gi-ryong area in Kyung-sung country is not only abundant in Kaolin, the raw material for ceramics, but also has some Indium and Cerium elements in abundant wastes rocks from Kaolinte mining process (Private source, 2010). Due to the DPRK's competitive labor costs relative to costs of Chinese labor, development of DPRK rare-earth resources for export would yield significant benefits (ibid).

5.5.2. Obstacles to Effective Minerals Sector Development through Foreign Investment, and Solutions to Overcome Obstacles

Key obstacles to effective minerals development in the DPRK with funds from overseas investors include 1) the shortage or lack of adequate and consistent constant supplies of oil and coal as energy in DPRK; 2) the fact that the DPRK lags behind other nations in technologies and operational methods for minerals (due to reliance on old methods), as well as in the use of modern equipment in mining and other minerals sector operational activities; and 3) a shortage of funds for education of engineers and for investment in technologies.

Key solutions to the obstacles above are as follows: 1), stabilizing coal mining operations to supply adequate coal for power plants; 2) attract overseas funds for investment in modernization of mining equipment and related technologies; and 3) balancing in mining business management between production and exporting operations.

5.5.3. Infrastructure Investments for Stable Operation of Mining Industries

With the above obstacles and solutions in mind, key infrastructure investments to allow stable operation of mining industries in the DPRK will be:

- Thermal power plants should be stabilized in order to provide reliable sources of power for mining and minerals refining facilities, thus investments in the DPRK's coal mining industry should be carried out as soon as possible as a short-term solution.
- Modernizing minerals processing facilities such as metals refineries and iron manufacturers is necessary for the DPRK to be able to export secondary goods derived from mineral resources, steel, or refined metals at higher prices (relative to raw ores) so that the DPRK can increase its foreign exchange earnings.
- In the longer term, a self-supporting accounting system for the management of mining and minerals refinery industries should be applied and implemented (adopted) in the DPRK. Capacity-building will be needed to train DPRK workers and officials in management techniques consistent with operating self-supporting businesses.

5.5.4. Feasible Strategies for Overseas Investors

Cooperating with South Korean firms would be beneficial for overseas investors in order to assist in enhancing the security of investments in the DPRK minerals sector, and to build relationships with future consumers of mineral products. South Korean firms investment in the mining industry in the DPRK, and Chinese firm's experience in the DPRK in investment in mining trading and mineral resource development represent valuable experience that overseas investors can learn from (private source, 2010). South Korean firms are also likely to be willing buyers of minerals products from the DPRK.

Building sustainable relationships with DPRK authorities in mining departments and other officials is significant for hedging risks in the uncertain business environments that prevail in the DPRK. First, using the Korean-Chinese business network, for instance, by trading between the DPRK and China via Chinese-Korean community channel, would be beneficial. These Chinese live in the DPRK and have been playing major roles to in the trading business between the two countries since the 1980s. According to private sources, approximately 5,000 Chinese live in the DPRK (with Pyong-yang home to about 2,000, and Ham-Nam, Buk province, and Ryan-gan province homes to another 3,000). These Chinese have knowledge of outside news and skills for trading between the two countries, and could play major roles to promote international business for overseas investors. Second, contributing towards North Korea's social and humanitarian needs (for example, by providing free supplies of basic medicines, milk, childrens clothes, and food) is an alternative strategy to deal with those focused targets. In fact, DPRK authorities wish to build partner relationship in developing the country's mining sectors. As an example, during a visit by Tony Nam-Kung, an advisor to the governor of the US state of New Mexico, to Pyong-Yang, DPRK officials suggested foreign investment in DPRK mineral resource development be considered by the USA, in particular, in the Dan-Chon Magnesite mine for mine development and exporting of ore.

5.5.5. Alternative Strategies and Issues for Overseas Investors

Alternative strategies and special issues relating to investment by foreign companies in the DPRK's minerals sector are described below, incluidng possible funding approaches for development of the minerals sector, issues to consider when reviewing investment possibilities, approaches to making investments in the sector, and mining rights issues for foreign investors, A case study of an investment possibility in a Molybdenite mine concludes this section.

Establishing Special purpose Enterprises (SPEs) for Funding Development of the DPRK Mineral Sector

Due to the large amount of funds needed for investment in this sector, one approach for developing mining businesses would be to establish SPEs and then issue company debentures or bonds to attract large amounts of investment funding. In fact, individual and institutional investors would be interested in this business opportunity due to the fact that the DPRK's mineral sector could generate significant benefits (return on investment) if the US or South Korean government could provide assurance for those investments as, for example, the ROK government has been providing assistance and assurance to Korean companies investing in Kaesong and other joint ventures (Private source, 2010). According to the South Korean government policy for investing in the DPRK, funding for ventures could be subsidized by the South Korean government on the basis of its contrbution to North-South Korea economic cooperation. This means that more than 50% of investment funds could be provided in the form of government assistance. The USA and other governments can also provide such assistance for overseas mineral exploration businesses (Korean Central Bank report, 2008).

Factors to Be Considered When Evaluating Potential Investments

There are five major issues that should be considered when overseas investors are making decisions regarding investment in DPRK's mineral sector: (1) the attributes of the deposit of mineral resource with repespect to its possible development; (2) the quality and cost of available labor; (3) the availability and status of infrastructure needed for mining, such as power plants , railways, roads, and ports; (4) the status of environmental regulations; and (5) the political and economic stability of the country. In the case of the DPRK, in its current situation, (5), (1), and (3) should be improved to allow safe investment in the mineral sector. Based on the; experience of South Korean companies, DPRK authorities seem to have principally been considering three factors when overseas investors offer investment possibilities: (1) the scale of the investment, (2) whether the investment will result in the transfer of mining technologies to DPRK, and (3) whether the investmetn will support infrastructure development.

Possible Scenarios for Investment

Contracting for equipment supply in exchange for mineral products is an option that avoids the possible failure of large investments in the DPRK. Due to environmental concerns in developed nations that result in mine closures and a surplus of mining infrastructure, second-hand mining equipment and facilities could be assembled at low cost and exchanged for minerals resources in initial deals with the DPRK then, if the deals proceed as expected, small amounts of funds could be invested in DPRK mining operations in a step-by-step fashion.

In addition, investing in mines already operating and drawing on economic deposits of mineral resources reduces risk. Investing in new mine development requiring an initial exploitation step is a significantly more risky business when compared with investing in existing mines. Investing in existing mines would be an appropriate strategy to reduce the possibility of failure of investments in the DPRK. With regard to difficulties in the DPRK energy sector as they might affect the more than 20 mine development projects for overseas investors that have been identified by DPRK authorities (according to private sources and South Korean sources), energy supplies can be provided if investments in mining projects require energy supply upgrades.

The DPRK has been experiencing a lack of technology and equipment in the mining sector. Thus, overseas investors or companies could offer exploration systems and equipment and engineers as an in-kind investment in the DPRK minerals sector, and new minerals finds or production could be shared between the DPRK and the company providing the technology and expertise.

Mining Rights Issues for Foreign Investors

In cases of cooperation between foreign investors or overseas companies in development or exploitation of DPRK minerals resources, it is very rare that mining rights will be transferred to foreigners who invest in mining technology, equipment, and facilities such as dump trucks and drills. Rather, foreign companies would likely gain only the rights to sell the products produced by the mining operation.

There are a number of reasons why the DPRK has been reluctant to transfer its mining development rights to foreign companies and investors thus far: The first reason is political concern that the authority's power would be reduced in terms of its power/ability to mobilize workers, that is to control its people, therefore resulting in political risk. Second, the authorities believe that mineral resource development could be a significantly beneficial business in the future, and thus are reluctant to offer rights to outsiders. Third, the DPRK expects that it could make enormous profits in this industry if funds, facilities and mining engineering technologies one day become available, despite the current shortage and lack of those resources for mine development. This means that DPRK authorities have been overstating the potential profits from their mining development businesses, and are less willing, as a result, to part with mining rights.

Case Study of Investment in a Molybdenite Mine

According to the (DPRK) Pyong-Yang IP Centre, in a research paper (obtained from confidential sources) focused on estimating the potential economic benefits from expanding the Yon-San Molybdenite ore production and exporting venture, US$ 397,307 would need to be invested in equipment and an electricity generating plant, materials, labor costs, and freight costs in order to increase annual production capacity of the mine from 10,000 tonnes to 40,000 tonnes. The authors of the research paper estimated that the investment would have a six-month payback. The analysis, however, incorrectly estimated that the investment could produce 17.2

million dollars as profit within 5 years ($3.94 million per year). In fact, it should be considered that production capability per DPRK worker is unlikey to be higher than a South Korean worker's production capacity, given the South Korean workers will have generally superior tools and conditions to work with, but the per capita production capacity of Molybdenite ore by N. Korean workers was estimated to be higher than that of South Korean workers in the research paper. This appears to be an example of the overstatment of the potential economic benefits from mining businesses by DPRK authorities. This tendency to overstate potential benefits suggests that DPRK authorities would likely suspect, in reviewing estimates prepared using standard procedures and provided by Western companies, that foreign investors or companies are underestimating its mineral resources.

The DPRK lacks experience in attracting foreign investors to participate in its minerals sector development. This example shows that negotiations between foreign investors and DPRK authorities should be implemented carefully, and based on reasonable estimation procedures and international benchmarks in the industry, with supervision and participation by DPRK experts who have some experiences in the industry.

5.5.6. Establishing Sustainable Mining Practices

Prior to, or at the very least concurrent with, the expansion of foreign investment in the DPRK minerals sector, capacity-building on sustainable mining practices are needed to ensure that a rush to exploit the DPRK's mineral wealth does not results in significant adverse environmental and social impacts. Rather, investment and joint-ventures in the minerals sector should do everything possible to improve conditions for mine workers, and to amerliorate existing environmental problems associated with the DRRK minerals sectors. There is much to be learned by DPRK officials, mining company personnel, technicans, and engineers from both potential regional partners in minerals development and from experts in the broader international minerals arena, and any large-scale minerals sector development in the DPRK, particularly if it involves foreign partners, should include a component of capacity-building on sustainable mining practices, backed up by project organization and investments in equipment and monitoring practices designed to implement sustainable practices. Several presentations on the topic of sustainable mining practices from different nations and different points of view were provided at the 2010 DPRK Energy and Minerals Working Group Meeting organized by Nautilus Institute and convented September 21st and 22nd in Beijing, China[264]. The presentations from this Meeting are avaialble at http://nautilus.org/projects/by-name/dprk-energy/2010-meeting/papers/.

[264] Examples of relevant presentations from the 2010 Meeting include Peter Denura, "The Global Minerals Sector: Production Trends, Markets, and Lessons for the Future", Arabella Imhoff, "Key Issues and Best Practices for Minerals Sector Development: Overarching Themes", Ji-hyun Lee "Key Issues and Best Practices for Minerals Sector Development: ROK Case Study", Allen Clark, "Minerals, Economic Development, and Local Communities: Key Approaches and Case Studies from Asia", Natalia Lomakina, "A Case Study on Mineral Development in the Russian Far East: Best Practices for Sustainable Development", Odonchimeg Lundaa, "The Mongolian Minerals Sector, Future Plans, and Regional Cooperation", Ren Peng, "Development of Environmental Policy for PRC Investment in Mineral Sectors Abroad"', Hu Yuhong, "Key Issues and Best Practices for Sustainable Minerals Sector Development in China", and Chung Woo-jin and Park Jimin, "Experience and Goals of the ROK in Regional Mineral Sector Development Cooperation".

6. A Redevelopment “Pathway” for the DPRK Energy Sector, and Institutional Changes and Support Needed to Make it Happen

6.1. Introduction

Despite a few outward and sometimes intermittent 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 not drastically in error, 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 chapter examines these questions, and provides some ideas for initiatives that could assist the DPRK in building a sustainable energy sector.

6.2. The DPRK Under a Medium-Term "Redevelopment" Pathway

Below we describe, in a very qualitative way, what a medium-term "Redevelopment" 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 "Redevelopment" pathway implicitly assumes a major breakthrough in relations with the ROK, and probably with 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 "Redevelopment" 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. Some of these “collapse” scenarios—which the authors of this report stress that we feel are unlikely—are presented and discussed qualitatively in Chapter 7.

A “**Redevelopment**” 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 revive in earnest (for example, in 2013)—but note that the structure of the economy may well evolve along quite different patterns than those prevailing in 1990.
- 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[265].
- 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 be sufficiently rehabilitated to use within the DPRK even some of the power from nuclear reactors such as those that were being built by KEDO until 2002. There is at present no way to use 1000 MW-class reactors within the existing DPRK grid[266], so to use such a reactor interties to other countries must be constructed, and preferably, from a political and practical perspective, the DPRK grid would need to be totally rebuilt as well. Had the construction of the KEDO reactors at Sinpo continued, interconnection issues could have been both a huge problem that could have led to poor relations between the DPRK and the outside for years to come, or, if handled correctly, could have constituted a huge opportunity for building of economic links (and better relations) between the countries of the region. If construction of the LWRs at Sinpo is taken up again in the future, this technical consideration, and its various solutions and non-solutions, will remain. Given the unresolved nature of the various nuclear-related issues (nuclear weapons, uranium enrichment, the DPRK's stated aim to develop a domestic small light water reactor, and the lingering possibility of resuming work on the large Sinpo LWR units with ROK or international assistance), we have chosen to leave nuclear power out of the modeling of the Redevelopment path, and also out of the major variant paths described below. We have, however, also prepared preliminary "with nuclear" scenarios corresponding to the Redevelopment path and to each of its variants. In those paths, we assume the construction of large (1000 MW) reactors, with the bulk of the power from those reactors, at least initially, exported directly to the ROK through a direct tie-line to the larger, stable ROK grid.

6.2.1. Variants on the Redevelopment Path

In the context of collaborative research on regional energy security in Northeast Asia[267], Nautilus Institute has developed and evaluated alternative paths that provide the same energy services as the Redevelopment path described (in summary) above, but incorporate features of energy efficiency and renewable energy, as well as strengthened regional cooperation in the energy area. The two alternative paths evaluated are:

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[265] Depending on the nature of the diplomatic breakthrough, the degree to which it is embraced by the DPRK leadership, and the economic opportunities it offers to North Korean citizens, it is entirely possible that the DPRK armed forces may be partially demobilized, resulting in lower military energy use. Partial mobilization seemed to be under discussion in the DPRK as of about 2002.

[266] 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.

[267] In the Asian Energy Security project, and the related and follow-on East Asia Science and Security project, collaborating groups of researchers from each of the countries of Northeast Asia work together to research the energy security implications of different energy policy choices, both within their countries and regionally. See, for example, "East Asia Science and Security Meeting 2010", at http://nautilus.org/projects/by-name/science-security/workshops/2010-east-asia-science-and-security-meeting/.

- <u>The "Sustainable Development" Path</u>. This path provides the same energy services as "Redevelopment" Path—with, for example, the same demographic assumptions, and the same levels of economic output—but applies energy efficiency, renewable energy, and other measures, in an aggressive fashion, including upgrading of industrial infrastructure to levels above average standards to high-efficiency international standards, a rapid phase-out of existing coal-fired power plants, and earlier addition of LNG (liquefied natural gas) terminal and gas CC (combined cycle) generating plants.
- <u>The "Regional Alternative" Path</u>. This path resembles the Sustainable Development path, but as a result of regional cooperation, efficiency improvement targets are reached two years earlier than in Sustainable Development path, and at costs that are 10 percent lower. In the fuel supply sector, a gas pipeline from the Russian Far East to the DPRK and the ROK begins operation in 2011, with 3 percent through the gas provided by the pipeline used in DPRK initially, 10 percent by 2020, and 15 percent by 2030. The DPRK receives $10 million per year as "rent" for hosting the pipeline. Also, a larger LNG facility is installed than in the Redevelopment or Sustainable Development paths—and is again shared with the ROK. A power line from the Russian Far East through the DPRK to the ROK is also installed. Cooperation in renewable energy technologies yields earlier deployment of those technologies, and a 10 percent reduction in cost of wind and small hydro technologies relative to the redevelopment path. In the Regional Alternative Path, the last of the DPRK's existing coal-fired plants are retired by 2020.

Some initial results of the evaluation of these three paths are provided below. Note that these results been only partially updated to reflect the updates to the 1990 through 2009 energy balances described in Chapters 2 and 3 of this report, so the results shown here should be considered provisional.

Figure 6-1 shows final demand by fuel for the Redevelopment Path. Trends here of note after 2010 include the decrease in the use of biomass fuels, the increase in the use of electricity, and the introduction of natural gas after about 2015.

Figure 6-1:

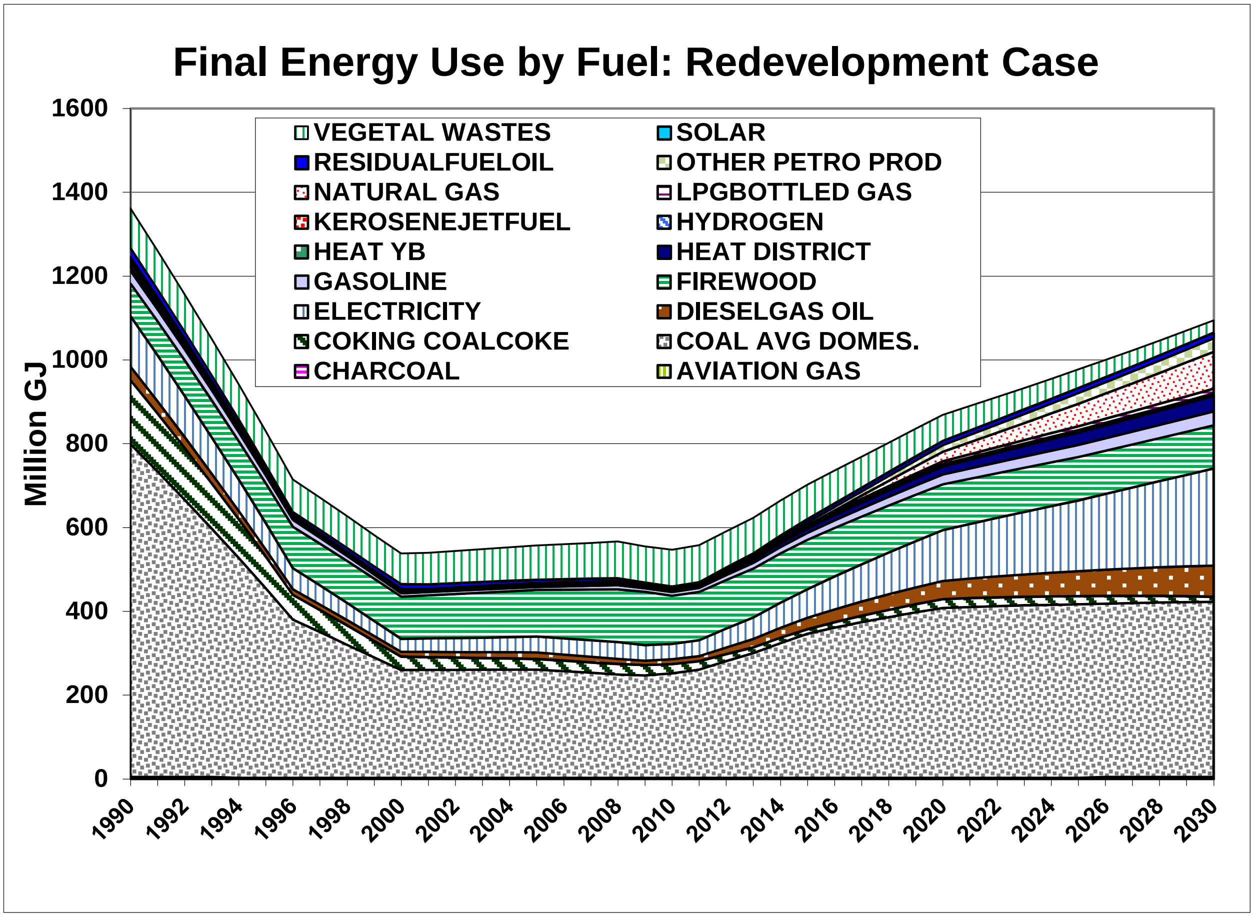


Figure 6-2 compares electricity use over time in the three paths evaluated, as well as in a "Recent Trends" path where a solution to the current impasse over the DPRK's nuclear program is not found, and large-scale economic redevelopment in the DPRK does not occur. Note that as a result of the aggressive implementation of energy efficiency measures, the consumption of electricity (and thus the need for power generation facilities) is much less, by 2030, in the Sustainable Development and Regional Alternative paths, relative to the Redevelopment Path. The reduced need for generation capacity is underlined by the difference between Figures 6-3 (showing the Redevelopment Path) and 6-4 (showing the Sustainable Development Path), where even with the incorporation of more low-capacity-factor renewable power sources, the overall generation capacity in 2030 in the latter path is nearly 4000 MW less in the Sustainable Development Path.

Figure 6-2:

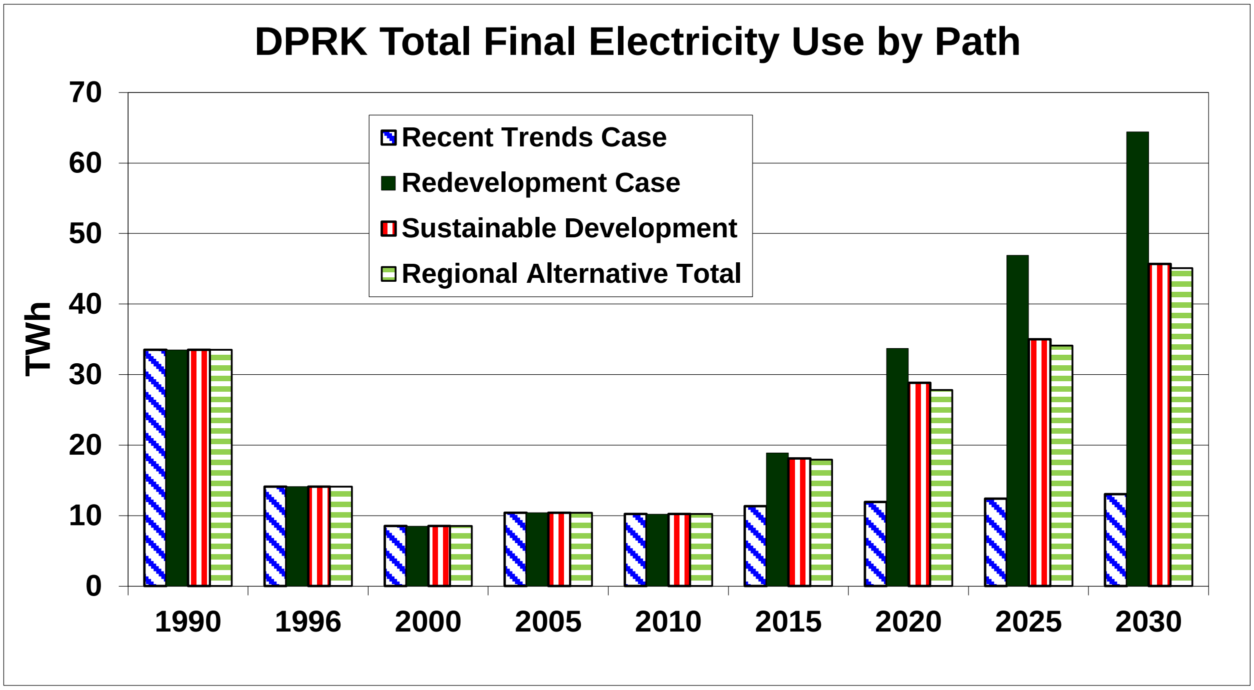


Figure 6-3:

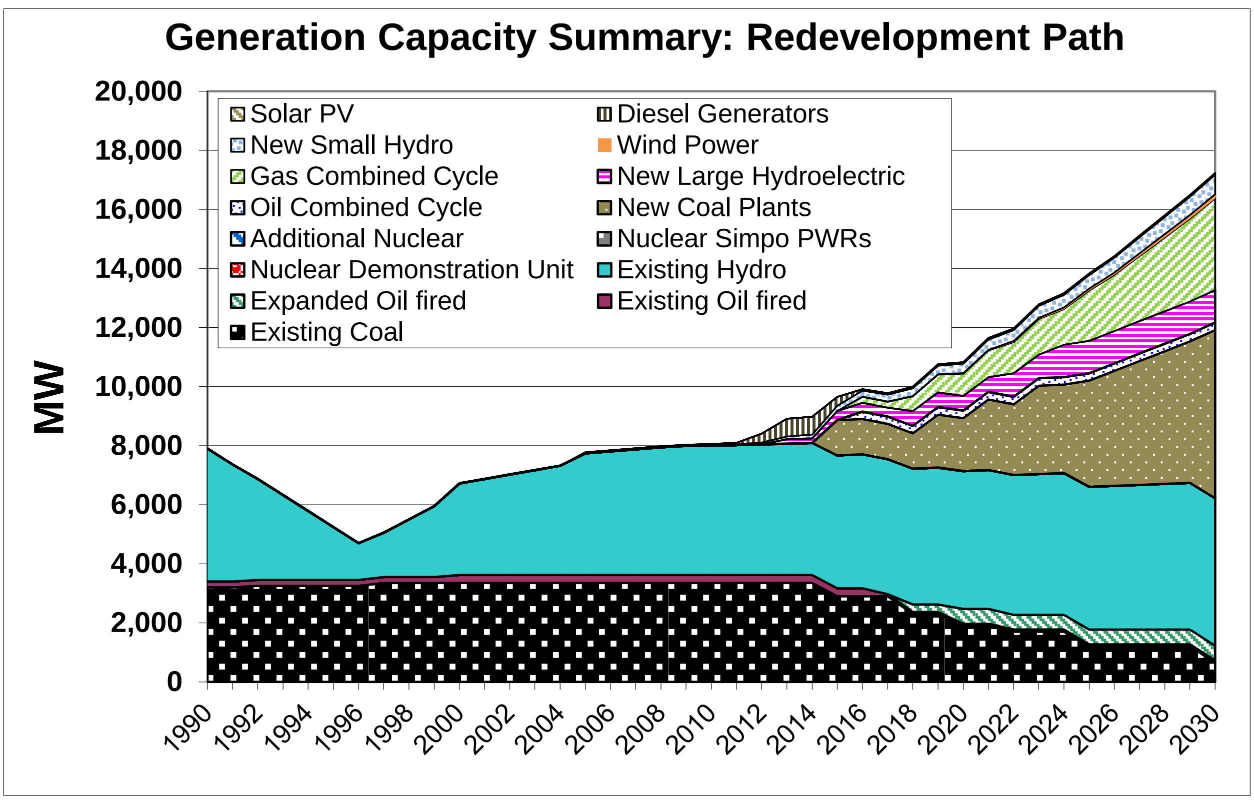
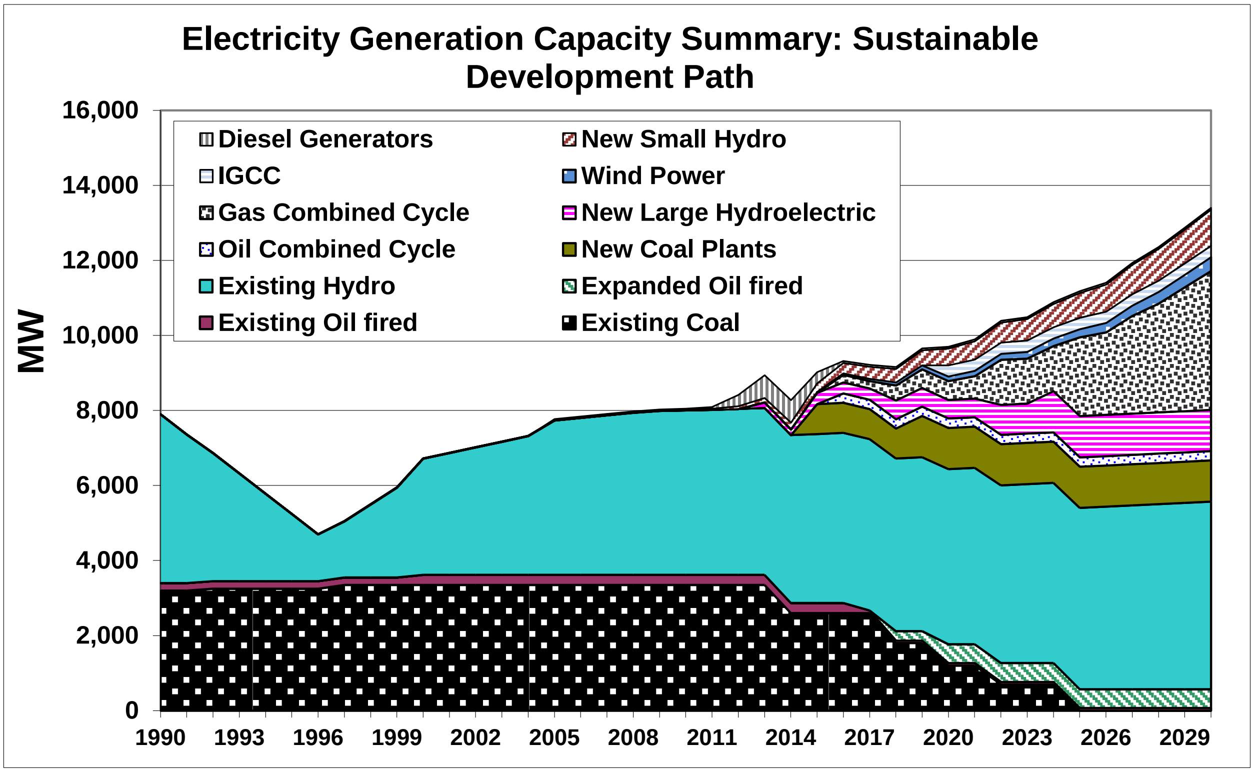


Figure 6-4[268]*:*



The result of aggressive energy efficiency and renewable energy implementation in the Sustainable Development and Regional Alternative Paths is that air pollutant emissions (including carbon dioxide, as shown in Figure 6-5) are much lower in those paths by 2030. Though costs on the demand side (for higher-efficiency equipment) are considerably higher than in the Sustainable Development and Regional Alternative Paths than in the Redevelopment Path, offsetting savings in the transformation sector (mostly due to the reduced need for electricity generation capacity) and in resources (avoided fuel production and imports) mean that the Sustainable Development and Regional Alternative Paths are less expensive than the Redevelopment Path, overall, even before any credits are taken for avoided environmental impacts, as shown in Figure 6-6.

[268] Note that both figures 6-3 and 6-4 assume that nuclear generation capacity (for example, the reactors at Sinpo) is not completed, though we have prepared variants of these scenarios that do include nuclear generation, starting operation in approximately 2018, which is probably the very earliest that a plant could possibly come on line. The exclusion of nuclear plants from each of these cases should be considered one of many possible variants in each case, but at present, possibly the more likely variant.

Figure 6-5[269]:

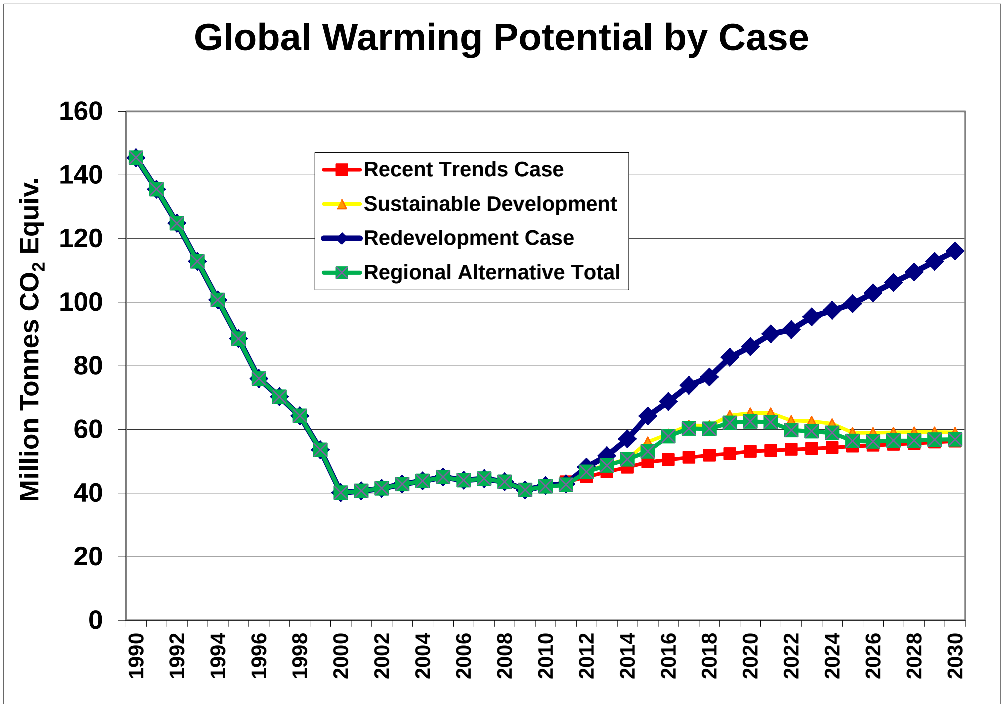
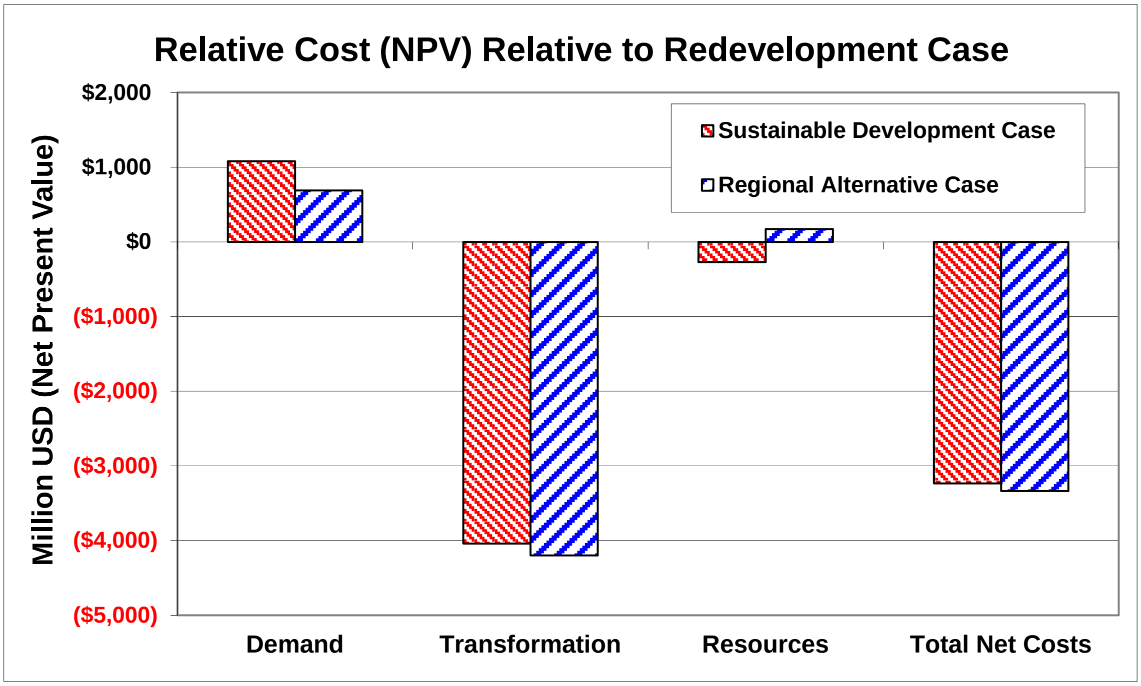


Figure 6-6:



[269] Global Warming Potential is a measure of how the radiative forcing of air pollutant emissions with direct or indirect impacts on climate compare, on a per unit basis, to that of Carbon Dioxide (CO_2). As such, it allows the tonnes of emissions of different pollutants to be totaled within a common metric, but CO_2 dominates the total.

6.3. 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. The 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.

6.3.1. 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*** is needed to encourage more efficient use of energy. Some of these reforms have begun in the DPRK, but the process remains in its infancy, and issues related to corruption by officials and "black market" activity may well have to be addressed as reforms are implemented. 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[270].

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 (some of these changes are reportedly underway, at least in the Pyongyang area of the DPRK, as noted in previous chapters in this report). To be effective, parallel reforms that sensitize local decision-makers to prices (that is, that allow, for example officials responsible for purchase of industrial

[270] That the DPRK is aware of this need for managerial reform is suggested by a recent article in the newsletter North Korea Today, number 65, published by Good Friends, and dated 3/28/07 (in Korean—available as http://www.goodfriends.or.kr/download/newsletter/newsletter65.pdf). The article on the DPRK electricity situation notes that Kim Jong Il has stressed the need to increase the rate at which new hydroelectric and thermal power generation capacity is built, and that the DPRK is looking for aid and/or investment to help solve the energy shortage, but at the same time realizes that there are problems of management inefficiency that might hamper reform of the power sector, and is in the process of replacing the managers currently running the electricity and water facilities in the DPRK with "experts"—presumably meaning managers with more technical training and background in the specific industries. (Content of article paraphrased by Tim Savage of Nautilus Institute).

equipment to benefit from energy cost savings by retaining the savings for their organization) 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 above), 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.

6.3.2. 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 the earliest energy cooperation projects 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 (or at least much of it) has 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.

6.3.3. 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 ***develop and implement practical standards, and to 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 (or adapted/adopted from other nations), 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 (measurement and testing equipment, and adequately equipped labs, for example) and the high-level administrative and political 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 evaluations based on output levels and product quality. This system is losing its effectiveness as China's transition to a market-oriented economy progresses (although it has recently been revived somewhat as a tool for greenhouse gas emissions reduction in China) and the central planning apparatus weakens, but it may still be quite appropriate for North Korea at this time, if temporarily during a transition toward a market system.

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[200]. 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.

6.3.4. 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. Chinese entrepreneurs have already established many operations in the DPRK, though it is not clear to what extent the Chinese government has provided support for these ventures[271]. ROK businesses and organizations have

[271] Judging from anecdotal reports of some Chinese businesses that have had difficulty reaching profitability in trading with the DPRK, it is unclear to what extent the Chinese government actively supports these ventures.

also, during the last decade, started businesses and joint ventures in the DPRK, with mixed (and sometimes transitory) results.

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[201] [272], and our understanding is that in the past decade a factory for local production of CFLs has been set up in the DPRK. As technology has moved on, at this point, joint venture manufacturing of LED lighting in the DPRK might be an interesting choice, though the key electronic components of LED lamps would probably need to be imported for at least several years before a workable modern electronics industry could be built in the DPRK, as well as a stable electricity grid to power both the manufacturing and the lighting products it would produce.

As examples of technology transfers, 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, and are being widely manufactured there. A similar process for similar devices is possible for the DPRK.

Wind turbine-generators are another intriguing possibility, given the apparent success of such ventures in former East-bloc nations[202] and China, 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, and relatively little progress in fulfilling the initial plans for the Zone has occurred in recent years, though bilateral action between China and the DPRK and Russia and the DPRK has occurred around ports and other transport facilities in the region in recent years), this area could be the location most acceptable to the DPRK for the first such ventures, along with the Kaesong Industrial Zone in the southern DPRK. It is likely that the foreign companies that would 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, and require those guarantees for a number of years until the DPRK's legal and regulatory systems evolve to operate consistent with the practices of typical industrialized nations.

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.

[272] We have been told by a delegation from the DPRK that a CFL factory has been set up in the DPRK, though it is not clear to us whether this factory is a joint venture or a domestic DPRK enterprise.

7. DPRK "Collapse" Pathways: Implications for the Energy Sector and for Strategies of Redevelopment/Support

7.1. Introduction[273]

The prospect for the DPRK (Democratic People's Republic of Korea) and its leadership remains unsettled. The ongoing succession of power to Kim Jong Un following Kim Jong Il's death has appeared to proceed relatively smoothly, though many of the impacts of the succession remain unclear or are yet to unfold. There is as yet little sign, however, given the economic and energy sector situation described in the earlier chapters of this report, that the economic poverty of almost all North Koreans will change for the better in the near future. The external powers will likely continue to squeeze the DPRK with sanctions over its nuclear weapons program, although the combination of the DPRK leadership change, and the upcoming elections in the United States and ROK may change the sanctions regime—but could make it either more or less stringent. Inflation occurred in the aftermath of the currency redenomination failure of 2010, and droughts and floods continue to plague DPRK agriculture. External aid will be minimal so long as the nuclear weapons issue remains unresolved.

This dismal future does not mean the DPRK is about to collapse. "Collapsists" have been arguing since the end of the Cold War that the DPRK "is about to collapse."[274] Many scenarios, including a persistent, slow recovery and gradual modernization of the DPRK, are possible.[275] The continued survival against all apparent odds of the DPRK is not regarded as refutation of the collapsist prediction. Nor apparently does the DPRK's regime pose a longevity worthy of investigation and explanation. Apparently, the only way to prove the prediction is to wait for the predicted outcome, at which time the prediction has a *post-ad hoc* character of truth after the fact. Thus, we should tread warily when it comes to claims about the prospective nature of collapse in the DPRK.

There is a reason, we suggest, that the DPRK has outlasted every other statist, personalized regime since the end of the Cold War. The DPRK is different, it is unique, and it represents a sample of one. It is hard to conduct authentic social science with a sample of one, especially from a distance. Moreover, this sample of one is intimately connected with and arguably inextricably linked with the status of United States policies towards the DPRK. The DPRK and the US national security state were born in war with each other; they have remained at war for nearly six decades; they are at war today. In our view, one cannot analyze the

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[273] Much of the text presented in this chapter was developed for a paper originally prepared as part of The Korea Project, co-organized by the Korean Studies Institute at the University of Southern California and the Office of the Korea Chair at the Center for Strategic and International Studies, Washington D.C., and presented at the conference "The Korea Project: Planning for the Long Term" Conference, August 20-21, 2010, Los Angeles, USA. Versions of that paper are available as http://csis.org/files/publication/101215_Collapse_Pathways_North_Korea.pdf and as http://nautilus.org/napsnet/napsnet-special-reports/dprk-collapse-pathways-implications-for-the-energy-sector-and-for-strategies-redevelopmentsupport/.

[274] See, for example, Bryan Kay, staff reporter: "Is Collapse of NK Regime Imminent?" *Korea Times*, November 15, 2009, at: http://www.koreatimes.co.kr/www/news/nation/2010/08/120_55550.html, and Aidan Foster-Carter, "The Gradualist Pipe-Dream: Prospects and Pathways for Korean Reunification," in ed. A. Mack, *Asian Flashpoint: Security and the Korean Peninsula*, Canberra: Allen & Unwin, 1993, 159-175.

[275] J. Witt, *Four Scenarios for a Nuclear DPRK*, US-Korea Institute, Working Paper 10-01, February 2010, at: http://uskoreainstitute.org/bin/s/g/USKI_WP10-01_Wit.pdf

prospects for change in the DPRK without simultaneously analyzing the rates and types of change in US foreign and military policy.

Rather than outright collapse in the next decade, far more likely is either a "slow burn" by which we mean continuing slow degradation of the economy and consequent adaptation at local levels to tighter scarcity constraints; or a very slow recovery nurtured by economic reforms, buttressed by external support from and trade with China, and large-scale labor exports; or a faster recovery based on rapprochement with the ROK and the integration of DPRK state-owned-enterprises with the ROK's chaebols.

In an overall spectrum of possibility, we estimate that the non-collapse pathways dominate, covering roughly 95 percent or more of the policy spectrum. In this 95 percent plus range, the primary question is what support and reconstruction policies are available to avoid outright collapse, the outcome that is most likely to lead to loss of control of fissile material, nuclear warheads, people, and escalation to war via civil war or cross-DMZ war. Many, perhaps most, of the policy responses needed to avoid collapse are the same as will be needed in the case of outright collapse.[276] The main difference in the post-collapse pathways is greater scale and speed and therefore cost needed to re-establish stability rather than to merely maintain it. Perhaps there is an obvious lesson in economics of policy choice in that difference.

The biggest single qualitative difference between non-collapse and collapse pathways will be in the military dimension after a DPRK regime collapse. Obviously, the highest velocity policy response in the case of DPRK collapse will be the moves by the ROK military (in particular, its special forces) to occupy and control key leadership posts, military bases, critical infrastructure, and transport chokepoints. How long this intervention would last is impossible to know in advance, but it could be held in place for many months or even years, depending on the degree to which local populations comply with the legitimacy of the occupying forces as against rebel against perceived injustices inflicted during the takeover. This particular policy response has its energy implications, both in its execution, and in its implications for energy sector reconstruction and immediate humanitarian assistance to the DPRK population. We will not cover, however, the military-energy aspects of establishing post-collapse control of the DPRK in this paper, although we will review the implications for post-war reconstruction of how a war might be fought with the DPRK.

In spite of these caveats and our best judgment that collapse is unlikely, it is conceivable and therefore should be addressed. Indeed, we have observed situations in the DPRK where the fabric of rural life was literally coming apart, and the demands on individuals and social units

[276] We have outlined in detail appropriate policy options for this goal in, for example, von Hippel, D.F., and P. Hayes (2009), "DPRK Energy Sector Development Priorities: Options and Preferences", forthcoming in the Asian Energy Security Special Issue of Energy Policy, and available as http://dx.doi.org/10.1016/j.enpol.2009.11.068; von Hippel, D.F., and P. Hayes (2007), Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths (Nautilus Institute Report, available as http://nautilus.org/napsnet/napsnet-special-reports/the-dprk-energy-sector-current-status-and-future-engagement-options/); von Hippel, D.F., and P. Hayes (2007), "Energy Security for North Korea", Science, volume 316, pages 1288 – 1289, June 1, 2007; von Hippel, D. F., P. Hayes, J. H. Williams, C. Greacen, M. Sagrillo, and T. Savage, 2008, "International energy assistance needs and options for the Democratic People's Republic of Korea (DPRK)". Energy Policy, Volume 36, Issue 2, February 2008, Pages 541-552; and D. von Hippel and P. Hayes, DPRK Energy Sector Assistance to Accompany Progress in Denuclearization Discussions: Options and Considerations, produced as part of the project "Improving Regional Security and Denuclearizing the Korean Peninsula: U.S. Policy Interests and Options.", organized by Joel Wit of Columbia University's Weatherhead Institute for East Asia and the U.S.-Korea Institute at the Johns Hopkins University School of Advanced International Studies, Washington, D.C., and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/vonHippel.pdf.

were beyond what would in most conditions be considered the bounds of human endurance. By collapse, however, we have a specific meaning in mind in this essay, namely, the complete breakdown of central government in Pyongyang. Given the number of interacting internal and external variables that affect the probability of DPRK collapse in the long-term (ten plus years), that probability is simply unknowable. Thus, we will concentrate largely on the short to medium- term in our analysis.

Whether precipitated by war, coup, or simply continuing slow economic decline, it is incumbent on the international community to help to provide services and support to stabilize North Korea in the unlikely event of outright collapse. Fortunately, many of the measures that would be needed are the same as should be undertaken in the non-collapse pathways. Among the many likely needs of the North Korean population following a collapse—food, clean water, heath care, and economic development among them—the need to promptly provide the population with reliable and demonstrably improving access to energy services (heat, light, mechanized transportation, and so on) will be a key to stabilizing the country, meeting other post-collapse needs, and readying the North for eventual smooth (one hopes) integration with South Korea. In this paper, we begin, in a largely qualitative way, the exploration of the implications of various DPRK "collapse" pathways for the energy sector of the North Korea, and for the approaches that the Republic of Korea (ROK) and other interested parties will need to take to rebuild and redevelop the DPRK energy sector, and in planning for same.

The remainder of this Chapter is organized as follows:

- **Section 7.2** provides a brief summary of the background on the status of the DPRK energy sector relevant to the prospects of a DPRK "collapse", drawing on the materials presented in earlier chapters of this Report.

- **Section 7.3** provides a summary of Nautilus Institute's approach to evaluating the impact of "collapse" pathways, and presents our illustration of four potential pathways that could lead to the collapse of the government of the DPRK, ranging from a quick collapse brought on by a "shooting war" or a West-friendly coup to a collapse from continued isolation and slow decline, which could take years or decades.

- **Section 7.4** describes our assessment of the implications of collapse pathways for the DPRK energy sector, and for provision of energy services (including energy supply and demand infrastructure) in the DPRK. For each collapse pathway, we identify key measures that the international community—including but hardly limited to the ROK and the US, would be obliged to or could take to help the DPRK transition toward eventual reunification with the ROK (whether official or *de facto* through economic integration).

- **Section 7.5** summarizes key overall lessons from our preliminary analysis of collapse pathways, focusing on near-term initiatives and planning efforts that the international community might carry out and support that would help to manage, smooth, and make easier the post-collapse transition for the DPRK populace, independent of how collapse actually occurs.

7.2. Background: The DPRK Energy Sector since 1990, and Nautilus Analytical Approaches

When the Soviet Union was dissolved in 1990, the DPRK lost not only its major supplier of crude oil and of parts for its power plants and factories, but also the markets for the bulk of the goods that its factories were designed to produce. The rapid economic and resource contraction, compounded by a series floods and droughts that affected both agriculture and energy production, plus economic isolation resulting from the international reaction to the DPRK's nuclear weapons program, resulted in a downward economic spiral of reduced energy availability and reduced industrial energy demand as the country's infrastructure fell into disrepair and markets dried up. By 2000 the DPRK's use of coal and production of electricity had fallen (by our estimates—see below) to almost a quarter of its 1990 levels, and overall energy end use had fallen to less than 40 percent of what it had been a decade before. Since this period, the DPRK's energy sector has been sustained primarily by an annual half-million tonnes of crude oil from China, modest imports of refined oil products, Korean tenacity and ingenuity that have kept some of its coal mines and aging power and coal production infrastructure running, and the substitution of wood and other biomass for subsistence energy use. Much of the DPRK's major energy and industrial infrastructure dates to the 1950s, '60s, and '70s, with some, including major hydroelectric plants, dating to the 1920s Japanese occupation era.

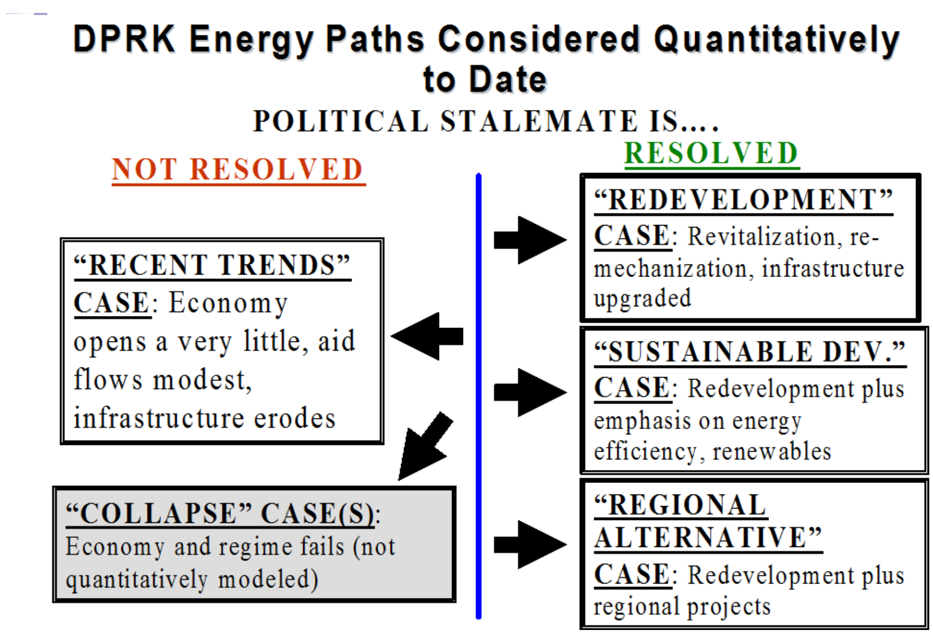
Since 2000 there have been modest improvements in the DPRK economy and energy sector, with some power plant repairs, new small hydroelectric facilities, and new mining activity underwritten, in large part, by Chinese investment. Still, shortages of power, district heat, and coal persist, with blackouts even in Pyongyang, and much more tenuous power supply in other areas. In effect, the North Korean electricity system, though it is nominally a nationwide transmission and distribution grid, is in effect an patchwork of a few regional and some local grids, centered around major and smaller power plants. Most of the large thermal (almost all coal-fired) power plants and heating plants are only partially in operation due to damage of various kinds to one or more boilers/generating units, and/or to transformers, substations, or other parts of the transmission and distribution system. This means that even if large amounts of fuel or electricity were suddenly to be available to the DPRK, distribution of that energy would be problematic.

The combination of erosion in its energy system and industrial infrastructure, together with similar erosion in its transport infrastructure in many areas and lack of investment capital, means that the DPRK will not be able to reconstitute, or perhaps more accurately, redevelop, its energy system and economy in general without outside help. Rebuilding power plants—most of which, remember, were built with major components imported from the USSR or elsewhere—could not be done, at least for many years, using materials "made from scratch" in the DPRK because the industrial infrastructure to make the required power plant components either is no longer operating or, in fact, was never present in the DPRK. Similarly, decades of relative isolation have left the DPRK substantially without the capabilities in metallurgy, electronics, and other fields that would allow it to develop new industries. This means that the DPRK cannot redevelop its infrastructure sufficiently to develop a sustainable, peaceful economy without outside help.

Even for the DPRK economy to remain at its current "subsistence" level, help from other nations has been required. As noted above, the DPRK receives sufficient crude oil from China to keep one of its two oil refineries running, though at well below full capacity. This oil is paid for at market prices, but the DPRK runs an annual trade deficit with China. China could provide more crude oil to the DPRK, and has done so in the past (in some years during the 1990s), but the fairly constant flow of oil from China to the DPRK for the past decade or so suggests that China has determined the amount of oil that the DPRK economy needs to receive to fuel basic economic functions, and is providing that amount. This suggests to us that although China is willing to provide fuel to keep the DPRK economy (and society) from failing, it is unwilling, until the DPRK can afford the additional imports on its own, to provide sufficient assistance to actually redevelop the DPRK economy.

Starting from the estimated energy balances presented in earlier Chapters, we prepared (and are currently updating) future scenarios of energy-sector development for the DPRK, using the Long-range Energy Alternatives Planning energy/environment software tool or LEAP[277]. Interim results of that effort are presented in Chapter 6 of this Report. In that work, as shown in Figure 1, we compare a "Redevelopment" path, implying significant opening of the DPRK economy to outside investment and assistance, but without significant emphasis on energy efficiency improvement, with a "Sustainable Development" path emphasizing energy efficiency and (to a lesser extent) renewable energy, and a "Regional Alternative" path also including DPRK participation in several types of regional energy infrastructure (for example, gas pipelines and electricity trading). An additional path modeled, the "Recent Trends" path, assumed that a substantial solution to the DPRK nuclear issue was not forthcoming, and recent trends in the DPRK economy continued. Not modeled quantitatively, as indicated in the shaded box in Figure 7-1, are the "collapse" cases that are the subject of this Chapter.

Figure 7-1:



[277] The LEAP software tool is developed and maintained by Stockholm Environment Institute—United States. Please see http://www.energycommunity.org/ for information about the LEAP tool.

7.3. Potential "Collapse" Pathways

7.3.1. Analytical Approach and Listing of Pathways Considered

Our general approach to the analysis of potential pathways of DPRK regime collapse is as follows. First, we define several significantly different, illustrative regime collapse pathways. We make no predictions about the relative likelihood of any of these paths, and freely admit that the four paths we illustrate have been chosen out of a universe of many possible options. The second step in the analysis is to think about the impacts of regime collapse, for each path, on the DPRK energy sector, and, by extension on energy and related infrastructure that supports the DPRK economy. Third, we consider how the ROK, the US, and the rest of the global community might or would need to respond to energy needs following each different type of collapse. Finally, we identify "robust" planning approaches that, if pursued now or soon, would prove useful in the event of any type of collapse pathway.

We consider four possible paths of regime collapse. These paths are described briefly below, and in more detail in the section that follows:

- **War**: A brief but very destructive war occurs between the DPRK and the ROK and its allies, precipitated by a military incident that rapidly escalates, and leads to essentially immediate unification
- **Regime Implosion Leading to New Authoritarian Regime:** A death or other event leads to regime replacement in the DPRK, with the new regime being modernizing, but leaning toward China and Russia for economic support, and away from the ROK and its Western allies.
- **Regime Change by Palace Coup Leading to ROK-installed Regime**: While not immediately leading to unification, this collapse path would lead to modernization that in turn would lead to at first de-facto economic unification, then, somewhat later, political unification with the ROK.
- **Slow Collapse Leading to Regime Change through Internal Conflict**: In this path, the Kim family and/or other leaders continue the current (largely) isolationist policies, which leads eventually, though perhaps not for many years, to the collapse of the DPRK state, with the ROK and its allies obliged to "pick up the pieces".

7.3.2. The "War" Path

The "War" path of regime collapse assumes that a shooting war between the DPRK and the ROK (and its allies), once set off by a military incident of some kind, quickly escalates. Given the proximity of DPRK artillery to the ROK border, we assume that this path results in considerable destruction in the Northern ROK (including the parts of the Seoul area close enough to the DMZ as to be within range of DPRK artillery and rocket fire—to the extent that DPRK ground-launched weapons capacity is not suppressed by ROK and US counter-fire), and also in considerable destruction in many areas of the DPRK, especially in areas associated with military installations, but perhaps sparing areas near the DPRK's northern borders (for reasons touched on below). Based on previous work (see text box below), our rough estimate is that the DPRK would not be able to sustain a conflict long (probably for weeks, or at most, a month or two) due to lack of fuel supplies. This assumes that China does not somehow step up fuel deliveries to the DPRK, which seems unlikely if the DPRK is seen as the aggressor in the conflict.

We assume that war leads to ROK (assisted by US and others) administration of the DPRK. We further assume that the ROK's administration of the DPRK is managed in such a way that significant dissatisfaction with the administration on the part of the North Korean population is avoided. This is a crucial assumption, as an insurgency related to popular local dissatisfaction with ROK administration of the DPRK would set DPRK rebuilding and redevelopment back years, as has been the case following the US wars in Iraq and Afghanistan. Would the DPRK population welcome ROK/US victors with open arms? Iraq/Afghanistan provide cautionary tales, but an analysis of that particular issue, though it has potentially significant ramifications for what types of energy infrastructure improvements will be possible/effective, is beyond the scope of this paper. Clearly, however, one of the lessons of Iraq is that the degree to which the administration quickly ramps up the provision of the essentials of life—food, clean water, health care, electricity, waste treatment, jobs—to the populace will play a huge role in how well the populace adapts to its new government.

How the war is prosecuted by the ROK/US side will have a significant bearing on the tasks needed to reconstruct the energy system. For example, will the ROK/US alliance choose to:

- Destroy power plants wholesale, or just render plants relatively temporarily unusable with surgical strikes on key, relatively easily-replaceable components?
- Destroy the DPRK's operating refinery, or just cut refined products supply lines?
- Destroy coal mines, or just cut power to them, rail lines from them?

DPRK Energy Supply during a War

Several years ago, we carried out a rough calculation that suggested that it would take about three months of DPRK refinery output, at current levels, to resupply the gasoline and diesel fuel that the military would use in the first month of an active conflict. By the end of the first month of conflict, it would take about two months of total refinery production plus imports (assuming current levels) of gasoline and diesel to operate for an additional month of war the DPRK military vehicles that we estimate might remain operable after the initial 30 days of conflict.

This calculation includes several simplifying assumptions, each with significant to considerable degrees of uncertainty. First, it assumes that 50 percent of DPRK military ground vehicles and armaments would be inoperable after 30 days of conflict, and that 90 percent of the DPRK's navy and 100 percent of its air force would be similarly inoperable or in deep storage. Given the superior firepower, particularly from the air, of the ROK/US alliance, these assumptions seem reasonable to us. Second, it assumes that the DPRK does not have many months of fuel stored in deep bunkers. Here, we have no direct information one way or another, but suspect that the relatively constant fuel shortages over the past decade and more have probably eroded stocks, at least somewhat. Third, it assumes that the one operating refinery continues to provide fuel at current levels, and that the second major DPRK refinery, at Sonbong on the DPRK's northeast coast (currently and recently inactive) is not reopened. The degree to which the currently-operating refinery, in the DPRK's northwest and connected by pipeline with China, maintains its output depends largely on the degree to which China continues supplying crude oil. Refineries are easy military targets, but it seems unlikely to us that the ROK-US forces would attack a facility so close to China. Whether China might increase or decrease the flow of crude oil to the refinery is an open question—our guess is that they might not do either. Reopening the Sonbong refinery would likely take much too long to help much in the event of a conflict, and it is unclear where the crude oil to fuel it would come from. Fourth, we assume that the current (mostly minor) sources of refined products would not increase or decrease much as a result of a conflict. If anything, it seems to us that it would be more difficult, not easier, to import oil by truck, train, or small tanker ship in the event of an armed conflict.

These caveats notwithstanding, the essential finding from our calculation is that the DPRK military would quickly—in a matter of weeks or certainly months—run short of fuel in any major armed conflict. With regard to the "War" path to regime change discussed in this paper, this finding has (at least) two implications. First, the major part of a war between the DPRK and the ROK and its allies is likely to be over, at least in terms of use of large fuel-using vehicles by the DPRK, within two or so months. Second, knowing that a war is likely to be brief, the ROK and its allies might be more inclined NOT to inflict difficult-to-reverse damage on major DPRK energy facilities.

We assume that, given that ROK/US air power superiority will provide control of the skies within days, the ROK/US military command can be prevailed upon to knock out energy infrastructure surgically. War planners will probably deem it necessary to knock out electrical grid to deny power to munitions and armaments factories and other military installations (although the latter will likely have their own power sources). Doing so by wholesale destruction of the transmission and distribution (T&D) grid and major power plants, however, would make it much harder to redevelop the DPRK energy sector in a timely fashion, and probably isn't necessary. Targeting and destroying, for example, substations at power plants, which are already in very poor shape, will knock the power plants off line indefinitely, and be much easier to fix than would major damage to the power plants themselves. It seems unlikely that ROK/US forces would try to destroy or permanently disable the DPRK's one major operating (Northwest) refinery, as it is so close to China, but they might seek to bomb major rail and road links that would be used to provide fuel to the front, and possibly sink or disable some coastal tankers used to transport petroleum products, and/or target petroleum fuel depots. Disrupting the provision of power to DPRK coal mines would knock most coal production off line, but again, targeting rail links would be inflict damage that would be relatively easy (once the war ended) to fix, but still effective in reducing the DPRK's supply of fuel to the front lines of the war. Probably some war damage would be sustained in DPRK seaports, especially those that host submarines or Special Forces that use naval craft. Due to concerns about humanitarian impacts, plus effects on ROK water resources (rivers that flow across or near the DPRK/ROK border) and on China (for rivers in the northern part of the DPRK), we assume that ROK/US forces would avoid damaging hydroelectric facilities, at least the dams, but might, again, choose to knock hydropower stations off line (except probably, the several Supung and other power stations shared by the DPRK and China that are located along northern border rivers) by destroying key substations.

The descriptions of the "War" path above, and analysis of the energy implications of the War path provided below, assume that Russia and especially China stay out of the conflict. If they do not stay on the sidelines, at least in a military sense, the ROK/DPRK conflict becomes a very different and much more dangerous altercation, to say the least, with possible global consequences.

7.3.3. "Regime Implosion Leading to New Authoritarian Regime" Path

In the second path considered here, a new regime takes over from the Kim family as a result of the death of Kim Jong Il or his successor, or as a result of some internal coup. The new regime is authoritarian but modernizing, and is dominated by military and technocratic elements. Despite its modernizing elements, the new regime continues to spurn the ROK and the West. Rather, the modernizing approach implies much higher than recent rates of investment (from non-ROK, non-Western sources), and as a result energy infrastructure is rebuilt/redeveloped in close cooperation with China and Russia. For the most part, international governmental organizations and international financial institutions are also excluded by the new regime from the DPRK modernization process.

The elites of the new regime serve themselves by modernizing the DPRK economy enough to modestly improve the lot of the general population, but do so in the process of establishing businesses that mostly emphasize export of the DPRK's mineral and labor resources, with China and Russia as major partners. The elites of the regime operate the export companies, and thereby install themselves as a Korean equivalent of the Russian oligarchs of the 1990s. The ROK remains locked out of DPRK economy in the short and medium-term, but may in the longer term obtain regional network integration (via agreements on and construction of electricity interties and gas pipelines) by paying rent to the DPRK government for energy infrastructure and transport corridors through the DPRK to resources in Russia and markets in China and beyond.

7.3.4. “Regime Change by Palace Coup Leading to ROK-installed Regime” Path

In this path, following, for example, an act by Kim Jong Il or his successor that it considered the “last straw”, a group of cosmopolitan younger DPRK diplomats and technocrats backed by young officers in the KPA takes power, and immediately establishes links with the ROK, the United States, and their allies. The result, initially, is an authoritarian regime that sympathetic to the ROK and the West. The regime slowly, perhaps very slowly, installs elements of democracy in the DPRK, but focuses first on economic reforms. These economic reforms place emphasis on planning a DPRK economy that complements the ROK economy. For example, initially, economic reforms would likely emphasize development of the DPRK mineral resource base to help provide raw materials for ROK industry, and would utilize cheap labor in the DPRK to compete in industries (for example, textiles, and basic electronics) that have been moving out of ROK to lower-cost suppliers such as China and India. To fund these economic reforms, significant investment is drawn from the ROK, and probably from the US and elsewhere as well.

As with the China- and Russia-leaning elite in the “Regime Implosion Leading to New Authoritarian Regime” path, the new, ROK-leaning regime elites seek to serve themselves, but do so possibly by setting up ROK-style chaebol that they control, and that interface with/draw investment from analogs in the South. Such a regime might be amenable to large-scale virtual exports of DPRK labor via the internet, for example, for Korean language records processing for the insurance, medical, and telecommunications industries.

7.3.5. “Slow Collapse Leading to Eventual Reunification” Path

In this variant of “Regime Implosion”, either Kim Jong Il or a successor from the Kim clique maintains control, or another regime (perhaps run by a “regent” governing the country in the name of a Kim successor) takes power. In either case, however, there is a failure to modernize or open the DPRK significantly to the outside world. Aided by continued isolation, the national regime’s control over the country becomes progressively less effective due to continued erosion of energy and other infrastructure, and its inability to provide food and other essentials for the population as a whole.

As this erosion continues, possible situations between national control and total collapse of authority might include the effective fragmentation of the DPRK into “fiefdoms” run by powerful party or military (or criminal) leaders, perhaps supported individually by national neighbors (China, Russia, Japan?) or large foreign investors such as Chinese companies.

We assume that this scenario will lead to eventual reunification of the DPRK with the ROK. Control of information coming into North Korea would breaks down as the power of the central authority to impose order wanes[278], which, coupled with continued decline in living standards, leads eventually to disillusionment on the part of the majority of the population,

[278] Some would say that, due to the advent of cell phone usage in the Chinese border region and in Pyongyang, the control of information in the DPRK is breaking down already.

internal conflict, civil disorder, and possibly even civil war in DPRK. A "Civil War" situation may be difficult to conceive of, given the lack of significant ethnic or religious divides in the DPRK, but a possible mechanism might occur in a "fiefdom" situation where rival warlords controlling (for example) different provincial areas, and using arms smuggled from different friendly nations/groups, begin to struggle for territory or power.

Overall, the process of decline under this path may be very slow, taking years or even decades to play out, but would likely end with a rapid collapse at the end stage that requires urgent intervention by the ROK and its allies (and possibly others on Northern borders to stem/support a flood of refugees leaving North Korea.

7.4. Implications of Collapse Pathways for the DPRK Energy Sector and for Provision of Energy Services in the DPRK

Each of the four "collapse" pathways outlined above has its own implications for how the DPRK energy sector will be affected. As such, each of the pathways implies different ways in which those in the international community with the wherewithal to help might provide or plan to provide energy services to the DPRK population and economy in response to, or to soften the effects of, regime collapse. What follows are our initial thoughts on the energy sector and energy assistance implications of each of the paths described above.

7.4.1. <u>"War" Path</u>

As noted above, a major military conflict between the DPRK and the ROK (and its allies) would, depending significantly on the military strategy that the ROK/US alliance chooses to imply, eliminate considerable energy and industrial infrastructure in the DPRK, though much of it is already failing and/or obsolete. If a "surgical" military approach is used, the minimum short-term requirements to supply basic energy services to the DPRK and to start to build a peaceful DPRK economy would likely be:

- Replace virtually all substation equipment, including both equipment that was war-damaged and equipment that has simply become inoperable (or close to it) over time, as most substation transformers and related equipment are reportedly in poor condition.
- Establish emergency electricity generation, initially fueled with diesel oil or possibly liquefied petroleum gas (LPG, a mixture of propane and butane). This generation might take the form of power barges in coastal areas or where river transport is possible, and package diesel or portable combined heat and power plants in inland areas.
- Try to get major coal-fired power stations restarted, and restart or stabilize output from coal mines to supply them, while undertaking temporary transmission repairs sufficient to get electricity onto the local or regional grid on a semi-reliable basis.
- Ramp up petroleum products production in ROK refineries in order to substitute for whatever DPRK fuel production/transport capacity was destroyed in the war, with additional fuel provided to supply emergency generation facilities. ROK refining capacity is large enough that it could easily supply the ROK and the DPRK together today, though possibly not the both the ROK and DPRK at ROK per-capita levels of consumption. Given the status of

DPRK fuels demand infrastructure, however, the DPRK wouldn't reach ROK levels of consumption for many years. As such, overall refined products supplies might not be a problem in a suddenly reunified Korea (though some products will be easier to supply than others), but the infrastructure to move supplies to where they are needed in the North—port facilities, rail facilities, and roads—will need upgrading even if they not damaged by war.

- Try to get major hydroelectric facilities restarted, including required transmission repairs and/or repairs to dams.
- Provide critical power and fuel for agriculture. The urgency of doing so will, of course, depend on the season in which the conflict occurs, but planning for supporting DPRK agriculture as much as possible will be a priority in any circumstance in order to reduce the quantity of food aid that will inevitably be required.

If a surgical military approach is NOT used by the ROK and its allies, supplying basic services and economy-building in the DPRK would be more difficult. For example, immediate replacement of most power plants would be needed, meaning more "triage" solutions to restart parts of energy facilities however possible, and more provision of emergency generation. Significant emergency civil engineering work will be also needed to shore up damaged infrastructure, repair ports, rail facilities, roads so that emergency supplies of refined products can be brought in.

A key complication of the "War" path is that it will somehow be necessary to rebuild/develop the DPRK at the same time as the considerable damage to the ROK infrastructure (and society) is being repaired. This complication argues for the need for countries beyond the ROK and US to take a very active role in DPRK reconstruction, as a great deal of ROK rebuilding effort will necessarily be domestically focused. The need to support/rebuild both South and North Korea makes coordination, even in the midst of post-war chaos, even more necessary if citizens both south and north of the 38th parallel are to get needed services in a timely manner. All of these factors underline the need for detailed and coordinated pre-crisis planning[279].

In any post-war path there will be a need to quickly ramp up capacity-building for energy, environment-related, and other occupations. Capacity-building will be needed in part because trained people will be needed for reconstruction and redevelopment, but also because the North Korean population will need gainful, useful, peaceful employment. This is especially true for those officials and technicians associated with sensitive industries (for example, military industries and nuclear weapons programs) in today's DPRK. A key focus of early capacity-building efforts should be on providing skills and technologies that encourage the growth of local economies (for example, at the county level) that are capable, to a large degree, of providing essentials such as food and energy services for themselves. As concrete example, training should be provided for redeployment of scientists and technicians working at the Yongbyon nuclear weapons complex and military missile development/production programs so as to make sure their skills are directed toward productive and peaceful activities, rather than having their skills diverted to serving threatening states or organizations.

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[279] We assume that at least some significant planning for DPRK collapse has been undertaken by ROK government agencies, but if these plans have been reported in the public literature, we have not yet seen them.

In the medium- and longer-term, several types of actions will be needed under a collapse via the "War" path:

- Plan for and start to build an integrated ROK/DPRK grid, probably starting with extending ROK grid into areas in the southern part of the (current) DPRK, and building local/regional grids in other areas for eventual hook-up to national grid.
- Make sure to replace damaged (or otherwise unserviceable) energy demand infrastructure with the most energy-efficient devices available, so as to lessen the requirements for new or rebuilt energy supply infrastructure.
- Make sure to choose energy-efficient devices for all of the new housing, commercial, and industrial developments that will be built as the North's economy and living standards start to gain on those of the South.
- Evaluate which industrial facilities need to be developed (or in rare cases, rebuilt), and plan for evolving supply systems for fuels (such as electricity, gas, heat) to serve the evolving economy. In this case, serving the "evolving economy" means, for example, putting supply systems where people will be, factoring in elements like re-mechanization of agriculture and shifts in economic composition toward the services sectors, and away from heavy industry, and probably toward cities and away from the countryside. That is, don't plan to necessarily put facilities where the people happen to be located now (or shortly after collapse) as they work in the planned economy and survival-level cottage industries.
- Work with the Russians to reconstruct--or, more likely, construct a new--Sonbong refinery, related port facilities, and the combined heat and power facilities associated with and serving the refinery and the local area.
- Work with the Russians to bring gas supplies and gas transmission and distribution infrastructure into and through DPRK to the ROK, and/or develop new liquefied natural gas (LNG) import, storage, and regasification facilities (again, with associated gas T&D facilities) somewhere near the 38th Parallel (for example, in or near Nampo in the DPRK). LNG facilities would likely be shared to serve both the North and South.

7.4.2. "Regime Implosion Leading to New Authoritarian Regime" Path

In the "Regime Implosion Leading to New Authoritarian Regime" Path, the technocratic regime would presumably assess the country's energy needs, and attempt to focus internally on energy infrastructure redevelopment, taking advantage of largely Chinese and Russian technical help. Energy infrastructure development would be focused on serving raw materials export industries, and as such might be focused on areas in the North and West of the DPRK, leading to somewhat geographically and sectorally unbalanced energy systems. For example, if the regime is focused on maximizing income from raw materials and labor exports, it might give limited attention to improving energy supplies to and infrastructure in urban areas (outside of areas where elites live) or to rural areas (outside of where minerals are found).

The ROK and West would be expected to have limited short and medium-term influence under this path. The main options the ROK and West might have to influence the DPRK energy sector might be to try and work through the Russians and Chinese to provide capacity-building, and thus affect patterns of change in DPRK energy infrastructure at the margin, and also to look for opportunities for joint ventures with Russians on regional infrastructure (for example, in electricity and gas networks, and on oil refining). Working through the Chinese and Russians, however, may be complicated by the bottom-line focus of Chinese and Russian trading companies operating in the DPRK, which may leave little room for modifications in approach that would help an eventually-reunified Korea. In general, the ROK and West could offer capacity-building on energy and related topics as a lever to start opening the DPRK economy to other influences, but how those overtures might be received by the new DPRK regime, under this path, is hard to predict.

In the longer-term, assuming an eventual gradual or sudden opening of the regime, the ROK/West will need to focus on providing energy infrastructure in areas and populations left underserved by export-oriented infrastructure.

7.4.3. "Regime Change by Palace Coup Leading to ROK-installed Regime" Path

The implications for the energy sector under the "Regime Change by Palace Coup Leading to ROK-installed Regime" path are similar in many ways to those under the "surgical strike" variant of "War" path, but with less DPRK destruction/dislocation to address, and without the need to rebuild infrastructure in the ROK

As such, short-term needs under this path would include:

- Making a full assessment of the status of the North Korean electricity grid (T&D and generation) and other major energy and related infrastructure, including mines, refineries, rail facilities, and ports.
- Replacing virtually all electrical substation equipment, starting with failed and failing units.
- Establishing emergency electricity generation, initially with diesel or possibly LPG-power barges in coastal areas, and package diesel or combined heat and power plants in inland areas, focusing where power supply is particularly inadequate, in order to build social stability in those areas and stem out-migration.
- Where possible, applying quick repairs to keep the best of the major coal-fired power stations going for a few years while the national power grid is being replaced.
- Look for ways to upgrade existing hydroelectric facilities to improve their safety of operation, efficiency, and generation capacity.
- Ramping up ROK refined products production to supply currently unmet demand for transport fuels in the DPRK, plus diesel fuel needs for temporary generation.
- Providing critical power, fuel, and equipment for farming.

In the medium- and longer-term, one priority under this path will be to assess coal supply infrastructure to determine if any existing mines will be cost-effective to operate in the longer-term; and to shut down and abandon (and remediate) mines with poor prognosis. Poor prognosis for North Korean mines may be as a result of a damaged mining infrastructure that would be too difficult to repair, unsafe mining conditions, a poor resource base (in terms of coal quantity and/or quality), or simply poor mine economics (which could be a function of many factors, including all of the above, plus coal transport and other considerations). Even under this path, it would not make sense to abandon mines immediately as the regime changes, given the importance of coal to the existing infrastructure and the importance of the coal industry as an employer, but the coal mining sector should be reviewed soberly and shrunk if needed in favor of importing coal from major international low-cost producers if the assessment so indicates. A second major priority will be to evaluate which industrial facilities need to be developed, based in large part, on demand for DPRK-located facilities as indicated by willingness of private sector actors (in the DPRK, the ROK, and beyond) to invest. In addition, in the medium- and longer-term, plans need to be developed for evolving supply systems for fuels (electricity, gas, heat, and refined products) to serve the evolving Northern economy.

Again in the medium- and longer-term, under the path leading to an ROK-friendly regime, a key requirement will be to establish markets for fuels, and the regulatory authorities to oversee them, with an eye toward merging markets and regulatory authorities in a unified Korea. For markets, the DPRK could in fact lead the ROK into the world of “smart grids” and smart electricity meters. This could include, for example, widespread use of time-of-demand pricing, local generation, and renewable generation. Demand for electricity in North Korea under this path could be expected to increase rapidly, accompanied by an opportunity (not to be missed) to build a very modern, very high-efficiency supply and demand-side electricity sector. Hand-in-hand with this effort should go development of progressively tighter building energy efficiency regulations, and build human capacity to enforce building energy efficiency and other regulations, and to design and construct high-efficiency buildings.

As with other paths, it will be desirable to work with Russia, and possibly with China and other nations, to explore and extend regional electricity and gas grids, and to partner on a new Sonbong refinery. It will also be necessary to develop gas use infrastructure (demand-side and distribution) for all sectors, including electricity generation and combined heat and power, for a number of reasons, including reducing the greenhouse gas emissions in a unified Korea, and providing energy services as cleanly and efficiently (in terms of overall fossil fuel use) as possible. As in other paths, another priority will be to explore extending gas grids north from ROK, and building shared (North/South) LNG facilities.

Last, but certainly not least, this path will provide both the opportunity and need to do aggressive capacity-building on a vast host of topics, starting as soon as possible. This will mean sending the best North Korean students to the ROK, the United States, and elsewhere for study, and providing them with incentives to return to work in North Korea, but also, just as if not more importantly, building up North Korean educational institutions at all levels.

7.4.4. “Slow Collapse Leading to Eventual Reunification” Path

In the “Slow Collapse Leading to Eventual Reunification” path, energy infrastructure continues to slowly decay, following the general pattern—albeit occasionally partially reversed by occasional isolated repair projects and new developments—over the last two decades. As infrastructure decays it continues to become more inefficient over time, and also loses capacity (for example, electricity generation capacity, transport capacity, heat production capacity, and so on) as the performance of individual units continues to decline, and as units fail altogether. In this path, scavenging for metals to sell for scrap may take an increasing toll on important energy infrastructure (such as T&D) systems and other infrastructure (such as rail lines) as well.

In the "Slow Collapse…" path, the DPRK's efforts to keep infrastructure running will continue, but will run up against diminishing returns due to a lack of replacement parts (for infrastructure originally manufactured outside the DPRK) and of outside expertise that can only be acquired with scarce foreign exchange dollars. Exceptions to the pattern of decaying infrastructure may be infrastructure that is required to support export ventures with outside investors, for example, Chinese companies, where outside investors have a vested interest in making sure that key infrastructure is operable.

From the perspective of the ROK and its allies, actions to usefully help to address DPRK energy sector and related needs in the short-to-medium term are limited. So long as a central regime hostile to the outside remains in power in North Korea, little can be done but to take advantages of the (likely) rare opportunities that occur for engagement and capacity building. As the central regime loses power, there may be more opportunities for small, local engagement projects addressing energy sector needs, but such projects will be difficult and potentially hazardous to carry out, and may more likely be the province of non-national groups such as non-governmental or international organizations. If an era of "fiefdoms" occurs during the slow collapse, arranging any type of regional project (electricity interties, gas pipelines, or rail interconnections) will be very difficult due to shifts in who is in charge or in power in areas transited by proposed infrastructure at any given time.

In the longer-term, when the collapse of the state is complete, with or without an interim "fiefdom" era, the types of measures required of the ROK and its partners following reunification-by-default are the same as in the "Regime change by palace coup" path, but with a significant difference. Continued degradation of energy infrastructure, leading (in part) to extreme scarcity and suppressed demand, is likely to make eventual reconstruction/redevelopment and recovery of North Korea a progressively larger and larger long-term issue for the ROK, with growing complexity and expense.

Also in the longer-term, relative to a more immediate collapse, the Slow Collapse path implies that full assessments of DPRK energy and related infrastructure will not be possible for some time. Full, on-the-ground assessments of infrastructure needs, energy demand, and other key factors that are needed to plan effective energy sector assistance will be stymied by lack of access for years. As a result, the countries and organizations that would need to step in to provide energy services and rebuild energy infrastructure under a collapse scenario will not be able to fully assess the slowly deteriorating situation until actual collapse occurs, at which point needs (for food, water, electricity, waste treatment, health care, jobs, and other essentials) will likely be more urgent than they would have been had collapse occurred sooner.

The lack of access to the DPRK for a full energy sector assessment means that planning for energy sector support, and increasingly, as time passes, redevelopment, will need to continue to be informed by fragmentary information. This underlines the need for the international community to A) coordinate and share information on the DPRK whenever possible, B) use that information to formulate and regularly update plans for energy sector triage and rebuilding under a collapse scenario, even if collapse is long in coming, and C) provide resources to consistently support both A) and B). Gathering and making sense of energy sector information will require coordination by interested parties in data gathering and analysis. Considerable persistence and patience will also be required of those in the ROK and the international community who must prepare for DPRK regime collapse in keeping energy sector assistance and contingency plans updated, and remaining in readiness to effectively activate plans when needed.

7.5. Lessons from Collapse Pathways for Near-term Initiatives and Planning Efforts

Our initial consideration of the energy sector implications of potential DPRK regime collapse pathways suggests that there are a number of initiatives that the ROK, the United States, and the broader international community that is interested in the future of the Korean peninsula can undertake to be ready to assist in the event of a DPRK regime collapse. Possible initiatives include:

- Do capacity building on lots of topics whenever possible. Capacity-building is cheap, useful, and necessary in any path, and has many ancillary benefits. Required capacity building topics include technical training in electricity generation, energy efficiency, oil refining, renewable energy, environmental remediation, waste treatment, reforestation, and other similar disciplines. In addition, training will be needed in running commercial enterprises, including economic analysis, building and operating regulatory and legal systems, and many other organizational topics. Ancillary benefits of capacity building include engagement on the individual and organizational level, opening minds to new ways of thinking, increasing the availability of competence and personal connections for application at key movements of transition, as well as availability of in-country trainers for to rapidly expand training as needed.
- Plan now for the wholesale rebuilding of the transmission and distribution system. Doing so will be necessary sooner or later An initial step might be to stockpile key components, such as transformers and substation switchgear, for rapid installation as needed
- Assess the ROK's current refining capacity versus the petroleum products needs of a reunified (in fact if not in deed) Korea. Start talking with Russians about possibility of rebuilding and expanding the Sonbong refinery so as to be ready to rapidly start a refinery project when conditions permit.
- In order to reduce the burden on energy supply infrastructure (including reducing the amount of new energy supply infrastructure needed), have the discipline to provide high-efficiency energy demand (and supply) devices when rebuilding the DPRK economy. Provide high-efficiency demand and supply devices rather than, for example, marketing secondhand appliances, industrial motors, power plants, automobiles, and other devices to the DPRK, so as to make sure that the DPRK has a better chance of "catching up" with technology in the South, yielding better outcomes from social, resource conservation, environmental, economic/infrastructure integration perspectives.
- Think through how markets for energy goods can be established so as to spur private sector investments.

- Plan integrated energy infrastructure/economic development demonstration projects, for example, on a county scale, and try to get some integrated projects implemented even before collapse.
- Network with other interested parties to provide the best assessment possible of DPRK energy sector status and needs, and collaborate on concrete plans so as to be able to swiftly and effectively address those needs when an opening occurs.

Finally, medium- and long-term regional energy projects such as a regional electric grid tie-lines and/or regional gas pipelines should be implemented in ways that provide China and Russia with some leverage over the reconstruction agenda should the DPRK collapse. This leverage may be needed, in part, to ensure that the ROK hands over all fissile material and nuclear weapons-related hardware and knowledge to the IAEA and/or to nuclear weapons states in the scenario where such hardware and knowledge is obtained/inherited by the ROK from DPRK sources after the collapse of the DPRK. Meanwhile, policymakers should focus on the measures needed to stabilize the DPRK to avoid collapse by the DPRK in the short- and medium-term.

8. Redevelopment of the DPRK Energy Sector: Assistance Approaches and Project Options

8.1. Introduction

When and if the Six-Party Talks (or whatever diplomatic venue emerges to replace them) resume, negotiations will center on the dismantling of the DPRK's nuclear weapons program, and on the incentives that will be offered by the international community to induce the DPRK to do so[280]. Chief among the incentives will be energy sector assistance to the DPRK. This chapter outlines a number of generic policy areas where assistance would be in order, as well as some ideas for cooperation activities in specific energy sectors. Neither set of suggestions is intended to provide an exhaustive list of the opportunities for cooperation, and neither is intended to provide a "schedule" of any kind to guide the development of a package of options to offer the DPRK. Development of such a package is necessary (and is a critical need), but is beyond the scope of this Report, and must necessarily involve consultations among key policy actors in the ROK, the US, China, Russia, the EU and other nations, as well as, to the extent that such conversations are possible, the DPRK.

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

Key economic resources for the DPRK, as noted earlier in this Report, 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 improvements in agricultural methods), and above all, substantial financial 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

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[280] For a perspective on the views of DPRK officials regarding energy assistance options and nuclear weapons dismantlement, see Siegfried Hecker, "Energy Dialog with DRPK Officials Aug. 23-27, 2005 Visit to DPRK", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA. Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Hecker.ppt.

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, and will not improve the security situation in the long term. 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[281]. All of these interventions would put foreign (US, ROK, or other) engineers, trainers, consultants, 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 the DPRK.

Many of the options described below are also consistent with the key areas for international cooperation to assist in developing the DPRK energy sector and the broader DPRK economy outlined by Dr. Ji-Chul Ryu of the Korea Energy Economics Institute in his presentation for the DPRK Energy Experts Working Group Meeting entitled “Energy Crisis in DPR Korea and Cooperation Issues”[203]. We summarize Dr. Ryu’s key areas for cooperation as:

1. Abandoning the DPRK’s self-reliance economic policy, including opening the energy system to commercial energy supply from overseas.
2. Establishing market mechanisms for distribution of energy, and creating energy markets, including introducing energy pricing and tax systems and reforming energy legal structures.
3. Promoting active regional/international cooperation, including for rehabilitation of the existing energy facilities, and expansion of the energy system through accommodating foreign investments.
4. Adopting cost-effective energy options in rebuilding the DPRK energy sector, including increasing the role of petroleum in the DPRK’s energy mix while at the same time pursuing in parallel the development of new and renewable energy in the short term, and development of natural gas in the medium-long term goals.
5. Strengthening the energy policy-making capability in the DPRK by improving energy statistics and modeling infrastructure, and through training of energy experts and scientists.

ROK--DPRK cooperation in many of these areas is already underway, as reported by Dr. Kyung Sool Kim of KEEI in his presentation “Current Situation and Prospects of Energy Cooperation between Two Koreas”. Though Dr. Kim noted that the cooperative interactions between the ROK and the DPRK thus far have been “very limited”, they have included the supply of oil for a railroad interconnection, the supply of materials for road building, the development of the Gaesung (Kaesong) industrial district, and humanitarian aid related to the

[281] See also Peter Hayes, “Options for DPRK Energy Sector Engagement”, presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA. Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Hayes_Options.ppt.

2004 rail accident. Dr. Kim noted that possibilities for "Major Inter-Korean Energy Cooperation Projects", including transmission lines and gas pipelines involving the Russian Far East as well as the two Koreas[282].

8.2.1. 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, North Korea's largest trading partner, 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. The flow of such equipment from China to the DPRK China has in fact stepped up in recent years, as the rapid growth of trade in televisions and bicycles (to name just two products) attests. China is the DPRK's major energy supplier, and thus may have an interest not only in marketing equipment, but in reducing North Korea's dependence on (in some cases, reportedly subsidized) energy imports from China (particularly given China's own tight energy supplies).
- ***Pursue sector-based implementation of energy efficiency measures.*** One point made forcefully by studies of East European economies "in transition"[204] 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[283]. It is people at the sectoral level who must work with energy-using equipment daily to do their jobs who are most likely to be interested in energy-efficiency opportunities, rather than planners in a central ministry.

  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

[282] Kyung Sool Kim, "Current Situation and Prospects of Energy Cooperation between Two Koreas", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/KEEI.ppt. Dr. Kim also presented information on the potential cost, capacity, and other features of these and other options, placed possible cooperation on these projects in the context of the goals of the 6-Party Talks, and reviewed an agenda for cooperation opportunities in other sectors, including non-physical capacity building, capacity building in the energy market system, and cooperation in the coal, oil, electricity, gas, new and renewable energy, and other sectors.

[283] 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, apparently, 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

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 product output and higher product quality as well, resulting in high rates of adoption once the benefits of the measures have been appreciated by other manufacturers.

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 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.

8.2.2. 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 support and technical know-how amount that the South can offer the North. In addition, given the premise that the two countries will ultimately 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.

8.2.3. Work to open opportunities for Independent Power Producer 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 products and services can be compensated. A necessary condition for the implementation of IPP projects is the development of markets for electricity in the DPRK that would allow IPP companies to recover their costs and profit from their investments.

8.2.4. 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[205]. 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, or the further development of the Kaesong Industrial Park[284].
- Initiate a program of exchange focused around methods of and training in energy planning (and the data gathering needed to make such planning relevant), including consideration of the environmental and economic impacts of energy choices.

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

[284] Relatedly, for example, Won Bae Kim, in a 2008 presentation for the DPRK Energy Experts Working Group Meeting, March 8 and 9, 2008, Beijing, China, entitled " Design of Infrastructure Development in North Korea: A Practical Approach", available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/WBKim.ppt, advocated focusing on industrial zones in the "four corners" of the DPRK for infrastructure development to serve as a catalyst for overall DPRK economic redevelopment.

8.3.1. Rebuilding of the transmission and distribution 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 Report. 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, in counties where key industries for earning foreign exchange (such as mines) are located, or in the Kaesong 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.

8.3.2. 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 pollutant emissions, 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, many of which have reportedly had little or no heat, or have used biomass fuels for heating, in recent years. 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 difficulties.

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 in 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 help to boost magnesite production, and would bring much-needed additional 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 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 the impact of high and fluctuating HFO prices on the United States and other Six-Party Talks partners providing energy sector assistance to the DPRK.

8.3.3. 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 and equipment, in evaluation of coal resources, in mine ventilation systems, and (we guarantee) mine safety. The needs in this sector are so extensive, however, that no one should expect that substantial rehabilitation of the coal sector will happen quickly. For example, even once power is restored to mines, electrical and other equipment has been replaced or upgraded, and in-mine life support systems are adequate, in many mines it may take literally years before many coal galleries are pumped sufficiently free of water to be worked again. Coal processing to remove ash and improve fuel value could be another focus of assistance, as could the tapping of coalbed methane for use as a fuel[285] (and to improve mine safety).

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 diesel fuel to operate, 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.

8.3.4. 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 (some of which have been noted in Chapters 4, 6, and 7, above) 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 (see Figure 8-1), but it is clear that assistance would be helpful to produce more reliable and cost-efficient units, as well as to expand mass production.

[285] Methane is the chief component of natural gas. Once processed to remove water, CO_2, and other impurities, coalbed methane can be used in the same way and with the same equipment as natural gas, and can be injected into existing natural gas pipelines.

Figure 8-1: DPRK-made Mini-Hydroelectric Turbine-Generator[206]

- 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 (see Figure 8-2).

Figure 8-2: Water-pumping Windmill Installed by Nautilus and DPRK Engineers at Unhari in the Year 2000[207]

- 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 sure that the diesel fuel that is used in agriculture goes further. Improvements in motors and drives for electrically-driven agricultural equipment, such as rice threshers and mills, will stretch supplies of electricity.
- Building Envelope Improvement/Building Energy Efficiency. As noted in Chapter 4, the thermal efficiency of building envelopes in the DPRK—the efficiency with which buildings keep heat in and cold out, or vice versa (depending on the season), is generally quite poor. Existing multi-unit residential buildings and commercial/institutional buildings in the DPRK are typically made of precast concrete or reinforced concrete pillar construction, with the

walls filled in with concrete blocks and mortar. Few such building have any substantial insulation, and those that do may have some insulation made of lightweight concrete, which has far less insulation value than modern insulation materials. Cooperation on building energy efficiency including production (or, initially, import) and use of insulating materials, collaboration on development of building designs in the residential and commercial/institutional sectors with excellent thermal properties, and production or import of key building components that would contribute to high-efficiency buildings (doors, windows, radiators, heat controls, and other components) is one of the most important options to pursue from the energy savings, economic, environmental, and humanitarian perspectives. It is also an option very much of interest to the DPRK, as witnessed, for example, by a presentation provided by a DPRK delegation at the 2008 DPRK Energy Experts Working Group Meeting, March 8 and 9, 2008, Beijing, China, entitled "Introduction of the Building Sector in DPR Korea", and including conceptual designs of energy-efficient buildings (see Figure 8-3) among other details[286].

Figure 8-3: Conceptual Residential Building Design from 2008 DPRK Presentation

- 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). As noted above, this measure has reportedly been taken up by the DPRK government, with distribution of CFLs to many households. 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

[286] Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DPRKBuilding.ppt.

improvement in the lives of ordinary Koreans (see Figure 8-4), as residents have found the improvement in light quality in their homes from installing CFLs to be considerable.

Figure 8-4: Compact Fluorescent Light Bulb Installed in DPRK Residence During the Unhari Project, 1998[208]

- 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.

8.3.5. 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 for the basic needs of the rural population to be met. The priority areas for rehabilitation 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. Some imports of tractors themselves may be necessary, as many of the DPRK tractors have suffered for years from lack of spare parts and poor fuel quality. A capital construction program for rural energy 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. An integrated, county-level project of rural rehabilitation would be more useful, and a more useful example for similar work in other areas of the country, than piecemeal efforts in many locations.

Another key element of rural rehabilitation with links to the energy sector is rehabilitation of the agricultural sector. The United Nations AREP (Agricultural Recovery and Environmental Protection) project in the DPRK noted a number of agricultural sector problems that, if addressed, would likely help to improve consumable crop production per unit energy input, including reducing post-harvest losses and early crop consumption, ensuring that field operations (tilling, planting, fertilization) occur at the right time of year (and have the inputs available to do so), optimizing fertilizer application (amount, type, and timing),improving seed stocks, and other improvements[209]. Post-harvest crop losses and early crop consumption alone have been estimated to reduce usable crop production by 20 percent in the DPRK.

8.3.6. 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[287]. The driving force for the implementation of such interconnections, in

[287] See, for example, Alexander Ognev and Ruslan Gulidov, "Russia – DPRK Electricity Cooperation: the Role of INTER RAO UES Company at Current Stage", prepared for the DPRK Energy Experts Working Group Meeting, March 8 and 9, 2008, Beijing, China, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/RussiaDPRK.ppt, Yoon Jae-young, "Analysis on DPRK Power Sector Data & Interconnection Option", prepared for the same meeting, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Yoon.ppt, and another presentation by the same author, entitled "Analysis on DPRK Power Industry & Interconnection Options", prepared for the 2010 DPRK Energy and Minerals

the medium-to-long term, will be, as noted above, the need to provide a means of safely "turning on" reactors built on the Sinpo site (in the event that construction is resumed) once they are complete (at this point, probably no earlier than 2018, if indeed they are ever completed at all), and/or to provide a means of transferring significant amounts of power from the ROK to the DPRK, as proposed by the ROK in 2005.

8.3.7. 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.

8.4. Conclusion

In this report we have provided our best estimate of DPRK energy supply and demand in the years 1990, 1996, 2000, 2005, 2008, and 2009. Despite what some observers report as a turn-around in the DPRK economy in the early years of the decade of the 2000s, and in some more recent years in addition (at least in some areas), our estimates are that on a nationwide basis the DPRK's energy supplies of commercial fuels, and probably wood and biomass as well, remain extremely limiting. 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.

Working Group Meeting, September 21st-22nd, 2010, Beijing, China, available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/01.-Yoon.ppt.

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