Modernizing the US-DPRK Agreed Framework: The Energy Imperative

February 16, 2001

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EXECUTIVE SUMMARY

- The Agreed Framework—the 1994 agreement between the United States and the Democratic People's Republic of Korea (DPRK) under which the DPRK is to be supplied with two light-water nuclear reactors for electricity generation in exchange for abandoning its existing nuclear reactors—is the underpinning of current US Policy with regard to North Korea. Abandoning or unilaterally gutting the Agreed Framework risks serious setbacks in US-DPRK and DPRK-ROK relations, and would be seen as a major breach of trust by the DPRK
- The Agreed Framework is not, however, a treaty, or even an agreement in any binding sense. It simply is a set of guidelines to align the behavior of the two state parties to allow them to walk forward in tandem, but separately. Along the way, there may be—and already have been—many and substantial detours. As long as the essential milestones are met by each party, the Agreed Framework has increased the predictability of each party's behavior with respect to the other, and has thus reduced the level of uncertainty that each party has with respect to the other's behavior. There is nothing in the Framework to stop the two parties from reformulating it and it is both likely and reasonable that after seven years the Agreement would need updating to account for new circumstances affecting the vital interests of both parties. It is inevitable that the new US Administration and the DPRK will need to come to terms on a new, modernized Agreement that serves the current needs of both parties while maintaining the diplomatic gains of the Framework to date.
- The United States could consider offering a package of infrastructure assistance to the DPRK in exchange for changes in heavy fuel oil (HFO) deliveries. The United States currently bears the cost for purchasing and delivering 500,000 metric tonnes of HFO to the DPRK each year until the reactors to be provided to the DPRK under the Framework are complete. By the

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time that the reactors have been completed, the net present value of these deliveries could be 530 to 700 million USD, based on recent oil prices. Given this expense and the limited utility of HFO in the DPRK, the Administration could explore with the DPRK alternative services—grid refurbishment, power plant and boiler rehabilitation, fuel supply infrastructure rebuilding, and alternative electricity sources and energy-efficiency improvements—that the United States could provide with a portion of the funds now earmarked for HFO purchases. The United States could, for example, offer to spend perhaps 50 to 75 percent of the value of the agreed-upon HFO deliveries, spreading the spending over these priority areas at $50 million or more per item over 5 years, limiting US costs and providing the DPRK with immediate, high value assistance on key energy sector issues with little or no risk of military diversion. Revising the Agreement so as to work with multinational banks and other partner countries to provide a coordinated and balanced package of energy sector assistance to the DPRK is also worth considering.

- The US commitments to the Agreed Framework are modest relative to those of our key allies in Northeast Asia. The Republic of Korea, and to a lesser extent Japan, are responsible for the lion's share of the financing and delivery of the nuclear reactors that are being built in the DPRK under KEDO auspices. In terms of its contribution to regional security, and relative to the considerable human, political, and financial cost to the United States of a military conflict or crisis in the region, the US contributions to Agreed Framework activities are a bargain.

- The DPRK energy infrastructure is disintegrating in many ways. The national electrical grid is essentially non-existent, operating, at best, as a collection of unreliable regional grids using poorly-maintained equipment that is 50 years out of date to begin with. Power quality, even in Pyongyang, is very poor. Coal mines have been flooded, and coal production is hampered by electricity shortages. The transport system is operating at a small fraction of its level of only a decade ago, meaning that in many instances, coal, even if it were mined, cannot reach consumers.

- The most effective course for the DPRK is an integrated, coordinated effort to rebuild existing energy infrastructure, develop alternative energy resources, build or rebuild key non-military foreign exchange-earning industries, increase energy efficiency, and meet humanitarian needs. The United States is in a position to assist such an effort through provision of technical know-how and training, support for joint ventures and independent power production, limited provision of technology, and support for intervention by the World Bank in the DPRK power sector. In terms of building confidence and trust between the DPRK and the United States, and, in fact, between the DPRK and the rest of the world, incremental, local measures where hard-working, helpful Americans work side-by-side in the DPRK with North Koreans are extremely valuable. Focusing on infrastructural (fuel supply and fuel/electricity delivery) and energy-efficiency investments will help to assure that the energy that is available within the DPRK provides maximal benefits to the DPRK people with minimal waste.

- The integrated nature of the DPRK's energy sector problems require coordinated action on many fronts at once. This will not be possible to carry out on a nationwide basis. As a consequence, projects that take a "holistic" approach to refurbishment and updating of energy and related infrastructure in local areas of the DPRK—perhaps on the county or smaller level—are a logical place to start.

- The DPRK electricity grid must be substantially rebuilt if the nuclear reactors provided as part of the Agreed Framework are to operate as intended. Nuclear reactors of the size of those being provided require reliable back-up power, and have difficulty in adjusting their output as demand changes ("following load"). The DPRK grid is so unstable that unless it is substantially rebuilt to modern standards, outages triggering shut-down of the reactors are likely to occur frequently enough to cause nuclear safety concerns. In fact, the DPRK grid, even if it were in prime condition, is too small to safely operate the KEDO reactors without an intertie to the larger ROK, Russian, and/or Chinese grids.

- What are **NOT** needed in the DPRK now, or for the next decade or so, are new, large, coal-fired power plants. Even if such plants were built, it is unlikely that the DPRK domestic coal production and transport system, in its present condition, would be able to fuel the new plants, and DPRK coal is often of poor quality, and thus possibly problematic for use in modern coal-fired power plants. Furthermore the DPRK's nominal electric generation capacity is much higher than the capacity that is actually operable at present; therefore the most cost-effective investments will be in refurbishing existing plants, not building new plants that the North Koreans will not be able to operate. Fueling coal-fired plants with imported fuel requires foreign exchange, which at present the DPRK can only earn in quantity by selling arms.

- Providing coal-fired power plants, or, as the DPRK has requested, providing a transmission line to carry 500 MW of power from the ROK to the DPRK, are examples of impossible "quick fixes". Such piecemeal proposals at best divert attention from fully addressing the needs of the DPRK energy sector, and, at worst, offer excellent opportunities for technical and political failure. In the case of the transmission line request, the poor technical match between the ROK and DPRK grids means that the two systems cannot be connected in any substantial way without 1) huge South-to-North power transfers to stabilize the DPRK grid, 2) the construction of a considerable amount of generation capacity in the DPRK, 3) isolation of a small portion of the DPRK grid with only that portion served by the line from the ROK, or 4) a large AC to DC to AC converter station at the border. Each of these options is administratively difficult and/or (mostly "and") will both cost hundreds of millions to billions of dollars and take years to show substantial results.

TABLE OF CONTENTS

1. Introduction

In this study, we present our best information and advice regarding the future direction of US policies related to the energy sector in the Democratic Peoples' Republic of Korea (DPRK, sometimes referred to as "North Korea").

This study contains the following sections:

- A summary of the **Agreed Framework** signed by the United States and the DPRK in 1994, including a brief history of the Framework, a summary of the Framework's status, and a suggestion as to how the Framework might be by agreement reconfigured so as to better meet the needs of both parties (Section 2 of this memo).
- A summary, including a general review over the last half-century, and a closer look at the last decade, of the **evolution of the DPRK economic and energy situation**, as well as changes in the relations of the DPRK with other nations (Section 3 of this memo).
- A review of key **problems in the DPRK energy sector**, including our view of the ramifications of these problems for US policy (Section 4 of this memo).
- An outline of key areas where US **assistance and leadership in energy sector issues** will help North Koreans to help themselves, and contribute to further easing of tensions on the Korean Peninsula (Section 5 of this memo).
- A roster of policy options that, in our opinion and experience, the United States should **avoid** in addressing DPRK energy sector issues (Section 6 of this memo).

As such, this memo is of necessity a brief treatment of a set of very complex issues. Nautilus Institute would be pleased to provide additional information on specific topics of interest to the Administration.

2. The Agreed Framework: History, Status, and Options

2.1. History of the Agreed Framework

As a condition of the October 1994 Agreed Framework signed by the governments of the United States and the Democratic People’s Republic of Korea (the DPRK), the DPRK is to be supplied two pressurized-water-type light-water nuclear reactors (referred to as LWRs) for electricity generation 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 Sinpo in the DPRK) began in August of 1997 with an official groundbreaking attended by project personnel from several countries. Until the reactors are completed, the Korean Peninsula Energy Development Organization (KEDO) has an obligation under the Framework to supply 500,000 metric tonnes (te) of heavy fuel oil (HFO) to the DPRK annually. KEDO oil deliveries started in 1995. The oil delivered by KEDO is intended to be used to fuel electricity generation facilities, and the use of KEDO HFO in the DPRK is subject to monitoring by KEDO.

2.2. The Agreed Framework is Not a Treaty

The Agreed Framework is not a formal treaty or even an agreement in any binding sense. It is simply a set of guidelines that helps to regulate and render more predictable the behavior of the two state parties toward each other; to allow them to walk forward in tandem, but separately. Along the way, there may be—and already have been—many and substantial detours. As long as the essential milestones are met by each party to the agreement, however, the Agreed Framework has increased the predictability as to each party's behavior with respect to the other, and reduced uncertainty on both sides. There is nothing in the Framework to stop the two parties from reformulating the agreement in a mutually agreed-upon manner. Furthermore, it is both likely and reasonable, after seven years, that the Agreement would need updating to account for new circumstances affecting the vital interests of both parties. It is inevitable that the new US Administration and the DPRK will need to come to terms on a new, modernized Agreement that serves the current needs of both states while maintaining the diplomatic gains of the Framework to date.

2.3. Consider Offering a Package of Infrastructure Assistance to the DPRK in Exchange for Changes in HFO Deliveries

The United States currently bears the cost for purchasing and delivering, via KEDO, 500,000 metric tonnes of heavy fuel oil to the DPRK each year. Deliveries are scheduled to continue until the LWRs provided via KEDO are complete, which, realistically, could be between 2007 and 2010. International HFO prices roughly doubled during 1999. Assuming that the average price paid by KEDO for HFO in the first half of 2000, approximately $190 per tonne, holds through the end of KEDO HFO deliveries, the annual cost of fuel oil delivered to the DPRK will be $95 million. Through completion of the LWRs, the net present value of these deliveries would be some 530 to 700 million USD.

HFO was chosen as the fuel to be supplied to the DPRK under the Agreed Framework because it has limited uses in the DPRK, and, particularly, is practically useless to the DPRK military. HFO from KEDO is intended for use in electricity generation and heating plants, but there is only one large generating plant in the DPRK designed specifically to use HFO. This plant, located on the DPRK's Northeast coast, lacks the capacity to annually utilize the entire 500,000 tonnes of HFO. As a consequence, KEDO HFO is also used to some degree in plants designed to be fueled with coal, meaning that KEDO must deploy relatively expensive monitoring equipment at a number of different sites. Heavy fuel oil is also relatively high in sulfur, which may cause problems in DPRK boilers.

Given the considerable expense of HFO, and the limited utility of HFO in the DPRK, we suggest that the Administration consider exploring with the DPRK alternative services that could be provided with a portion of the funds now earmarked for HFO. Tapering down oil deliveries, and using the savings (or a portion of the savings) to fund activities such as refurbishment of existing power plants, aid for grid planning and modernization, supplying energy-efficiency services, and providing assistance with harnessing renewable energy would help many of the "putting the horse back in front of the cart" activities described in section 5 of this study to get well underway. In addition, expenditures that formerly went "up in smoke" would, at least in part, be recycled back to the United States.

Clearly any change in oil deliveries must be carefully negotiated with the DPRK and with KEDO partners. The DPRK's reaction to a proposal of a substitution of services and equipment for HFO is uncertain, but it seems to us that a package of services designed to upgrade the DPRK infrastructure, and to be delivered so as to displace HFO deliveries at an acceptable rate, might be of considerable interest to the DPRK. Alternatives include supplying only enough oil for the oil-fired plant, or having one of the services provided be an upgrade to the oil-fired plant to make way for when the refinery with which the plant is associated goes back on line. Another alternative is to offer to provide, in exchange for reducing HFO deliveries, some coal for existing power plants for a limited time. Note that this latter alternative would need to be coupled with assistance in refurbishing selected DPRK coal-fired power plants.

As just one example of such a "trade", the following might be considered. The United States could make an offer to the DPRK that the United States would spend perhaps 50 to 75 percent of the expected net present value of the agreed-upon HFO deliveries (perhaps $260 to $500 million), spreading the spending over the five priorities areas identified in section 5 at $50 million or more per item over 5 years, or $10 million per priority per year for five years. This type of approach limits (and reduces) US costs, and provides the DPRK with more assistance "up front" in areas that make it better able to peacefully help itself. Alternatively, the United States could offer to concentrate funding on one of the priorities. In order to make sure, however, that other priorities get the necessary attention, such assistance would need to be tied to opening the doors for World Bank (IBRD and IFC) involvement in the DPRK energy sector—by taking the DPRK off of the "terrorist list"—and working out a division of donor responsibility whereby, for example Japan takes on one of the major priority assistance areas, the ROK another, and the EU another, with coordination by an organization like KEDO. Such a scenario could be attractive to both the DPRK and the United States in that the DPRK gets a "multiplier effect" in assistance in exchange for cooperating, the United States' costs are reduced, and opportunities for US firms in the DPRK are potentially opened up in ways that a pure program of HFO purchase and delivery could never hope to facilitate.

3. Summary of the overall economic and energy situation in the DPRK

In the pages that follow, we provide a brief review of the history of the economy and energy sector of the DPRK. This information is intended as a cursory introduction to energy sector issues, and is drawn from Nautilus' considerable experience in analysis of Korean energy, security and policy issues going back to 1980, as well as experience working in the DPRK itself.[2]

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[2] 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 scenarios 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 scenarios for the DPRK to 2005 (D.F. Von Hippel, and P. Hayes, Demand and Supply of Electricity and Other Fuels in the Democratic Peoples' Republic of Korean (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);

3.1. The Economic Trajectory of the DPRK

Kim Il Sung and his government were able to rebuild the North Korean economy by focusing on economic autarchy, state-owned heavy industries such as the extraction and refining of minerals, and collectivized agriculture. The resulting economy was energy intensive, relying on imported oil, domestic coal, and hydroelectric power. In 1990, estimated per capita energy use in the DPRK was more than twice that of China in the same year, and over half that of Japan's.

3.1.1. Changes in the DPRK since 1990

The economic, if not social and political, landscape in the DPRK has changed markedly during the 1990s. Although little data have been available from inside the DPRK, information from outside observers of the country indicates that the North Korean economy has been either stagnating or in decline virtually every year since 1990. Key causes of this decline have been:

- The decline and eventual collapse of the Soviet Union, and the resulting reduction in Soviet/Russian economic aid to the DPRK. Over just a few years, subsidized oil shipments, technical aid, and imports of parts for Soviet-designed factories declined to a few percent of their pre-1990 levels. The collapse of the USSR also meant that most DPRK exports, earmarked for the consumers and factories of the Soviet Union and Eastern Europe, suddenly had no markets. Although North Korea has raw materials, particularly minerals, that are of interest to trading partners, it at present produces few finished goods (with the exception of armaments) that are of high enough quality to attract international buyers.
- A decline in aid from China as a result of economic reforms in the PRC. In total, it is estimated that the DPRK economy may have lost $1 billion in annual aid from China and the USSR over the past decade.
- Poor grain harvests in the early 1990s, exacerbated by droughts, flooding, tidal surges, and typhoons in the latter half of the 1990s, plus lingering environmental damage from poor agricultural practices. The result, as the world has seen, has been an acute shortage of food throughout most of the decade. Apart from the overriding human concerns associated with the food shortage, the slow starvation of the DPRK populace decreases economic production still further, as poorly-fed people are less capable of work.
- Economic isolation caused by internal DPRK politics, a significant trade deficit, trade sanctions, and the lack of availability of domestic or international capital.

Economic decline has been both a result and a cause of substantial changes in energy demand and supply in North Korea over the last decade. On the supply side, changes have included a significant drop in oil imports, a steady decline in the exports of coal to China. In addition, flooding in 1995 and 1996 inundated key coal mines, and severely damaged major

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and a long-term project, which to date has included three missions by U.S. engineers to the DPRK, to provide wind-powered electricity generation, electricity storage, efficient electric end-use equipment, and water pumping windmills to a flood-affected village in a rural area of the DPRK. In the latter project, Nautilus engineers have worked (and played) side-by-side with North Korean counterparts to construct facilities in the village. The project has also included what is to our knowledge the first systematic survey of rural energy use ever carried out in the DPRK. (J. Williams et al, "The Wind Farm in the Cabbage Patch", Bulletin of the Atomic Scientists, May/June 1999).

hydroelectric facilities. Figure 1 presents a summary of selected energy supply flows in the DPRK in 1990 and 1996.

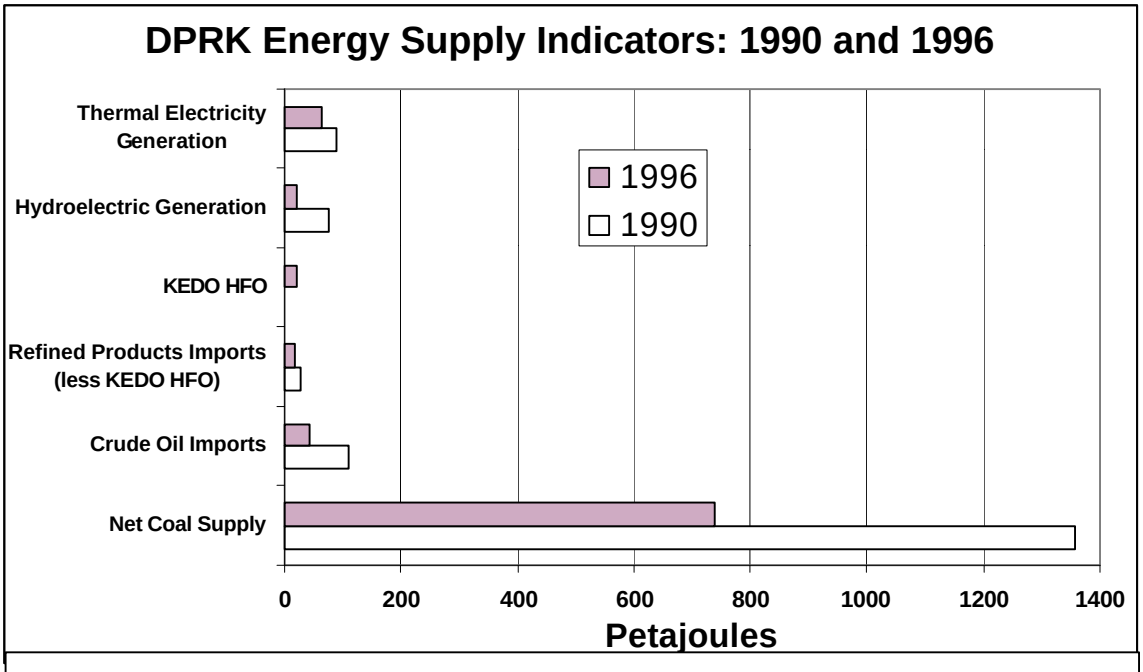

FIGURE 1: Selected Energy Supply Indicators in the DPRK. One Petajoule (10^{15} Joules) is equal to approximately 24,000 tonnes of oil equivalent.

On the demand side, the lack of electricity, diesel fuel, and spare parts for trains and trucks has crippled the system for transportation of goods (including coal) and people, while the lack of energy and markets for goods have reduced the output of heavy industries to a small fraction of 1990 levels. Residential and commercial lighting, heating, and cooking have been affected by energy shortages, with indirect effects on health, productivity, and the quality of life. Increased use of biomass fuels has exacerbated decades-old erosion problems. Hospitals are unheated in winter, lack electricity for lighting and medical equipment, and even lack fuel to boil water for human consumption. Negative "feedback loops" between and among energy and economic sectors exacerbate the situation. The lack of sufficient coal to run factories that craft spare parts or make steel means that there will not be sufficient spare parts to keep coal trains operating or enough steel to repair tracks, but, delivery of coal to factories is difficult because the trains are often not running. The lack of power idles coal mines, resulting in fuel shortages at power plants. Other examples of such unfortunate feedbacks abound and are discussed in Section 4 of this study.

3.2. Summary of the Overall Energy and Electricity Situation in the DPRK: 1990, 1996, and Beyond

DPRK energy supplies were at their historical maximum in 1989-90. Since that time, the combination of the economic decline described above and other influences have resulted in a severe contraction in the supplies and consumption of fossil fuels and electricity in the DPRK . Figure 2 shows the estimated changes in supplies of coal, electricity, oil, and biomass (wood and crop wastes) between 1990 and 1996, and Figure 2 shows estimated 1990 and 1996 demand for

commercial energy forms by sector in the DPRK. Coal constituted and continues to make up well over 80 percent of all non-biomass primary energy use in the country, but estimated coal output decreased by more than 50 percent between 1990 and 1996, and has probably declined significantly since. Supplies of crude oil, all of which is imported, had declined by 60 percent by 1996.

At present, to our knowledge, all of the crude oil entering the country is supplied via pipeline from China. The refinery that processes this oil constituted the source for most of the diesel, gasoline, and heavy fuel oil used in the DPRK in 1996 (and probably today), though some oil products are likely imported through barter or other arrangements. We have estimated that with the decline in availability of electricity and coal for household use, the use of biomass fuels (including wood, grasses, and crop wastes) has increased, but given the poor state of the forest stock in the DPRK, our estimate is more likely to be high than low. The distribution of fuels and electricity consumption by sector described in Figure 3 shows the very steep decline in industrial sector energy use between 1990 and 1996. Our own first hand—if anecdotal—observations, and those of others, indicate that industrial energy use is probably even less today than our 1996 estimates indicate. Residential sector consumption of fossil fuels and electricity is estimated to have decreased significantly between 1990 and 1996, but the largest decrease in sectoral energy use has probably been in the transport sector.

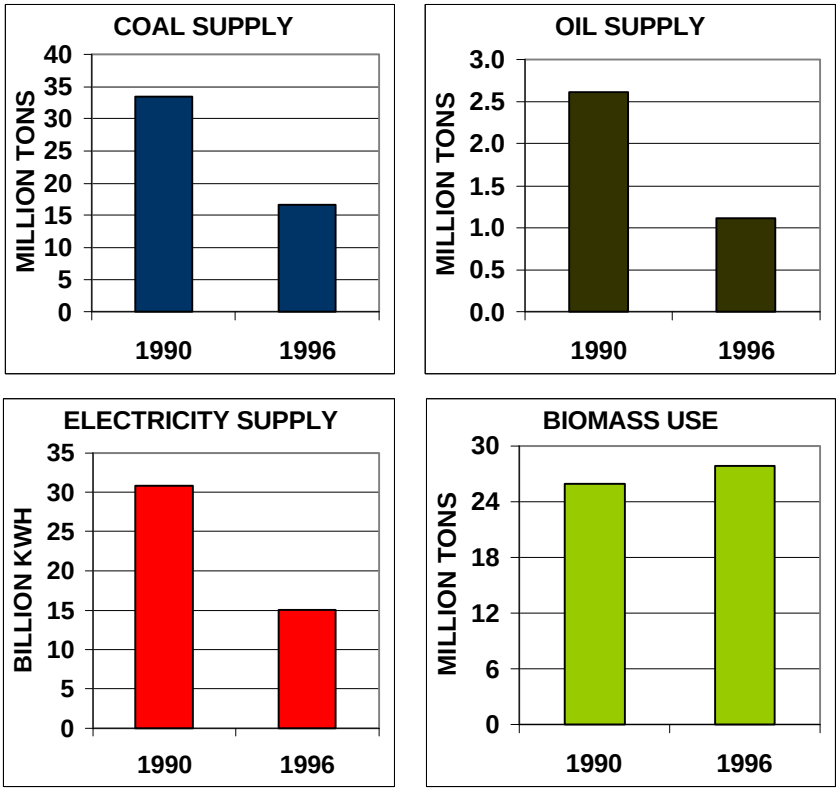

FIGURE 2: Commercial energy supply in North Korea, 1990 and 1996. All forms of commercial energy supply declined. Biomass energy use increased.

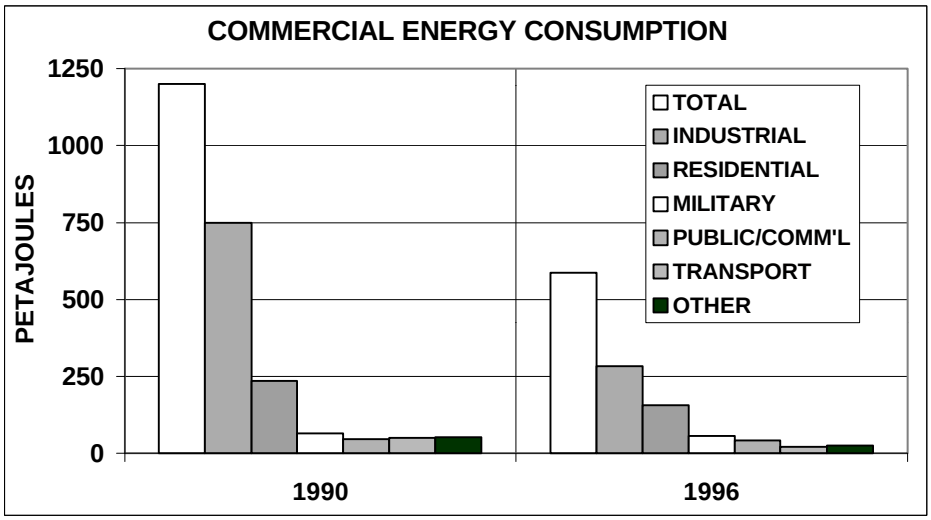

FIGURE 3: Commercial energy consumption in North Korea by sector, 1990 and 1996. Total estimated consumption fell by 51 percent during the period. Consumption decreased in all sectors, but by very different rates.

Electricity generation fell from about 46 terawatt-hours (TWh) in 1990 to about 24 TWh in 1996. In 1990, thermal (coal- and oil-fired) and hydroelectric power stations contributed approximately equally to electricity supply, but damage to large hydro plants in the north of the DPRK tipped the balance toward thermal generation by 1996. Since that time, the addition of small hydro stations and the repair of large ones have probably increased the fraction of electricity supplied by hydro, but it is likely that overall generation has fallen even further as a result of fuel supply and maintenance problems at power plants and at transmission and distribution facilities.

4. Specific Energy-sector Problems and their Ramifications

As noted above, the DPRK's supply of commercial energy has fallen by one-half to two-thirds or more in the last decade, with impacts felt throughout the economy. While the demise of the energy sector is just one result of, and one cause of, the DPRK's overall economic decline, it is clear that economic recovery will not occur without a major reversal of the present situation. Below, we briefly discuss several particular energy-sector problems with ramifications for ways in which energy-sector assistance to the DPRK can most usefully be provided.

4.1. Decay of the transmission and distribution grid

The electricity transmission and distribution grid has a nominal frequency of 60 Hz (cycles per second), and is designed to deliver 240 volts at the end-user (household) level. The main transmission lines in the DPRK are rated at 220 and 110 kV (kilovolts), with additional transmission and bulk distribution lines at 60 and/or 66 kV, and additional bulk distribution feeders at 10 and 3.3 kV. Though the DPRK grid is nominally a national system, evidence indicates that it operates as a collection of increasingly fragmented local grids. Even in the best of times (around 1990), the dispatch system was primitive by modern standards, with orders for

closing or opening of switches, for example, relayed by (unreliable) telex or telephone. A UNDP project carried out in the early to mid 1990s supplied the DPRK with a computer control system for use with one power plant and a limited number of substations near Pyongyang, but no significant additional progress in T&D modernization has occurred.

Concurrently, the lack of spare parts, reported scavenging of metal (for barter for food) from remote lines, and overall wear and tear degrades the T&D system. Even in Pyongyang, power outages are reportedly frequent, and in the village where we worked, only 100 km from Pyongyang, grid power was normally available to residents only between midnight and 5 AM. We measured grid voltages that ranged from 140 volts to about 200 volts, and frequencies from 48 to 52 Hz. Note that in a modern grid, fluctuations of even a tenth of a Hz are considered excessive. A series of power quality measurements taken in Pyongyang during a portion of the year 2000 indicate that an average of one blackout and several "brownouts" (low voltage incidents) were experienced just during business office hours each day. Grid voltages in Pyongyang recorded during this period averaged about 200 V, but voltage spikes more than 10 percent higher than the average voltage were common. Frequencies varied from less than 47 to more than 52 Hz, and frequency variations of 3 or more Hz during the course of a day occurred regularly.[3] . Given the poor state of the conductors and transformers in the distribution system, distribution losses are undoubtedly excessive as well.

The status of the DPRK grid has a special meaning for the utilization of the LWRs being supplied by KEDO. In short, without an extensive modification of the grid and a connection to another system—the ROK, China, or Russia—or a direct connection to another grid with a limited connection to the DPRK grid, the LWRs cannot be used. LWRs must have a stable source of back-up power for coolant pumps and other equipment, and must be operated such that the sudden loss of load is kept to an absolute minimum. Neither is possible with the DPRK grid as it is currently configured. Furthermore, the total capacity of generation included in the DPRK grid, even if it were all functional (which is far from the case) is too small to support two 1000+ MWe (megawatts of electric capacity) nuclear units.

Rehabilitating the DPRK T&D system will require new conductors, substation equipment, switching equipment, and perhaps above all, modern control facilities. Existing right-of-ways may be adequate, but in many places new towers or poles will be needed as well. The labor to accomplish these changes is readily available in the DPRK, though training will be needed in some areas. Rebar, channel iron, and cement can be supplied locally as raw materials for towers and supports, but grid-quality wire may not be available in-country without retooling a manufacturing facility specifically for the purpose, and even bolts and nuts are hard to come by in quantity. We have estimated the overall cost of grid reconstruction at 3 to 5 billion USD.

4.2. The DPRK Coal sector

Lacking oil or natural gas production facilities, the DPRK's sole domestic fossil fuel is coal. The DPRK has substantial reserves of anthracite and lignite coal, and most coal is produced from underground mines. Some mines are mechanized, but many are not. Coal is the principal fuel for electricity generation, but coal mining typically requires electricity for lighting, jackhammers, and moving coal out of the mines. Electricity shortages and T&D problems

[3] Greacen, C., (2000), Analysis of Pyongyang Grid Data from UPS Recordings. Internal Nautilus Institute study.

therefore reduce the amount of coal that can be mined. Key coal seams in the important Anju area actually lie beneath the seabed, and require seawater to be continuously pumped out in order for the mines to operate. Mines in the Anju area were flooded in the mid-1990s.

Coal quality in the DPRK varies across a wide range. We tested a sample of coal at 5000 kcal/kg, only slightly below an average US coal, but a reported range for DPRK coal is 1000 to 6000 kcal/kg, at some 12 to 65 percent ash. Coal at 1000 kcal/kg is little better, in terms of energy value, than dirt, and poor coal burns inefficiently, leaving a mountain of ash. It is not clear that DPRK coal, even if it were available in sufficient quantity, would be of high enough quality for use in a large modern coal-fired power plant.

Coal must be moved from the mines to power plants—most of which are located near population centers—and other consumers. The rail system is the primary mode of bulk transport in the DPRK, but it, too, suffers from advanced decay. The lack of diesel fuel, reliable electricity, spare parts, and steel for rails all contribute to decay. Coal reserves and coal mines sufficient to feed existing coal demand, and perhaps more, do exist in the DPRK, but it will realistically take many years before infrastructure rehabilitation allows the quantities of coal that can be extracted and moved to consumers to exceed even 1990 levels.

4.3. Electricity Generation Infrastructure--Current Status and National Goals

The installed capacity for electricity generation in the DPRK is on the order of 10 gigawatts (GWe, or thousand megawatts), approximately half of which is hydroelectric, and half thermal. Except for one 200 MWe plant that was built to use heavy fuel oil, essentially all of the thermal power is coal-fired. About 10 large thermal plants and 20 large hydro plants account for over 60 percent of capacity. A large number of small thermal plants have been reported, but may in fact have never been operable. The combination of lack of spare parts, maintenance difficulties at aging facilities, T&D constraints, fuel supply constraints, and damage from natural disasters means that the actual operable capacity in the DPRK is probably, by our estimate, more like 2 to 3 GWe at present.

The DPRK leadership, in practical recognition of the grid and fuel supply problems that the electricity system faces, is urging individual counties to develop, essentially, their own local electricity supplies and grids, focusing on small and mini hydroelectric facilities and (in the more distant future) wind power. These numerous small plants amount to about 500 MWe and may operate at low efficiency and capacity factors in the DPRK context. Meanwhile, additional development of larger hydroelectric facilities continues, but not rapidly.

4.4. The Impacts of Poor End-use Efficiency

End-use equipment in virtually all sectors is grossly inefficient in the DPRK. Domestically-produced electric and electronic devices would look familiar to Americans of the 1940s and 50s. The lack of modern alloys and casting methods mean that DPRK electric motors physically dwarf their modern counterparts of equivalent capacity. North Korean incandescent light bulbs are virtually unbreakable, but produce so little actual illumination that housewives clapped with delight when the replacement compact fluorescent bulbs we provided, even at one per room, were turned on. Coal-fired boilers are reportedly often less than 50 percent efficient, resulting in wasted energy and excessive pollutant emissions. Industrial plants were built by taking Soviet designs (already relatively inefficient) and "beefing them up" so that the plants

would survive under what Soviet engineers knew would be extra-arduous DPRK conditions. Systems for distribution of steam and hot water are highly likely to be porous as well. Tractors would be collectors' items in the United States. Even kerosene-style lamps—which are typically fueled with diesel oil—are for the most part just beverage cans with a wick inserted. The net result of inefficient end-use equipment is that the coal that does reach consumers, and the electricity that is generated (and isn't lost along the way) provide only a fraction of the energy services that they should. Fixing end-use equipment in the DPRK will be much cheaper than fixing the supply side, and will make existing fuel supplies go much further.

5. Providing Coordinated Assistance for the DPRK Energy Sector

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

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

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

5.1. Priority #1: Help to rebuild the T&D system

The need for refurbishment and/or rebuilding of the DPRK T&D system, and the types of materials and equipment that will be required, have been identified briefly earlier in this Memo.

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

5.2. Priority #2: Help to rehabilitate power plants and other coal-using infrastructure

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

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

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

Another early focus should be on rehabilitation of boilers in key industries that could help the DPRK to "bootstrap" the civilian economy. As a specific example, the DPRK has one of the world's largest deposits of the mineral magnesite, which is used in making refractory (furnace-lining) materials. Helping to rebuild the boilers or kilns that are used to produce magnesite, along with the fuel and ore-supply chains that feed them, would bring much-needed foreign exchange into the country. We suspect that with US government participation and guidance, a private sector partner from the United States 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 United States to provide the DPRK with coal for selected power plants in areas now poorly served by the existing coal and electricity supply systems. Providing such supplies, perhaps in an agreed-upon exchange for reduced HFO deliveries, would help restore humanitarian services and assist in economic revival while other energy sector upgrades are underway, and could reduce US exposure to high HFO prices.

5.3. Priority #3: Help to Rehabilitate 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. The US coal industry has significant expertise to assist with evaluating and upgrading coal mines in the DPRK, including improvements in mining technologies, evaluation of coal resources, mine ventilation systems, and (we guarantee) mine safety. Coal processing to remove ash and improve fuel value could be another focus of assistance.

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

5.4. Priority #4: Assist with Development of Alternative Sources of Small-Scale Energy and Implementation of Energy-efficiency Measures

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

- Small hydro turbine-generator manufacturing: Much of the rugged topography of the DPRK is well suited to small, mini, and micro-hydroelectric development, and the DPRK government has given its blessing for local authorities to undertake hydro projects. The DPRK does manufacture some small turbine-generator sets, but it is clear that assistance would be helpful to produce more reliable and cost-efficient units, as well as to expand mass production. From our factory visits we have noticed that the microhydro units currently manufactured in DPRK are a propeller/turbine variety. This is a difficult technology to build, as it requires bearings that operate submerged in water. There may be considerable gains to be had by introducing other microhydro turbine technologies such as cross-flow or pelton turbines that have proven easy and cost-effective to manufacture in other developing countries.
- Wind power: Likewise, the dissemination of wind turbines is a both a national goal and, from our first-hand observations, a keen interest of individuals in the DPRK. The barren ridges of the interior of the country are likely to be excellent wind power sites. The DPRK-manufactured wind generators and control components that we have seen, however, are at best grossly inefficient, and more likely non-functional. Design assistance and joint venture manufacturing of wind power systems are needed. A first phase might be the manufacture of lower-technology water-pumping windmills.
- Agricultural equipment efficiency measures: Helping North Koreans to feed themselves should be a high priority. The rice harvest in the DPRK is, based on our observations in the "rice basket" of the country, a nearly completely manual process. To increase productivity, improvements are needed in tractor design and maintenance (including spare parts manufacture) to make the diesel fuel that is used in agriculture go further. Improvements in

motors and drives for electrically-driven agricultural equipment, such as rice threshers and mills, will stretch supplies of electricity.

- Residential lighting improvements: Three or four times as many households can be supplied with much higher quality light with the same amount of electricity if DPRK incandescent bulbs are replaced with compact fluorescent light bulbs (CFLs). Ultimately, joint venture manufacturing (or at least assembly) of CFLs in the DPRK could be undertaken, but until then provision of CFLs of robust quality should accompany any local power supply or T&D improvement initiative. We have found this measure to be invaluable for securing grassroots support, as it provides a direct and tangible improvement in the lives of ordinary Koreans.
- Industrial and irrigation motors: The opportunities for efficiency improvement in large electric motors and motor drive systems are estimated to be considerable. Imports of efficient motors, pumps, air compressors, and other motor-related equipment may be the first step (once power quality has been improved sufficiently), followed by assistance in setting up facilities to manufacture or assemble equipment in the DPRK. Improving the reliability and efficiency of irrigation pumps will help the DPRK move toward feeding its populace.
- Power Back-up systems: For critical loads such as hospitals there is a huge need for reliable electricity. Inverter/battery/generator backup systems, possibly integrated with small scale renewable energy options such as wind power (see above) can ensure 24-hour electricity in areas where grid power may only be available intermittently or not at all.
- 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.

5.5. Priority #5: Work to Open Opportunities for IPP Companies to Work in the DPRK

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

6. Policy Options to be Avoided

Various groups have recently suggested changes in the course of US policy regarding the DPRK energy sector. Although some change in policy is inevitable, some of the changes that have been suggested are, in our opinion, inadvisable. Unilaterally abandoning the Agreed Framework and providing large coal-fired power plants (in connection with changes in the Agreed Framework or otherwise) are two of these "policies to be avoided"[4].

6.1. Update, but Do Not Abandon, the Agreed Framework

The Agreed Framework is the underpinning of the current US-DPRK relationship. Breaking the agreement would be seen as a major breach of trust by the DPRK. The transfer of LWR technology included in the Agreed Framework is sought by the DPRK as a means to maintain both a civilian nuclear program and a studied ambiguity as to its nuclear proliferation intentions. For the United States, the ROK, and Japan, the attraction of the Framework is that it is, and has been, a means to start the thawing of relations with the DPRK, a way to lessen the probability of nuclear weapons proliferation, and a means to exert better international control over the DPRK nuclear program. Despite its shortcomings—of which DPRK engineers are abundantly aware—the LWR transfer is a necessary first step to a political opening by North Korea, an opening that could lead to investments 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. The burden for financing the LWR transfer rests mostly on the ROK, which has both the most to gain and to lose by the success or failure of the Framework. If the United States were to unilaterally abandon the Agreed Framework, it would not only seriously affect US-DPRK relations, but would likely have a negative effect on US-ROK and US-Japan relations as well. Under such circumstances, US influence in the region might well erode, with the slack being taken up by other regional powers. Negotiating with the DPRK to update certain provisions of the Agreed Framework, however, is both possible and reasonable, as we indicated in Section 2 of this study.

6.2. Do Not Provide New Coal-Fired Power Plants Until the Refurbishment of the Electric and Coal Infrastructure is Well Underway

It has been argued that the drawbacks of the LWR transfer, including the technical issues described earlier in this memo, the high cost of the reactors, and the increase, once the reactors begin to run, of stocks of nuclear material in the DPRK, make it appropriate to renegotiate the Agreed Framework so as to replace one or both of the LWR units with coal-fired power plants. There are several reasons why we do not believe this to be prudent, including:

- The civil engineering work done so far at the LWR site may be only partially applicable to a coal-fired power plant at the same location. Though the site is probably technically suitable

[4] Sokolski, H. (2000), "This Is No Way to Curb the North Korean Threat". Nautilus Institute Policy Forum Online (PFO 00-07A: October 29, 2000). Note that in the referenced document Sokolski refers to substituting a "non-nuclear" power plant for the first LWR unit to be provided under the Agreed Framework, but does not specify the type of fuel to be used.

for the large flows and storage of fuel and wastes inherent in a coal-fired power operation[5], its location far from major electricity loads, though desirable for a nuclear plant, is sub-optimal from a power transmission standpoint for a coal-fired plant.

- The ROK and Japan, who are providing funding, labor, and technology for the project, are likely to be much less interested in assisting with a coal-fired plant. It seems likely that the ROK will ultimately end up operating the LWRs, quite possibly as an extension of the ROK grid. Their interest in adding a coal-fired plant to that grid is likely to be considerably lower than adding an LWR, with which they now have considerable experience. US insistence on switching to coal-fired power may leave the United States footing the bill, will likely raise costs (as the ROK's labor input would be lower), and leaves the United States or US firms holding DPRK debt.
- As noted earlier, the short-to-medium-term availability of coal in the DPRK, due to mining infrastructure and coal transport constraints, is problematic at best. Extracting and delivering the 7 million tonnes of domestic coal per year that 2 GW of coal-fired plants would consume is likely to be an impossible task for years even if a substantial program of coal infrastructure rehabilitation began today. Even if it were possible, providing this quantity of fuel would mean diverting it from other areas of the DPRK economy, causing shortages elsewhere (and probably among those who are the most at risk). Importing that quantity of coal annually would cost hundreds of millions of dollars that the DPRK does not have, meaning that either A) imports would have to be heavily subsidized by the United States or others, B) the DPRK would finance its needs for foreign exchange with more exports of armaments, or C) the plants would largely sit idle. By design, fuel costs per unit of energy generated are much lower for LWRs than with any fossil-fueled plant. The fuel and operating costs that the DPRK would bear in producing power with a coal-fired plant would be far higher than with the nuclear plant. Given the favorable terms for the DPRK's repayment of the LWRs' capital costs, the higher fuel and operating costs for a coal-fired option will make that option considerably more expensive (many billions of dollars over the plant lifetime), and thus considerably less desirable to the DPRK, than the LWRs.
- Though the nuclear safety concerns related to LWR operation in a shaky grid system would not apply to a coal-fired plant, any plant built within the DPRK grid faces the same problems in distributing its output. Building a different type of plant will not solve the grid-related problems that are obstacles to running any large generating plant at the LWR site.
- A large coal-fired power plant installed in the DPRK will either require coal of consistent quality, or will need to be designed to accept the widely varying levels of coal quality available in the DPRK. It is unclear that large, modern, Western-style coal plants would be suitable to the coal available in the DPRK. Spare parts from Western sources will be needed to keep the plant running, and maintenance needs under DPRK conditions may be greater than expected.
- Finally, the transfer of a large coal-fired power plant will not be of interest to the DPRK, which has had coal-fired plants for years and probably will not be actually short of coal-fired capacity for years to come. Coal-fired power neither provides the international status of nuclear power, nor provides much of an opportunity for the DPRK to learn something new.

[5] Special care in constructing a coal-fired plant at the LWR site may need to be taken to prevent contamination of surrounding waters from runoff from coal and waste piles.

It is probable that a US offer of a coal-fired plant in the place of the LWR will divert DPRK policy makers from attending to systematic solutions to structural problems, steering them instead towards piecemeal approaches that are likely to fail. As an example of the latter, the DPRK has recently told the ROK in negotiations that it "wants 500,000 kW [of] power to be promptly supplied to the DPRK through a transmission line".[6] Although this request on its face may not appear terribly unreasonable, the poor match between the size, frequencies and stabilities of the ROK and DPRK grids means that the two systems cannot be connected in any substantial way unless 1) enough power were to flow northward to stabilize the demand/supply balance on the DPRK grid and bring the frequency up to ROK levels, 2) enough reliable generation capacity were to be built in the DPRK to allow the grid frequencies in the two countries to be matched, 3) the portion of the DPRK served by the line from the ROK was isolated from the rest of the DPRK grid, or 4) a large AC to DC to AC converter station was built at the border in order to allow the exchange of power without matching frequencies. With the possible exception of isolating a portion of the DPRK grid, which is administratively difficult and still fairly expensive, each of these options would take years to carry out and would cost hundreds of millions to billions of dollars[7]. A major transmission line between the countries will likely eventually be implemented, but, like, a major coal-fired plant, will not work without a foregoing coordinated effort to shore up all of the other elements of the DPRK energy infrastructure. Focusing on an impossible "quick fix" from either a transmission line or a new coal plant is likely to result in technical and political failure that could stymie the process of rapprochement.

7. Conclusion

From the outside, the DPRK's manifold energy sector problems would seem to be an intractable morass indicative of the imminent collapse of a society. No one, however, should underestimate the toughness, discipline, or ability to endure privation of the North Korean people—especially given the extraordinary social and political control exercised by the DPRK Government. A US-backed, coordinated, program of grass-roots energy-sector assistance to the DPRK would yield huge dividends in terms of confidence building and regional security—dividends such as avoiding the costs of conflicts, maintenance of US influence in the region, and ultimately, profits for US businesses as well. Such a program, carefully designed and negotiated, could start in one or more local areas of the DPRK and work with DPRK authorities to provide energy infrastructure rehabilitation, energy efficiency measures, opportunities for earning foreign exchange, and harnessing of new sources of energy. At the same time, in order to retain credibility with the DPRK, the United States must abide by its commitments to date, including the Agreed Framework. Attempts to, for example, substitute coal-fired power plants for the LWRs specified in the Agreed Framework will be unacceptable to the North Koreans, uninteresting to the South Koreans, impractical for fuel supply, electricity T&D, and likely fuel quality reasons,

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[6] Chosun Ilbo ("NO AGREEMENT ON ELECTRICITY SUPPLY," Seoul, 02/08/01) as summarized in Nautilus Institute's Northeast Asia Peace and Security Network Daily Report (an electronic mail news digest service provided by Nautilus), February 9, 2001.

[7] In the case of the AC-DC-AC converter option, an added drawback is that the converter system—which would cost hundreds of millions of dollars to purchase and set up—would be rendered entirely obsolete if the ROK and DPRK grids are joined at some point in the future.

and could cause an unfortunate policy backlash. The DPRK propaganda machine is expert at providing unflattering (at best) portraits of Americans and the United States. Placing Americans in positions to provide aid to and work with North Koreans is, in our experience, the surest way to counter the influence of these images, to win the confidence of the North Korean people, and, ultimately to contribute to improvements in security on the Korean Peninsula.