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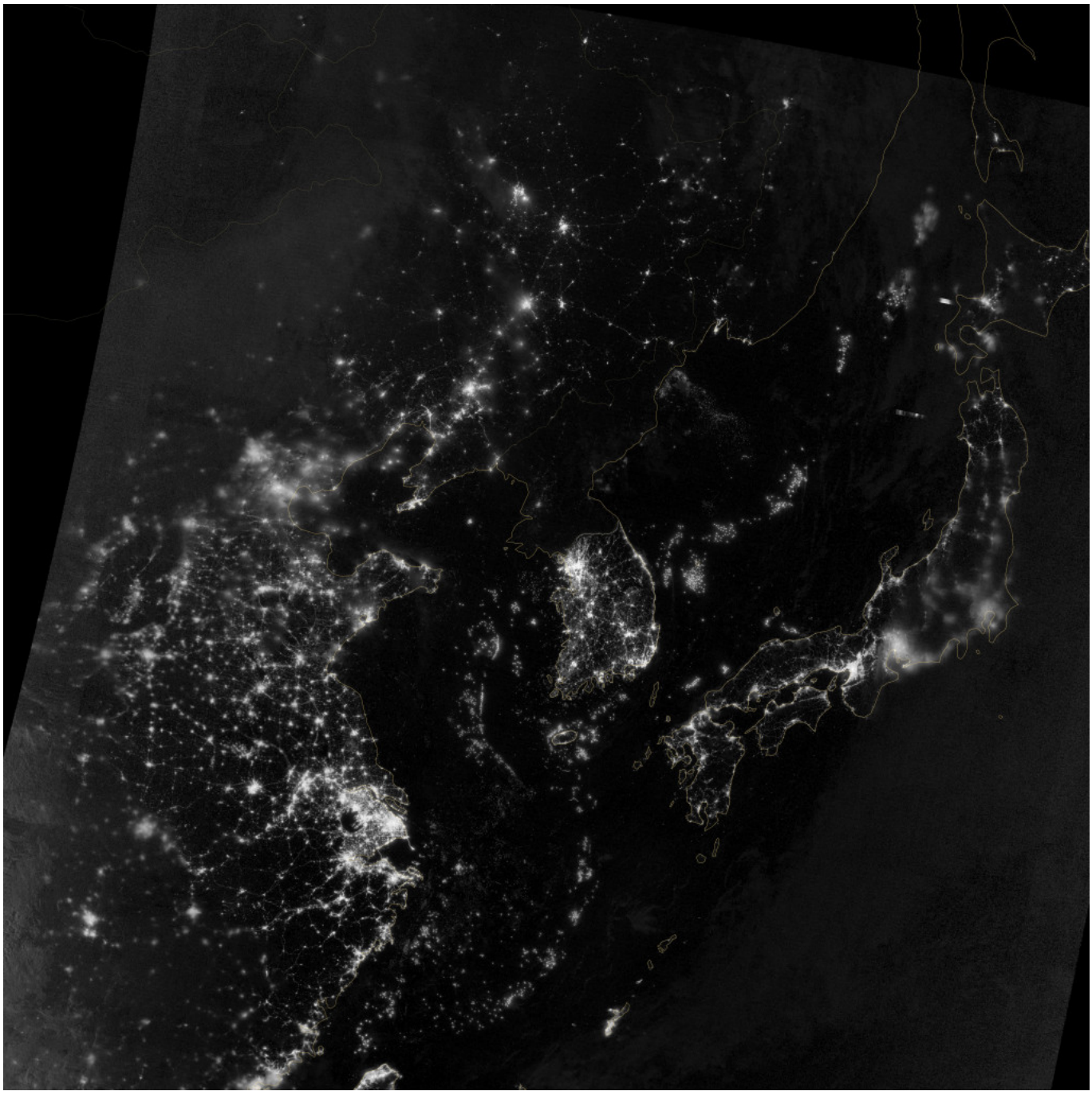
Strategies for the Rehabilitation of the DPRK Energy Sector



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I. INTRODUCTION

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 (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 DPRK leader Kim Jong Il and the passing of the 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 November, 2013) a central role in the resolution of the ongoing confrontation between the DPRK and much of the international community over the DPRK's 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). As long as the DPRK's nuclear weapons issue remains unresolved (or at least in the process of resolution), external powers will continue to squeeze the DPRK with sanctions, and external aid will be minimal. 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. Carefully-designed energy sector assistance projects of modest scale, particularly those that combine economic development and humanitarian focus, should be sought out, designed, and, as soon as conditions permit, undertaken. The Republic of Korea (ROK) is in a unique position to develop and deliver such projects, and it stands to gain considerably if such projects are successful. For the ROK, engagement with the DPRK on energy issues offers many possible benefits, including an opportunity to improve its relationship and understand its neighbor, a chance to potentially improve the environment which the two nations share, an opening for the ROK to invest in and benefit from the development of the DPRK's economy,

opportunities to potentially link its energy system with potential resource suppliers, most notably the Russian Far East, and an opportunity to improve the ROK's security by promoting peace on the Korean Peninsula.

In the remainder of this paper, we provide:

- A brief overview of the current status and recent past of the DPRK energy sector, an introduction to key energy sector problems, and a summary of our estimate of the current and recent energy supply and demand situation in the DPRK (**Section 2**);
- A summary of our recent work on DPRK "Energy Futures" and the lessons that the results of that work provides for the design of energy sector assistance to the DPRK (**Section 3**);
- A compilation of ideas on opportunities and approaches for collaboration on energy sector redevelopment in the DPRK (**Section 4**); and
- A presentation of selected ideas for potential research and engagement activities leading to cooperation with the DPRK on energy issues (**Section 5**).

II. DPRK Energy Sector: Status and Problems

In the two-plus decades since 1990, 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 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.

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 and significant other natural resources.

The DPRK economy has been stagnating since 1990 as a result of a number of factors, including:

- Foreign debt incurred in purchasing industrial equipment and oil.
- 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, particularly in the early 1990s, due to a combination of weather-related factors, lack of fuel and fertilizer, and environmental degradation.
- Economic isolation due to international sanctions.
- Natural disasters, including floods, severe storms, tidal surges, and droughts.

Although the DPRK 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 were

China, Russia, Iran (reportedly trading oil for armaments), and Japan. The DPRK at that time 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 already exceeded that of exports by $600 million in 1990. Trade even in 1991—both exports and imports—was down markedly from 1990 as a result of the dissolution of the USSR[1].

The economic, if not social and political, landscape in the DPRK changed markedly during the 1990s. In the early 1990s, the DPRK government openly admitted the country's failure to achieve the economic goals of its most recent seven-year plan[2]. 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[3]. This economic decline has been both a result and a cause of substantial changes in energy demand and supply in DPRK over the last decade. 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[4]. 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[5]. 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[6].

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[7], and have fallen to practically zero since, though more modest supplies of refined oil products continue to be imported into the DPRK from Russia, and there have been recent, though not yet verified, reports of some crude oil imports from Russia.
- 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 DPRK from China remained near the same level (in dollar terms) from at least 1982 through the early 1990s[8].
- 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 in 2010, followed by a vast increase to 11.2 million tonnes in 2011[9]. 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[10].
- Continuing degradation of electricity generation and transmission and distribution (T&D) infrastructure, though with modest local rehabilitation of power plants and T&D systems in a few areas and for key purposes (including, reportedly, military facilities).

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[11]. 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 more than 50 percent 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[12] by the mid-1990s. The DPRK's trade deficit as of 2000 stood at $US 856.88 million[13], remained at near one billion dollars through 2004[14], and was over one billion dollars in 2009 and 2010[15], despite increasingly lucrative exports to China.

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[16]. An additional blow to DPRK 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[17].

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 not only production of private gardens but wild foods, tree-bark, grass, and whatever other semi-edible materials they can obtain. 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[18]. 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.

2.1. Summary of the Overall Energy Situation in the DPRK: History and Problems

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[19] 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.

As shown in Figure 2-1, 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 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. Figure 2-2 shows the increasing importance of biomass fuels to the DPRK economy since 1990.

Figure 2-1:

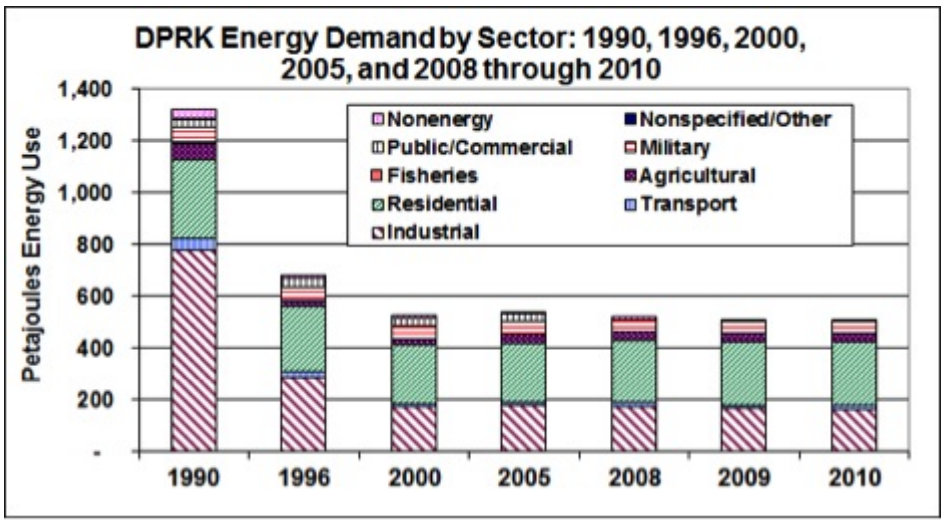
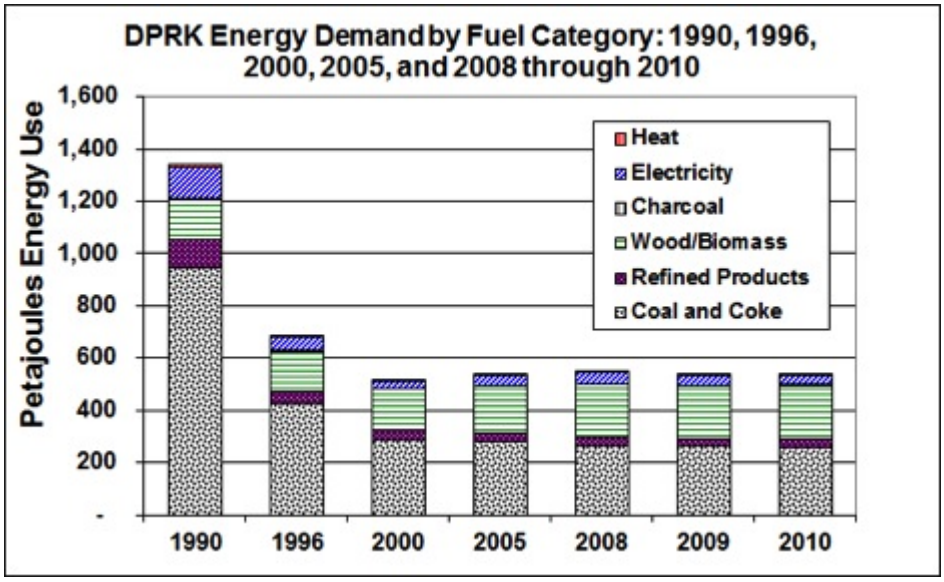


Figure 2-2:



Key energy-sector problems in the DPRK include:

- *Inefficient and/or decaying 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 significant, and often any, insulation, and the heating circuits in residential and

other buildings for the most part 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 DPRK 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[20]. 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 efficiencytechnologies, even when and if such technologies are made available.

The DPRK's energy sector needs are vast, and at the same time, as indicated by the only partial listing of problems many of these needs are sufficiently interconnected as to be particularly daunting to address. The DPRK's energy sector needs include rebuilding/replacement of many of its power generation and almost all of its substation equipment, repair, replacement, and/or improvement of coal mine production equipment and safety systems, updating of oil refineries, improvement or replacement of most if its energy-using equipment, including coal-fired boilers, electric motors and drives, transport systems, and many other items, modernization of energy use throughout the country, rebuilding of the DPRK forest stocks, and a host of other needs. As one example of the interrelations of energy problems in the DPRK, renovating the DPRK's coal mining sector is made more difficult because coal mines lack electricity due to electricity sector problems, and electricity generators in some cases have insufficient coal to supply power demand because of coal mine problems and problems with transporting coal to power plants.

2.2. Energy Supply—Resources, Technologies and Processes

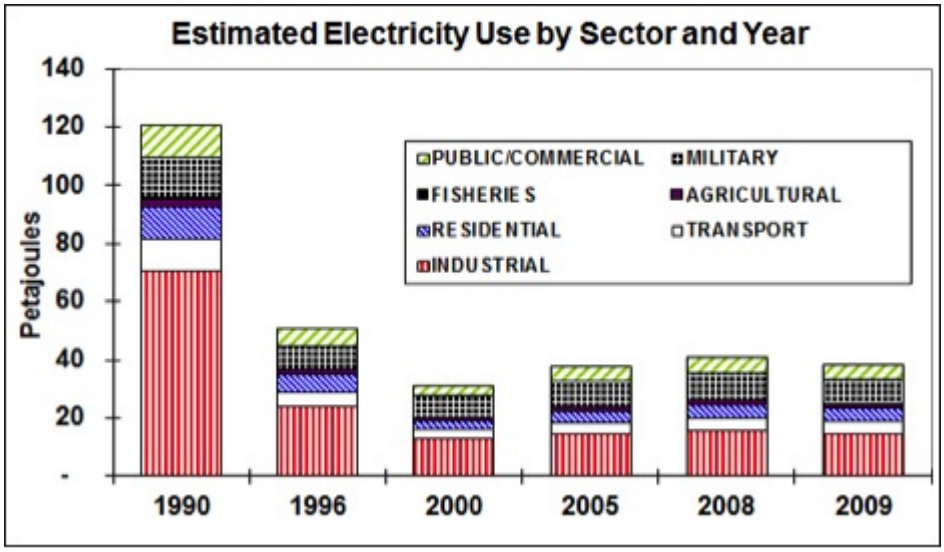
North Korea's major energy resource is coal. The DPRK has substantial reserves of both anthracite and brown coal, though the quality of its coal reserves varies substantially from area to area. There is little, if any, coal cleaning (washing and sifting of coal to remove impurities such as sulfur and ash) in the DPRK. There have been reports of some operating oil wells in the country, 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 and elsewhere. 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 apparently for at least most of 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.

2.3. Summary of Electricity Demand and Supply

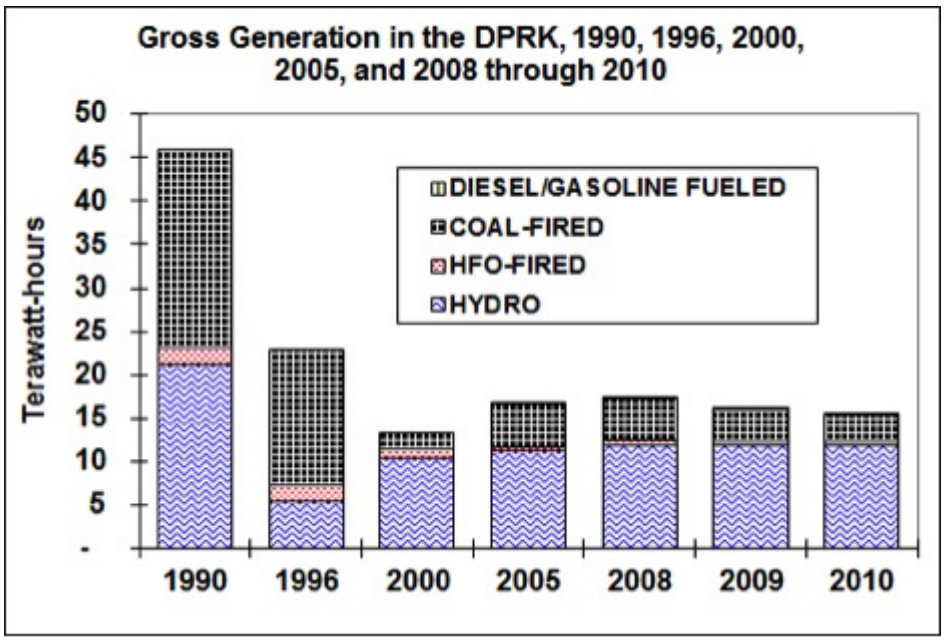
The estimated per-capita electricity end use in the DPRK in 1990 was about 1,500 kWh per capita. By comparison, overall 1990 electricity demand in South Korea was about 2,200 kWh per capita[21]. Per capita electricity consumption in the DPRK has declined very substantially since, due largely to reduced availability of power, though also as a results of reduced economic activity[22]. As with coal, the bulk of the electricity demand in the DPRK has traditionally been in the industrial sector, with the residential and military sectors (by our estimates) also accounting for significant fractions of electricity use. Figure 2-3 shows our estimates of electricity demand by sector in selected years since 1990.

Figure 2-3:



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[23]. 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, based on the availability of hydro power (including low output in the mid-1990s following plant damage due to flooding) and on the condition and fuel supply for coal-fired power plants. Figure 2-4 presents our estimates of electricity output by fuel type in the DPRK over the last two decades.

Figure 2-4:



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 (and in fact, given problems in the coal industry, only a fraction of this rate of coal supply is currently achievable). In a series of vicious spirals, electricity and coal infrastructure problems feed back on each other and link to problems throughout the economy. For example:

- No or sporadic electricity availability means that lights and pumps in coal mines don't stay on, reducing coal output;
- No or sporadic electricity means difficulties with coal (and other goods) transport, meaning less coal is made available for power plants and industry
- Lack of power and coal for industry limits production of spare parts for transport, generation and mining infrastructure;
- Lack of power makes outside investment in mining, manufacturing more difficult/less attractive; and so on.

Given weather patterns in the subregion, 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 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[24].

2.4. Current Context of Energy Cooperation with the DPRK—Overview of Opportunities and Challenges

As noted briefly above, and in much greater detail later in this paper, North Korea suffers under a host of energy sector problems, as well as many economic, humanitarian, environmental, and other problems that are often intertwined with, or exacerbated by (at least in part), energy sector problems. Addressing these problems, sometimes termed the DPRK's "energy insecurity", will require significant, concerted, and sustained effort by and coordination among a vast suite of actors from different nations. At the same time, these problems, in the types of cooperation that will be required to address them, also offer significant opportunities to all Koreans and to the peoples of Northeast Asia and beyond.

Key economic resources for the DPRK to address its "energy insecurity" 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 (or, in fact, any project, large or small, requiring hands and shovels) by mobilizing military and other labor, extensive reserves of minerals, and significant energy resources. What the DPRK lacks are modern tools and manufacturing methods, adequate supplies of fuel, reliable transport and energy infrastructure, sufficient arable land to reliably feed its populace, and above all, investment capital to enable the import and/or manufacture/development of tools, equipment, materials and know-how to fill these key gaps. As a consequence, a coordinated program of assistance from the ROK, the United States, and/or other countries that builds upon these attributes will be needed. Providing key assistance in a timely manner will enhance security in Northeast Asia, accelerate (or, given recent events, help to re-establish) the process of Northern Part rapprochement to its neighbors, and help to position countries and firms as major suppliers for the DPRK economic redevelopment 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. This approach is not necessarily well-suited to a top-down policies designed to help reach political agreements to rapprochement between the Koreas (and between the DPRK and others in the international community), which have tended, at least in the past, to look for solutions that involved large and hugely complex initiatives[25]. The multi-pronged requirement fits extremely well, however, with the need to engage DPRK organizations and individuals on a broad basis to bring the peoples of Korea and the region together, thus offering opportunities for many different ROK (and other) organizations to lend their diverse expertise to the solution of Korea's individual and shared problems. A multi-pronged approach also offers the opportunity for even organizations with limited budgets and staffing to cooperate with DPRK actors, given suitable authority to do so and with careful coordination between organizations providing assistance.

Below, we identify priority areas where we see DPRK energy sector assistance as both necessary and in the best interests of all parties. All of these interventions would put foreign (US, European, ROK, Australian, or other) engineers and other program staff in direct contact with their DPRK counterparts and with DPRK energy end-users, thus providing broad-based human interactions with the DPRK that are crucial to a lasting reconciliation between the DPRK, the ROK, and the international community.

- 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, pursue sector-based implementation of energy efficiency measures, and carry out demonstration projects. This type of assistance has the additional benefit of helping to improve markets for ROK and other suppliers of these products and services.

- Work to **open opportunities for private companies to work in the DPRK**. Grants or loans from foreign governments cannot begin to fill the needs for energy infrastructure in the DPRK, but the US, ROK, European, and other governments can help to facilitate the efforts of private companies (including independent power producers) from abroad in the DPRK energy sector. One key, in the medium and longer-term, to facilitating the involvement of private companies is to provide assistance for policy and legal reforms in the DPRK that are needed to make it possible, or at least more straightforward, for private companies to work there.
- Cooperation on **technology transfer for energy efficiency and renewable energy applications**.

Specific energy sector initiatives that will assist the process of rapprochement with the DPRK, help the DPRK to get its economy and energy sector working in a sustainable (and peaceful) manner, and help to pave the way for additional cooperative activities in the energy sector include:

- *Assistance for internal policy and legal reforms to stimulate and sustain energy sector rebuilding in the DPRK*. This should include, early in the process, reform of energy pricing practices, and the physical infrastructure to implement them, capacity building for careful energy planning to allow aid to be based on need and rational objectives, training for energy sector actors, strengthening regulatory agencies and educational/research institutions in the DPRK, and involving the private sector in investments and technology transfer.
- *Rebuilding of the electricity transmission and distribution (T&D) system*. The need for refurbishment and/or rebuilding of the DPRK T&D system has been touched upon earlier in this paper. 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 area of a special economic zone or in a "demonstration" county.
- *Rehabilitation of power plants and other coal-using infrastructure*. An initial focus should be on improvements in small, medium, and district heating boilers for humanitarian end-uses such as residential heating, as well as in small institutional settings such as schools and hospitals.
- *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. Coal supply system rehabilitation will require provision of basic systems for providing ventilation, light, and motive power for water pumping and extraction of coal to mines, as well as improvements in mine safety. Coal may or may not be the fuel of the future for the DPRK, but it is the fuel of the present, and it is hard to conceive of an economic improvement in the DPRK, in the short-to-medium term, that does not rely substantially on coal.
- *Development of alternative sources of small-scale energy and implementation of energy-efficiency measures*. The Koreans from the Northern Part that Nautilus has worked with have expressed a keen interest in renewable energy and energy-efficiency technologies (see below). 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, and should (especially initially) emphasize agricultural and humanitarian applications.

- *Rehabilitation of rural infrastructure*. The goal of a rural energy rehabilitation program would be to provide the modern energy inputs necessary to allow DPRK Korean agriculture to recover a sustainable production level and the basic needs of the rural population to be met.
- *Begin transition to gas use in the DPRK with Liquid Petroleum Gas (LPG) networks*. LPG is more expensive than natural gas, but the infrastructure to import LPG, relative to liquefied natural gas (LNG) is much easier, quicker, and less expensive to develop, and allows imports in smaller quantities. LPG is also clean burning, has limited military diversion potential, and setting up LPG networks can be a first step toward the use of natural gas in the DPRK-if done with a future transition to natural gas use in mind. Ultimately, natural gas pipelines and LNG terminals, shared with (most likely) the ROK, can serve as a step toward economic development coupled with regional energy system/economic integration.

Many of these options, or elements of same, are included later in this paper. Additional and more detailed descriptions of these options are provided in previous reports by the authors[26].

By way of historical context, the process of energy engagement with the DPRK, which began around 1994, has sought to provide short-term energy aid to the DPRK while at the same time (though to varying degrees) looking ahead to types of energy assistance that would help the DPRK in redeveloping its energy sector and economy. Because it is a fuel that has limited military uses, heavy fuel oil has been the form of energy aid most frequently provided to the DPRK as the agreed direct energy assistance. Other types of energy aid provided under the Six-Party Talks agreement have included parts and materials to repair/maintain DPRK power and heating plants, and of course the Kumho/Simpo LWR construction program was the focus of long-term energy assistance under the terms of the 1994 Agreed Framework. A variety of other options for energy sector assistance to the DPRK have, however, been suggested over the years.

The DPRK’s energy sector needs are vast, and at the same time, many of these needs are sufficiently interconnected and particularly daunting to address. The DPRK's energy sector needs are described briefly above and referred to in what follows, but they include rebuilding/replacing many of its power generation and almost all of its substation equipment, repair/replacement/improvement of coal mine production equipment and safety systems, updating of oil refineries, improvement or replacement of most if its energy-using equipment (i.e. coal-fired boilers, electric motors and drives, transport systems, and many other items), modernization of energy use throughout the country, rebuilding of the DPRK forest stocks, and a host of other needs. As one example of the interrelations of energy problems in the DPRK, renovating the DPRK’s coal mining sector is made more difficult because coal mines lack electricity due to electricity sector problems, and electricity generators in some cases have insufficient coal to supply power demand because of coal mine problems and problems with transporting coal to power plants.

International and ROK engagement of the DPRK on energy sector topics is also made more difficult by a number of challenges related both to the DPRK's situation and to circumstances facing the other nations that would seek to engage with the DPRK. We return to these challenges later, but very briefly, some of the circumstances that make engagement with the DPRK on energy sector issues particularly difficult include (but are by no means limited to):

- A lack of institutional capacity in the DPRK to efficiently engage groups from outside the country and to use energy aid in significant amounts.
- A lack of energy product markets that could help to sustain energy assistance activities.
- A lack of basic tools and materials to facilitate energy projects in the DPRK-in some cases, virtually

every bolt needed for an energy project must be imported.

- Logistical difficulties posed by poor transport facilities within the DPRK, as well as by often complicated arrangements and authorizations needed to ship into the DPRK key pieces of equipment needed for a project.
- Difficulties in reaching consensus within the DPRK between the different groups likely to be involved (for example, the Foreign Affairs Office, national ministries, local authorities in the area where a project is to be developed, and technical counterparts).
- Difficulties in aligning the goals of a project with the views and needs of different political constituents within the DPRK.
- Difficulties in aligning the goals of a project with the views and needs of different political constituents within the ROK and within key partner countries, including the United States.

At present, the key impediment to ROK engagement with the DPRK to provide energy aid and related development assistance is the political stalemate between the ROK and the DPRK, as well as the tension between the DPRK and the ROK's allies. The already poor relationship between the DPRK and the ROK was further strained by the sinking of the ROK's naval vessel Cheonan by a DPRK Korean torpedo on March 26, 2010 in the Korea West Sea, and the DPRK's shelling of Yeonpyeong Island in November 2010. Despite apparent offers summit meeting extended by the ROK to the DPRK, and despite an occasionally more conciliatory tone by the DPRK since the succession of Kim Jong Un to DPRK leadership (and recent suggestions of a more open attitude to the DPRK on the part of ROK leadership), contacts between the ROK and the DPRK have been limited over the past few years. The continued operation of the Kaesong Industrial District just north of the demilitarized zone (DMZ) is the only significant cooperative project currently ongoing. Even the Kaesong project, though important for both Koreas, has seen disputes over the number of workers that the ROK can bring into the district and other issues.

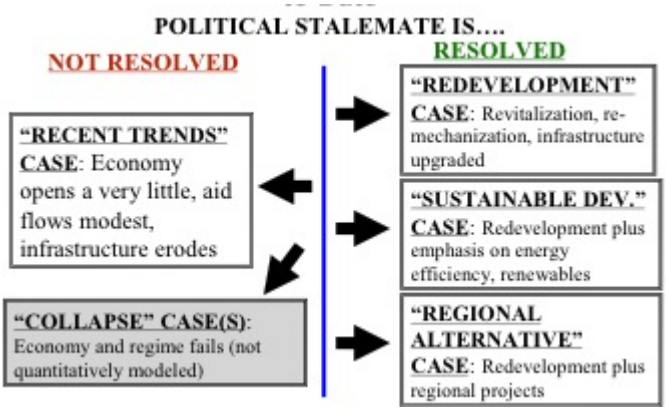
Despite the bleak outlook for near-term cooperation between the nations of the Korean Peninsula, history suggests that setbacks in talks with the DPRK are not at all unusual, and can and will be overcome with time, patience, and some flexibility on the part of negotiating partners. Since the negotiations could reconvene on relatively short notice, it is important for the international community to give serious consideration to the types of assistance options that would be required to address the DPRK's energy insecurity, and thereby to gain collectively a good a sense as to which types of energy sector assistance will be useful, practical, and possible in return for DPRK concessions on its nuclear weapons program. This is particularly true for the Republic of Korea, which has far more to gain or lose from the relations with the DPRK than any other nation.

III. THE DPRK'S ENERGY FUTURE

Despite a few outward though often 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 as presented above 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 less burdensome? This section provides a summary examination of these questions, and provides some ideas for initiatives that could assist the DPRK in building a sustainable energy sector.

There are essentially three different ways that the DPRK energy sector and economy could evolve from their current status. First, the economy could open, leading to economic redevelopment. This process, of course, could occur slowly or rapidly, and could take on very different characteristics, depending on how it is managed. Second, the economy could fail to open substantially, leading to a continuation of recent trends of stagnation in the economy and in energy supplies. Third, the current DPRK regime could collapse in one of many possible ways, leading, in most scenarios, to actual or de-facto economic integration with the ROK. We must emphasize that we do **NOT** think that DPRK regime collapse is likely in the near- or even medium-term, but it is instructive to think through the implications of collapse scenarios. Variants of the economic redevelopment scenarios fall on the right hand side of Figure 3-1, while recent trends and collapse scenarios fall on the left side.

Figure 3-1: DPRK Energy Paths/Scenarios Considered Quantitatively to Date



In the following subsections we:

- Summarize our exploration of the energy, environmental, and cost implications of a possible economic redevelopment scenario for the DPRK, as well as various variants of that scenario, with results for a "recent trends" scenario provided by way of comparison;
- Summarize our previous work in evaluating the potential energy sector impacts of qualitative "collapse" scenarios; and
- Explore the Lessons learned" from both quantitative scenarios and qualitative "collapse" scenarios, regarding the type and likely magnitude of future DPRK energy sector energy and infrastructure requirements, and the implications of those requirements for potential energy sector redevelopment/rehabilitation/assistance activities.

3.1. 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[1]. This qualitative sketch is a first step to the estimation of the quantitative attributes of such a path—what the path might mean, for example, in terms of future terajoules of petroleum, tonnes of coal, and megawatts of power.

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 (as e, providing that the unified Korea can obtain internal and external financing for infrastructure reconstruction in the Northern Part. Some of these “collapse” scenarios—which the authors of this paper again stress that we feel are unlikely—are presented and discussed qualitatively below.

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 2014)—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 and consumer goods.
- There is an increase in household energy use, as improved supplies become available and incomes increase, 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[2].
- 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 (recently the topic of news announcing investment in the refinery by a Mongolian enterprise), 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 be able 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[3], 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 Simpo 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 Simpo 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 Simpo 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.

3.2. Variants on the Redevelopment Path

In the context of collaborative research on regional energy security in Northeast Asia[4], Nautilus Institute has developed and evaluated alternative paths that provide the same energy services as the Redevelopment path described (in summary) above, but incorporate in an expanded way, relative to

the Redevelopment path, features of energy efficiency and renewable energy, as well as strengthened regional cooperation in the energy area. The two main alternative paths evaluated are:

- The “Sustainable Development” Path. 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 approaching high-efficiency international standards, a rapid phase-out of existing coal-fired power plants, and earlier addition of an LNG (liquefied natural gas) terminal and of gas CC (combined cycle) generating plants using the gas from the LNG plant.
- The “Regional Alternative” Path. 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 2016, with 3 percent of the gas throughput of 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.

One further scenario, the “Recent Trends” path, assumes that the DPRK remains largely a closed economy, but continues to trade with China and others in quantities such that it is able to maintain its economy at close to current levels, with possible modest improvements in some sectors. This assumes that the DPRK’s energy infrastructure, in particular its electricity generation and T&D infrastructure receives just enough investment to keep it from failing, but not enough to make significantly enhanced supplies of energy services available to the DPRK’s citizens, at least on average. The Recent Trends case serves as a counterpoint to the scenarios above, but is not strictly comparable to them, because it does not produce the same level of economic activity or energy services.

3.3. Results: Redevelopment Path

Selected results of the evaluation of the paths described above are provided below. The results were prepared with the Long-range Energy Alternatives Planning energy/environment software tool or LEAP[5].

Figure 3-2 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 2016. Figure 3-3 shows final demand by sector, showing the increase, in future years, of consumption in the transport, public/commercial (commercial/institutional), and residential sectors relative to the industrial sector. Relative growth in residential sector energy use would appear greater were it not for the gradual phasing out of biomass use in households.

Figure 3-2:

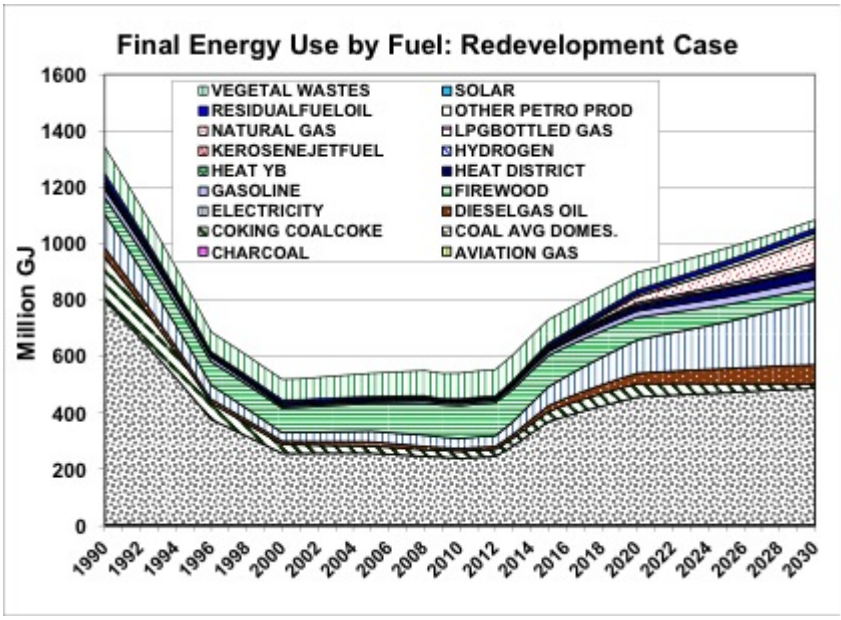
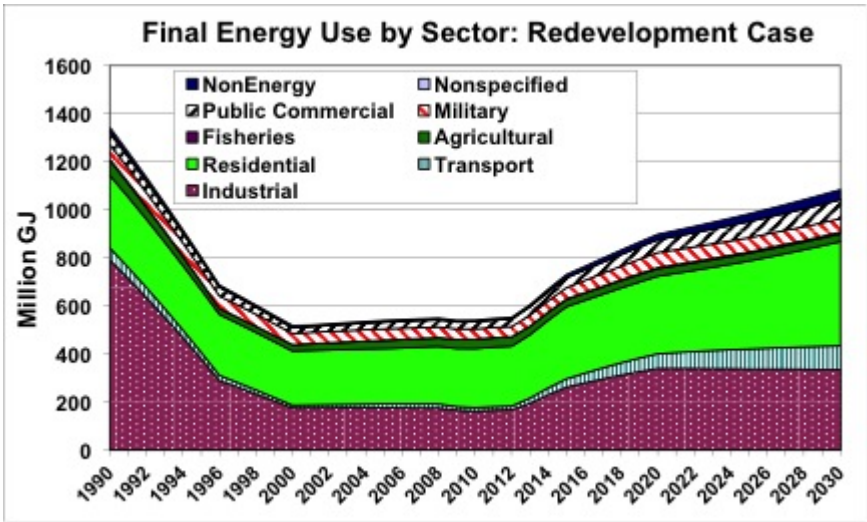


Figure 3-3:



Figures 3-4 and 3-5 show, respectively, the changing patterns of electricity generation capacity and of output by type of generator in the Redevelopment path. Other than hydroelectric generation, renewable energy plays only a small role in electricity production even as the DPRK redevelops. Existing and some new hydro remains a significant, though declining, portion of total capacity through 2030, but constitutes a smaller portion of output due to the limited capacity factor of hydro facilities (due to seasonal variations in water supply. As older coal plants are phased out, new coal plants and new gas combined cycle plants are brought on line, constituting a significant share of capacity, and a larger share of electricity output, by 2030.

Figure 3-4:

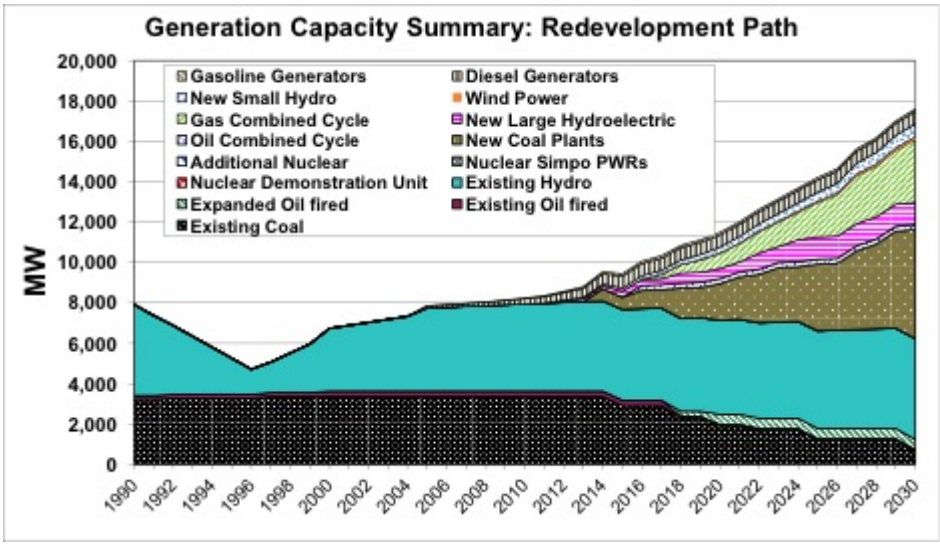
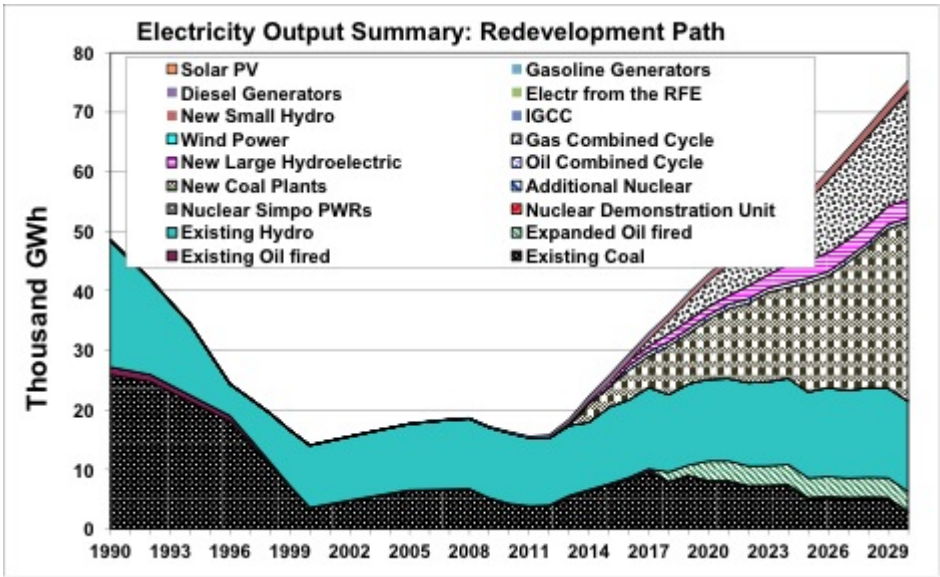


Figure 3-5:

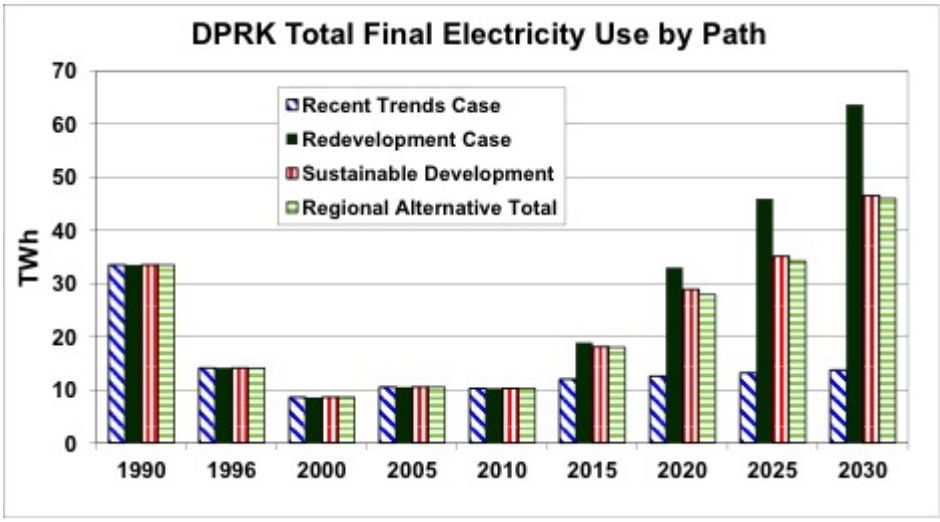


3.4. Results: Path Comparisons

The “Sustainable Development” path for the DPRK is an illustration of the potential impacts of applying a selected set of demand-side energy efficiency measures, together with expanded deployment of renewable energy systems (in this case, renewable electricity generation options). As such, it is designed to provide the same “energy services” (lighting, heating, cooking, transport, and industrial output, for example) as the Redevelopment case, but in a different way.

Figure 3-6 compares electricity use over time in the three main paths evaluated that include DPRK economic redevelopment, 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, as noted above, 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 result that in the Sustainable Development path, even with the incorporation of more low-capacit--factor renewable power sources, the overall generation capacity in 2030 is nearly 3000 MW less than in the Redevelopment path. This difference is significant in terms of avoided costs of generation capacity and of fuels for generation, as noted below.

Figure 3-6:



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 3-7) 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 path 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 path are less expensive than the Redevelopment path, overall, even before any credits are taken for avoided environmental impacts, as shown in Figure 3-8.

Figure 3-7[6]:

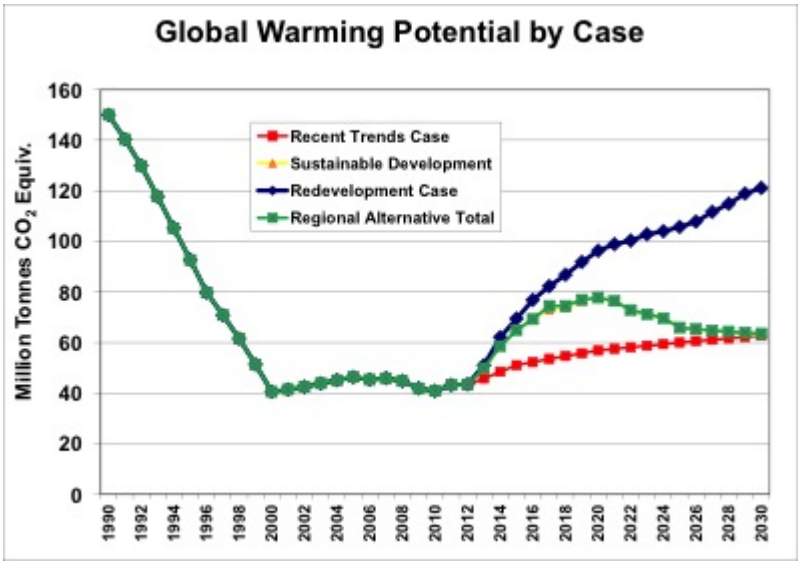
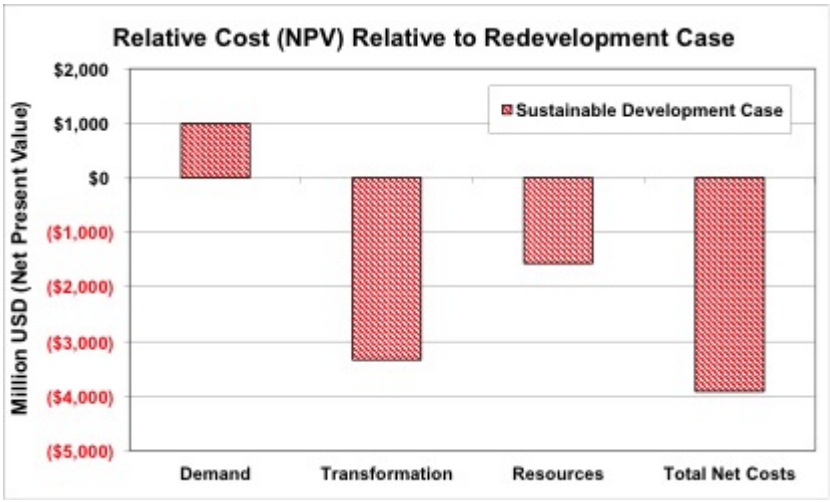


Figure 3-8:



3.5. DPRK "Collapse" Scenarios

Though the younger Kim has appeared, over the course of 2013, to have successfully consolidated power, the prospect for the DPRK and its leadership remains arguably 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 above, that the economic poverty of almost all DPRK citizens will change for the better in the near future. The international community will likely continue to apply economic sanctions on the DPRK 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" [7]. Many scenarios, including a persistent, slow recovery and gradual modernization of the DPRK, are possible[8].

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—perhaps a variant of the "recent trends" path described above; 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.[9] 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.

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 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 section, 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 the DPRK 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 DPRK 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. Below we explore, in a largely qualitative way, the implications of various “collapse” pathways for the energy sector of the DPRK, and for the approaches that the Republic of Korea and other interested parties will need to take to rebuild and redevelop the DPRK energy sector, and in planning for same. Please note that the descriptions of “collapse” scenarios below are derived from previous work by the authors, and readers are urged to consult those works for additional details[10].

3.6. Analytical Approach and 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 can be summarized as:

- **War**: The “War” path assumes that a shooting war, once set off by a military incident of some kind, quickly escalates, and leads to essentially immediate unification. Given the proximity of DPRK artillery to the ROK border, we assume that this path results in considerable destruction in the Northern ROK, 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 (to avoid conflict with China and other reasons). Based on previous work, 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? 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—specifically, choices to target or spare energy facilities, or to cripple such facilities in a way that they can be brought back on line by the ROK/US relatively easily--will have a significant bearing on the tasks needed to reconstruct the energy system. This description of the "War" path, and the 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, with possible global consequences.

- **Regime Implosion Leading to New Authoritarian Regime:** 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 spurns the ROK and the West, but secures much higher than recent rates of investment from non-ROK, non-Western, non-international intergovernmental sources, and as a result the DPRK's energy infrastructure is rebuilt/redeveloped in close cooperation with China and Russia. 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.
- **Regime Change by Palace Coup Leading to ROK-installed Regime**: In this path, following, for example, an act by Kim Jong Un 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 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, leading to modernization that in turn leads to at first to de-facto economic unification, then, somewhat later, political unification with the ROK. 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 work with and draw investment from analogs in the South.

- **Slow Collapse Leading to Regime Change through Internal Conflict**: In this variant of "Regime Implosion", Kim Jong Un maintains control, or another regime takes power. In either case, however, there is a failure to modernize or open the DPRK significantly to the outside world. Through 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 such as the effective fragmentation of the DPRK into "fiefdoms" might occur, with the 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 the Northern Part would breaks down as the power of the central authority to impose order wanes[11], which, coupled with continued decline in living standards, leads eventually to disillusionment on the part of the majority of the population, internal conflict, civil disorder, and possibly even civil war. 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 the Northern Part.

3.7. 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.

"War" Path

As noted above, a major military conflict could 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.
- Establish emergency electricity generation, initially fueled with diesel oil or possibly liquefied petroleum gas (LPG, a mixture of propane and butane), for example, with 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 could easily supply the ROK and the DPRK together today, 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 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.

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 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[12].

In any post-war path there will be a need to quickly ramp up capacity-building for energy, environment-related, and other occupations, both because trained people will be needed for reconstruction and redevelopment, but also because the North Korean population will need gainful, useful, peaceful employment. A key focus of early capacity-building efforts should be on providing skills and technologies that encourage the growth of local economies that are capable of providing essentials such as food and energy services for themselves.

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, and to choose energy-efficient devices for all of the new housing, commercial, and industrial developments that will be built.
- 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.
- Work with the Russians to reconstruct--or, more likely, construct a new--Sonbong refinery, and related port and power/heat generation facilities.

- 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 somewhere near the 38th Parallel. LNG facilities would likely be shared to serve both the North and South.

"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.

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.

"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 a "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.

- Looking 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. 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 the Northern Part 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 and other efficiency regulations, and building 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 economic and environmental reasons, 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 the DPRK, but also, just as if not more importantly, building up Northern Part educational institutions at all levels.

"Slow Collapse Leading to Eventual Reunification" Path

In the "Slow Collapse Leading to Eventual Reunification" path, energy infrastructure continues to slowly decay. As infrastructure decays it continues to become more inefficient over time, and also loses capacity 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…" scenario, 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 involving outside investors, for example, Chinese companies, where outside investors have a vested interest in making sure that key infrastructure is operable.

Under this scenario, actions that the ROK and its allies could carry out to usefully help to address DPRK energy sector and related needs in the short-to-medium term are likely to be limited to rare engagement and capacity building projects. As the central regime loses power, there may be more opportunities for small, local engagement projects, but such projects 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 potential shifts in authority over key areas.

In the longer-term, the types of post-collapse measures required of the ROK and its partners following reunification-by-default are the same as in the “Regime change by palace coup” scenario, 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 the Northern Part a progressively larger and larger long-term issue for the ROK, with growing complexity and expense. The Slow Collapse scenario also implies that full assessments of DPRK energy and related infrastructure will not be possible for some time, which will delay the provision of energy services and the rebuild energy infrastructure once collapse occurs. This in turn means that a planning for energy sector support and 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.

3.8 Lessons Learned from Paths/Scenarios

Both the energy paths evaluated quantitatively in section 3.1, and the “collapse” scenarios evaluated qualitatively in section 3.2, offer lessons for DPRK energy sector redevelopment. These lessons should be of value to the DPRK as it redevelops its economy, as well as to those in the regional and international community who would engage the DPRK on energy sector and related issues. In many senses, the lessors from the quantitative paths and the collapse scenarios are both convergent and complimentary, as described below.

3.9. Lessons from Consideration of Energy Paths Results

Although we certainly would not claim to have investigated a full suite of the possible energy futures for the DPRK, the clear lesson from the investigation of alternative energy scenarios, or paths, for the DPRK, as presented in section 3.1 above, is that a focus on reducing energy use by increasing energy efficiency, even as the DPRK economy is rebuilt and demand for energy services that not been fully met for most of two decades, begins to be addressed, has many positive aspects. Those demonstrated by the quantitative results above include, most obviously, reduced environmental emissions (and a substantial reduction in non-greenhouse gas emissions is also achieved in moving

from the Redevelopment path to the Sustainable Development path), as well as reduced transformation, resource and overall costs. A host of other benefits, many harder to put a value on, but valuable all the same, are also likely to accrue as a result of taking the "Sustainable Development path" or "Regional Alternative path" approach to DPRK energy sector redevelopment. These include (but are certainly not limited to):

- Increasing the diversity of energy sources that the DPRK uses, including increasing the use of domestic renewable resources.
- In particular, diversifying the DPRK's electricity supply sources so as to render some of the problems with the DPRK electricity grid more tractable in the medium-term by offering more local generation options.
- Increasing the experience of DPRK citizens with both technologies and people from outside the DPRK, reinforcing (assuming positive interactions) the benefits of economic opening.
- Increasing the participation of the DPRK in international cooperation, helping to facilitate resource sharing between the countries of the region, and helping to build regional markets for energy efficiency, renewable energy, and other products.
- Offering greater opportunities for investment by the international community in the DPRK's energy sector through Kyoto Protocol Clean Development Measures or similar international climate change mitigation cost-sharing efforts.
- Helping to more rapidly upgrade the efficiency of the DPRK's energy supply and demand infrastructure, thereby reducing the eventual cost of such upgrades following (or as a part of) political (or de-facto economic) reunification of the Korean Peninsula.

3.10. Lessons from "Collapse" Pathway Results

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.

IV. energy needs in the dprk, and opportunities for collaboration on energy sector redevelopment

As noted in earlier in this paper, the DPRK's energy sector needs are huge. At the same time, the choices that are being and will be faced by the DPRK, and the potential partners that could, particularly if the current political impasse is surmounted, assist the DPRK in economic redevelopment, will have crucial ramifications for the energy future of the DPRK and, indeed, the Northeast Asia region. This section summarizes Nautilus' thoughts, many of which have been identified above in the context of consideration of sectoral energy use and of future scenarios for the DPRK, on the energy needs in the DPRK, and on opportunities for bilateral, international, and private sector collaboration on DPRK energy sector redevelopment.

4.1.Key/attractive Energy Sector Technologies and Processes for Energy Sector Redevelopment in the DPRK

A selection of suggested energy sector technologies and processes for energy sector redevelopment in the DPRK are provided below. Most of these options—all of which, in our view, are crucial pieces of the redevelopment puzzle for the DPRK—have elements that can be implemented in the short-term (for example, capacity-building and humanitarian aid), and medium-term (for example, demonstration projects), but all, ultimately, will require a concerted program of assistance over many years[1].

4.2. Rebuilding of the T&D System

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

4.3. 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, and/or have used biomass fuels for heating, in recent years. If possible, it would be optimal to provide such upgrades first 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. To the extent not already addressed by Chinese investors, 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, as was done to some extent in one of the agreements made during the Six-Party Talks, in an agreed-upon exchange for reduced deliveries of HFO (if HFO remains a part of assistance packages in the future), 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.

4.4. 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[2] (and to improve mine safety).

In parallel with any mine upgrades, and as noted earlier in this Report, 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.

4.5. 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 (see Figure 4-1), but it is clear that assistance would be helpful to produce more reliable and cost-efficient units, as well as to expand mass production.

Figure 4-1: DPRK-made Mini-Hydroelectric Turbine-Generator[3]

- Wind power: Likewise, the dissemination of wind turbines is 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 4-2).

Figure 4-2: Water-pumping Windmill Installed by Nautilus and DPRK Engineers at Unhari in the Year 2000[4]

- Agricultural equipment efficiency measures: Helping DPRK Koreans to feed themselves should be a high priority. The rice harvest in the DPRK is, based on our 1998 and 2000 observations at harvest time in the "rice basket" of the country (as well as the observations of many visitors since), 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. 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 4-3) among other details[5].

Figure 4-3: 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 improvement in the lives of ordinary Koreans (see Figure 4-4), as residents have found the improvement in light quality in their homes from installing CFLs to be considerable.

Figure 4-4: Compact Fluorescent Light Bulb Installed in DPRK Residence during the Unhari Project, 1998[6]

- Industrial and irrigation motors: The opportunities for efficiency improvement in large electric motors and motor drive systems are estimated to be considerable. Imports of efficient motors, pumps, air compressors, and other motor-related equipment may be the first step (once power quality has been improved sufficiently), followed by assistance in setting up facilities to manufacture or assemble equipment in the DPRK. Improving the reliability and efficiency of irrigation pumps will help the DPRK move toward feeding its populace.
- Humanitarian measures: Even the best orphanages, hospitals, and schools in the DPRK are cold and bleak today. Providing on-site power (preferably with renewable energy systems), water purification equipment, and efficient lighting and other end-use devices are necessary and highly visible first steps toward meeting humanitarian needs in the DPRK.

4.6. Rehabilitation of rural infrastructure

The goal of a rural energy rehabilitation program would be to provide the modern energy inputs necessary to allow DPRK Korean agriculture to recover a sustainable production level, and for the basic needs of the rural population to be met. Rural infrastructure rehabilitation will also serve the crucial task of helping to slow the movement of rural citizens to the cities, once such movement is allowed, to a rate at which cities can accommodate them. 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 DPRK 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[7]. Post-harvest crop losses and early crop consumption alone have been estimated to reduce usable crop production by 20 percent in the DPRK.

4.7. 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[8]. The driving force for the implementation of such interconnections, in the medium-to-long term, will be, as noted above, the need to provide a means of safely "turning on" reactors built on the Simpo site (in the event that construction is resumed) once they are complete (at this point, probably no earlier than 2020, 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.

4.8. Gas supply/demand infrastructure

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

4.9. Assistance Approaches for the International Community

When and if the Six-Party Talks—or, more likely, 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[9]. Chief among the incentives will be energy sector assistance to the DPRK. Below we outline 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.

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 DPRK 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. For example, 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, 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[10]. 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 DPRK 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”[11]. 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 have been initiated in the past, as reported by Dr. Kyung Sool Kim of KEEI in his 2006 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 until that time (though this observation continues to be accurate) had 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 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[12]. These opportunities continue to be salient.

Below we describe several assistance areas that we think are likely to particularly productive in both helping to address the DPRK's energy sector problems and in promoting peaceful and productive engagement with the DPRK.

4.10. Provide Technical and Institutional Assistance in Implementing Energy Efficiency Measures

Focusing in particular on energy efficiency (though some of these ideas also apply to other types of measures), 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 dramatically in recent years, as the rapid growth of trade in televisions, bicycles, and computer goods (to name just three products categories) 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"[13] 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[14]. 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 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 DPRK 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 DPRK Korean way of doing things. One word of caution here is to make sure that any demonstration projects carried out can be replicated elsewhere in the DPRK—measures unique to one or a few specific industrial plants, for example, are not likely to be widely replicated.

4.11. Promote Better Understanding of the Northern Part Situation in the ROK

South Koreans have a deep and natural interest in what goes on in the DPRK, 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 DPRK and South Korea—in the types of research and training activities mentioned above. This suggestion follows partly from the proximity of the two countries, partly from the shared language and cultural bonds, 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.

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

As noted above, the scale and complexity of the energy sector problems in the DPRK mean that the most reasonable way to address those problems is on a local and regional level. Though the ROK (and US, for example) governments might reasonably provide technical assistance and limited direct humanitarian aid, as well as support for international efforts, it is probably unreasonable to expect other countries to directly underwrite the renovation of DPRK infrastructure on even a county scale. What the other governments can do, however, is pave the way for companies such as Independent

Power Producers (IPPs) to operate in the DPRK. In this liaison role, the governments could provide assistance to firms in identifying, negotiating with, and working with DPRK counterparts, underwrite performance guarantees, and provide low-interest financing. The governments can also help by providing DPRK Korean counterparts with training in the economics of project evaluation and in international contract law, both of which are, as noted above, at present largely 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 (perhaps, in many cases, refurbishing or completing existing 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, and of market mechanisms to collect payments for power and service customers. 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.

4.13. 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[15]. 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[16].
- 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.

4.14. The DPRK as a Participant in Regional Energy Infrastructure

Resolution of the DPRK nuclear issue would open opportunities for regional cooperation on energy issues that heretofore have been stymied, at least in part, by the difficulties in including the DPRK in regional projects. There remain, however, many different opportunities for developing regional energy infrastructure and for energy cooperation activities—many of which could involve the DPRK—that would potential benefit a number of regional parties on many levels. For example, as the DPRK economy becomes more integrated with the economies of the region, pipelines and transmission lines could be developed to pass through the ROK, providing service to the DPRK as well. Additional markets for all types of technologies (and services) would open as the DPRK is redeveloped. In fact, the redevelopment of the DPRK will provide a considerable opportunity to

install efficient end-use equipment and renewable energy systems, as the DPRK economy (and infrastructure) will need to essentially be rebuilt from the ground up. In the process the DPRK may in a way provide a “laboratory” for application of energy efficiency and renewable energy measures in a way that nations with infrastructure that has been more recently updated cannot. Regional cooperation on energy sector initiatives also provides an opportunity to utilize DPRK labor, and to help to build a sustainable economy in the DPRK. Finally, as the international rules for applying Clean Development Mechanisms (CDM), which allow nations to take credit for financing greenhouse gas emissions reduction in other countries, are worked out, redevelopment in the DPRK may provide a host of opportunities for countries within and outside the region to apply CDM in energy sector investments in the DPRK.

4.15. Regional Cooperation Options in the Energy Sector

Regional cooperation options in the energy sector range from very large infrastructure projects linking many of the countries of the region, to more modest arrangements on technology sharing and capacity-building. Some of these possibilities, in brief, include[17]:

- **Regional oil pipelines**, carrying oil from Siberia, the Russian Far East, and even Central Asia to consumer in Chinas, Japan, and possibly the ROK and DPRK. Some of these pipeline projects, most notably the Eastern Siberia to Pacific Ocean Oil Pipeline (ESPO) project, are well underway, while others are in the preliminary planning stages. It is possible that such pipelines could be routed through DPRK territory, providing some oil to DPRK refineries on the way to the major refineries in the southern ROK.
- **Regional natural gas pipelines** have long been of interest to both Russia and the ROK, with China and Japan also seen as possible consumers. Such pipelines would carry gas from The Russian Far East, Siberia, and East Asia to the ROK. Although undersea routings from Russia to the ROK have been contemplated, it is likely that a routing via the DPRK would also have benefits. In such a configuration, some gas could be used by the DPRK, perhaps initially in a few gas-fired power plants, and later by end-use sectors as DPRK distribution networks develop, with the remainder shipped to the ROK.
- **Electricity grid interconnections**, designed mostly to allow power produced from hydro, coal, and possibly nuclear plants in the Russian Far East to be shipped to the ROK, have also been contemplated for well over a decade. Key issues here include the technical requirements for grid interconnection, the choice of AC or DC power for transmission (and its implications on how power can be tapped from the line to consumers along the route), and economic and environmental issues such as how the power would be priced and how trans-border environmentally sensitive areas can be protected. Here, the DPRK could obtain “rent” from hosting the line, even if the DPRK does not initially (or for some year) receive power from the line. There are technical options for including the DPRK in a grid interconnection through the Korean Peninsula that would have ramifications as well for whether the nuclear plants at Simpo are completed and brought on line—and conversely, the completion of the LWRs at Simpo would have implications for the prospects of a Russian-Fa--East-to-ROK interconnection as well[18]. The Russian Far East, however, is not the only resource-rich country in the region, as recent years have seen discussions of moving electricity generated from renewable (wind and solar) resources in Gobi area of Mongolia to buyers in China, Japan, and the ROK. Receipts of power from Mongolia by the latter two countries would require potentially complex arrangements with China or Russia, but are not out of the question.
- The development of **renewable energy and energy efficiency technologies** have been of keen interest in many countries of Northeast Asia. Climate change, local and regional environmental concerns, and the desire for economic development all contribute to the attractiveness of these options. Northeast Asia includes countries that are leaders in the technical know-how needed to

mass-produce renewable energy and energy-efficiency devices, and have the funds to finance development and deployment of renewable energy and energy efficiency, as well as countries with significant markets for such devices. (In some cases, countries fall into both categories.) Cooperative strategies that allow the countries of Northeast Asia to share and co-develop technologies to utilize renewable energy sources and to improve energy efficiency could make for accelerated deployment of these technologies, relative to a situation where countries develop and/or deploy the technologies largely on their own. Cooperation could take advantage, for example, of technology, research and development infrastructure, and financing from the ROK, Japan, and possibly the United States, mass manufacturing infrastructure, labor, and quite likely financing from China, labor from the DPRK (once the current political impasse has been relieved), renewable resources in varying availability across the region, energy efficiency potential (that is, untapped energy efficiency "resources") in all nations, particularly the DPRK, China, Russia, and Mongolia (significant resource potential exists in the ROK and Japan as well), and potentially huge combined regional markets.

- **Sharing of excess oil refining capacity** to avoid the need to build additional capacity elsewhere in the region. For example, there may be available capacity in Japan that is "mothballed" or otherwise under-used, that could be used to provide oil refining for China, which faces a refining capacity shortfall soon. In so doing, China would defer or avoid having to increase its own refining capacity.
- **Cooperation on transportation infrastructure** to improve access by all of the nations to markets for their goods, and to reduce the time and energy required to deliver raw materials and finished goods to market. Improved roads, rail facilities, and ports have already, to some extent, been the targets of cooperation activities among the DPRK, China, and Russia, but broader cooperation, even towards the dream of developing a rail-based "New Silk Road" from the ROK through the DPRK and Russia to Central Asia and Europe, have also been discussed.
- **Co-development of LNG import capacity by the DPRK and ROK**. It is possible (given a settlement of the current political impasse) that the ROK and DPRK could share an LNG terminal located in a suitable area relatively near the border of the two countries. An LNG terminal located, for example, near Nampo on the West coast of the DPRK, would be able to serve both the Pyongyang area and, via pipeline, areas of the ROK near the border (possibly including some of Seoul). This would provide a way to finance gas import facilities in the DPRK (by selling gas to the ROK) while the DPRK's gas distribution infrastructure and gas demand is built up.
- **Cooperation on regional emergency fuel storage**, including, potentially, agreements on sharing fuel storage facilities, tapping shared storage resources in the event of a supply crisis, and rules for the amount of fuel to be stored (similar to those in force in OECD countries) are all possibilities[19].

4.16. Benefits of the DPRK's Involvement in Regional Energy Cooperation

As witnessed by the 15-20 years that options regional energy sector coordination in Northeast Asia have been under consideration and discussion with, thus far, relatively few concrete steps forward, there exist considerable barriers to such cooperation. Examples of such cooperation in other regions of the world, however, indicate that these barriers could, with time and patience, be surmounted. If and when energy cooperation strategies are implemented in the region, there are a number of potential benefits, to the DPRK, to the region as a whole, and to the broader international community, of the DPRK's participation. These benefits include:

- The DPRK could gain access to energy resources—oil, gas, and electricity, for example—that would be difficult to develop on its own (due to lack of capital and technology, for example), and could be

less expensive than securing those resources some other way.

- The DPRK could obtain “rents”, either in the form of monetary payments on in the form of energy (an allotment of gas from a pipeline, for example), in exchange for allowing energy infrastructure to transit its territory.
- The DPRK could obtain better access to conventional energy, energy efficiency, and renewable energy, and related technologies, allowing the more rapid and cost-effective redevelopment of the DPRK economy.
- The DPRK would be obliged to work with the countries of the region to negotiate access rights and fees, tariffs, and other parameters of cooperative projects. Doing so would provide on-the-job experience to DPRK counterparts of regional participants, which would help both the DPRK and the international community in subsequent interactions between the two.
- The DPRK would also need, in order to participate in international energy projects (particularly those involving shared infrastructure) to undertake thorough assessments of its own energy resources and infrastructure and, moreover, to make the results of those assessments available to the international consortium planning the project. For example, to participate in a regional power grid interconnection, the DPRK would need to supply data on its transmission and distribution grid, power plants, and electricity demand centers (and in fact did so, to some extent, during discussions of interconnection options during the 2000s[20]).
- Through cooperative projects, the DPRK will gain experience with economic cost-benefit analysis and other economic and financial concepts necessary to participate effectively in the international marketplace.
- Cooperative projects will provide substantial opportunities for, and in fact, require, capacity-building for DPRK officials and technicians. Many of the types of cooperation activities identified above, in fact, could have as their first step capacity-building and information-sharing programs of various types.
- In many cases, cooperative projects will allow foreigners better access to the DPRK, allowing them to learn more about the DPRK’s needs and situation, providing an improved appreciation for the perspectives through which DPRK citizens interact with the rest of the world, and forming individual relationships with DPRK Koreans.
- Correspondingly, through cooperative projects DPRK residents will have expanded contact with people from other nations, and will thus obtain a better appreciation for what life is like in other nations, and for how to interact constructively with foreigners, as well as forming their own individual relationships with international counterparts.

Overall, international projects involving the DPRK will be even more difficult to manage than cooperative project involving other Northeast Asian countries, which pose significant challenges of their own. Involving the DPRK in such projects, however, can offer significant benefits in terms of engagement of the DPRK with the international community, even apart from their energy and economic benefits.

V. Potential Research and Engagement Activities Leading up to Cooperation with the DPRK on Energy and Related Issues

In an ideal world, one could somehow wave a magic wand or invoke a time warp such that by the

mere application of will and considerable funding, the energy sector of DPRK, as well as the general economy that depends on the energy sector, would be transformed into an efficient, modern system, ready, willing, and able to be the ROK's partner moving forward. Unfortunately, the DPRK's limitations in terms of capacity to absorb aid efficiently and interact with those who would provide energy aid, and the linkage (both historic and likely in the future) between any significant energy aid and the resolution of the DPRK's nuclear weapons program, mean that most energy sector engagement projects will likely have to start small. Given that at the present, the number of groups within the DPRK authorized to work with foreigners is limited, as is the DPRK's experience in working with foreigners and in planning and managing projects and project budgets in a way that would be acceptable to most outside parties, it will generally be necessary to start with smaller projects that can be built upon. It is also important to design projects that can be built upon not just with future engagement activities but also be used as models for peaceful redevelopment activities by the DPRK itself. This means that good engagement projects should start relatively small but be scalable based on needs and funds available, designed to build and take advantage of both the technical and organizational capacity of DPRK counterparts as it grows, meets the needs of several different DPRK constituents (as well as project participants and supporters in the ROK and elsewhere), and be constructed to be built upon through both follow-up projects and via the DPRK's own initiative to help to provide peaceful, sustainable improvements in the economy of DPRK.

Research and engagement projects can and should be implemented by governmental and quasi-governmental organizations within the ROK and other nations, in collaboration with DPRK government agency counterparts. Such projects, however, should also look to involve non-governmental actors such as academic institutions, private foundations, and other groups, as these groups may find it easier, in the short run, to mount and to win approval on the DPRK side, and can thus get the processes of capacity-building and engagement started more rapidly. Private, for-profit groups can also be involved in research and engagement projects, but should probably be carefully chosen and briefed as to what their approaches and short-term expectations should (and should not) be. The DPRK's lack of consistent practices with regard to commercial transactions—including problems with graft, lack of structured and transparent processes to deal with legal disputes, particularly with foreign companies, and other issues—may mean that private companies will have to take a long view in their interactions with the DPRK for a few more years, until the DPRK's capacity to engage on the commercial level has been built up.

Below we provide some ideas as to potential projects that could potential serve multiple goals, including engagement of DPRK organizations and individuals to build good working relationships with groups and individuals from the ROK and elsewhere, building of DPRK capacity for further engagement and interactions, providing humanitarian assistance, providing opportunities to build economic self-sufficiency within DPRK communities, and serving as demonstrations and pilot projects upon which more extensive assistance/redevelopment efforts could be built, and often addressing other goals as well. These ideas are not intended to exhaust the possible universe of such projects, and we look forward to conversations with ROK counterparts to more fully flesh out and develop these ideas in specific contexts.

5.1. Potential Research Projects

Research organizations, whether governmental, non-governmental, private, or affiliated with regional multinational organizations, could help to develop useful background information to assist DPRK engagement projects in several different ways, including:

- **Continuing to update, at every opportunity, the publically-available knowledge about the**

energy sector and economy in the DPRK. Related research efforts could include working with visitors to the DPRK, including, for example, Chinese and Russian commercial interest who work there, to obtain a more complete view of the DPRK energy sector, working with DPRK refugees in the ROK and China to learn about energy availability in different locations and different sectors in the DPRK, and continuing to otherwise gather and assemble, in an organized structure, updated information on the DPRK energy sector, as has been summarized earlier in this paper.

- **Continue to investigate and refine future energy scenarios for the DPRK**, so as to learn more about the potential for different approaches to energy sector redevelopment, including the relative cost and performance of different approaches. This work could include assembly of updated information on energy efficiency and renewable energy measures that might be applied in the DPRK.
- **Assemble a roster of experts on DPRK energy issues, including those from the ROK and elsewhere**, and call together a meeting of a group of experts similar to the Energy Experts Working Group Meetings that Nautilus convened in 2006, 2008, and 2010, to allow experts to share experiences and learn from each other, and also to inform selected others, potentially including ROK government representatives and key members the international community (including bilateral and multilateral aid agencies and donors, for example).
- **Work to develop energy products and related goods for application in the DPRK and elsewhere**. Research organizations could also undertake R&D into what types of approaches—for example, insulation retrofits for the types of construction prevalent in the DPRK—might be most applicable and cost-effective in an DPRK context, so as to be ready to deploy those technologies in the context of engagement projects (and ultimately, commercial sales in the DPRK) when the opportunity arises.

The ultimate goal of all of these types of research are to increase the readiness of the international community, and particularly the ROK, to provide useful, well-informed, and well-designed assistance to the DPRK energy sector when the opportunity arises to do so.

5.2. Potential Engagement Projects—Training

In all likelihood, the first set of engagement projects undertaken between any ROK or other foreign institution and their DPRK counterpart will be related to training/capacity-building. Here the typical sequence of training on any topic would likely be:

1. Start with trainings in a third (not ROK) country, such as China or possibly Mongolia, for a few (4-10) DPRK counterparts. The training can be provided by experts from the ROK, US, or other nations, and should probably involve a brief local study tour. Such a training could, and in some cases would optimally, involve trainees from other nations, particularly those friendly to the DPRK and to others (such as Mongolia or other developing Asian nations), for whom the training is also applicable.
2. Offer DPRK counterparts the opportunity to undertake short courses of study at academic institutions in a third country, and/or organize study tours for DPRK counterparts in Europe, North America, Australia or elsewhere on the desired topic.
3. Send a delegation of experts to the DPRK to provide a course of perhaps one to three weeks in the desired topic for perhaps several dozen DPRK trainees. A follow-up course may also be necessary. One of the goals of such a training would be to “train the trainers”, that is, train DPRK counterparts sufficiently that they can pass on what they have learned to others, or at least be “up to speed” sufficiently to be active participants in pilot and demonstration projects (such as

those described below). A part of this visit will be for the foreign experts to assess the skills and needs of DPRK trainees, and see what "works" in the DPRK, so as to be able to improve the design of course offerings in the future.

4. Work to integrate trainings into more formal and regular course offerings at DPRK institutes of higher learning and/or research institutes.
5. Provide opportunities for DPRK researchers to undertake graduate courses of study abroad in various energy-related fields.

This generic sequence would be applicable to any of dozens of different training topics in the energy and related fields. These topics could include (but are most certainly not limited to) the following, which are presented in no particular order of importance:

- Organization and operation of energy markets
- Fossil fuel resources assessment
- Energy planning and energy survey design
- Building energy efficiency, including efficient and passive solar building design
- Renewable energy system design and implementation
- Renewable energy resource assessments
- Biomass energy use, and biomass resources assessments
- Soil conservation and reforestation techniques
- Minerals resource assessments
- Minerals extraction industry safety
- Energy economics, including techniques for economic assessment of energy projects
- Application of energy planning tools
- Environmental impacts of energy systems, including environmental monitoring and estimation of emissions
- Development of Clean Development Mechanism projects
- Electricity transmission and distribution system equipment, control, planning, and monitoring.
- Development of natural gas distribution systems
- Management of nuclear wastes

5.3. Potential Engagement Projects—Energy Assessments and Energy Planning

The first step to addressing energy sector needs in the DPRK is to better understand the existing problems and current conditions, as well as to explore with DPRK counterparts options for addressing those problems. These could include:

- Carrying out joint **surveys of energy use** in various sectors. Examples here include rural and agricultural energy use, household energy use, and energy use in specific industrial facilities. The results of these surveys, which should be carried out jointly with DPRK counterparts and used as both data gathering and capacity-building opportunities, would then help to inform, for example,

the development of pilot and demonstration projects as suggested below, and ultimately, to sector-wide implementation of energy use improvements. Working hard to maintain transparency at all levels of energy surveys will be a key to their success in the DPRK. That means involving DPRK counterparts in all phases of the survey process, from survey design to implementation, data processing, and interpretation of results.

- **Energy demand/supply assessment**s. Researching and compiling (with local authorities and engineers/technicians/researcher) a thorough quantitative assessment of the energy demand of a particular subject facility or area, which could be a hospital, school, industrial facility, or a village or town, together with an assessment of the existing energy supply resources (coal, hydro, wind) and infrastructure (power supplies, fuel storage, mines, electricity T&D, and others) available to provide energy. One tool in carrying out such assessments is energy surveys like those above, but other types of tools will be needed as well. The assessments themselves should, by involving a team of DPRK counterparts, help to complete the necessary surveys and measurements, provide "teachable moments" to start to build the capability to carry out such assessments wherever they are needed in the DPRK, which is essentially everywhere. As such, it will offer a first step in what will need to be a similar process nationwide, as the DPRK figures out (with whatever outside assistance can be practically provided) how to modernize its energy system to support a sustainable economy.
- **Engagement built around energy planning topics and tools**. Ideally in conjunction with some of the activities described above, engaging DPRK researchers in carrying out the building and testing of different energy scenarios for the DPRK, in the way that we have described in section 4 of this paper. A software tool such as LEAP (which we used to prepare and evaluate the quantitative scenarios in section 4, and have trained a number of DPRK delegations in the use of) could be used as an organizing mechanism for teaching and assembling data, as well as for learning about what data are missing. Other types of energy planning that could be explored, some of which could use LEAP, include greenhouse gas emissions mitigations mitigation/Clean Development Mechanisms application, utility integrated resources planning, climate change adaptation, energy efficiency measure implementation, and transmission system planning. In each case, the subject for these energy planning exercises could be the DPRK as a whole or, if that is initially politically difficult within the DPRK, could start with a smaller jurisdiction, such as a single county or province, moving on to a country-wide assessment (and, perhaps eventually, a two-Koreas effort), as DPRK authorities become more comfortable with the concept.

5.4. Potential Engagement Projects—Minerals Sector

Some of the options for engagement in the minerals and mining sector include:

- **Training in methods for assessment of minerals resources/reserves and ore quality**. This would include training in various chemical and other analytical methods, and in modern tools for assessments, as well as technical approaches to geological prospecting, including both direct physical methods (drilling) and more remote seismic and satellite-based techniques.
- **Training in 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 any rush to exploit the DPRK's mineral wealth does not result 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 ameliorate existing environmental problems associated with the DPRK minerals

sectors. There is much to be learned by DPRK officials, mining company personnel, technicians, 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[1]. The presentations from this Meeting are avaialble at https://nautilus.org/projects/by-name/dprk-energy/2010-meeting/papers/.

- Relatedly, **training in mine safety**, and, for coal mines, in **coalbed methane capture and use**, would likely also be welcomed, and could lead to deployment of safety concepts in one or more mines, and to pilot coalbed methane capture projects.
- Training in the **economic and financial aspects of mineral resources development**. This could include providing training on economic assessment of minerals resources, and economic modeling of possible mining ventures, but should also include training on what investors will expect by way of rights to mineral resources, how laws regulating mining and minerals extraction typically operate, and what investors will be looking for in terms of reliable partnerships with DPRK counterparts.

5.5. Help to Build Centers of Expertise

The DPRK has a tradition of developing centers of expertise on various topics, which are used both as R&D facilities and as means for dissemination of technologies and practices to places and organizations where they are needed. Potential options for engagement in building new, or enhancing existing, Centers of Expertise include:

- **Renewable Energy and Energy Efficiency Training Center**. This concept, discussed at some length and with great enthusiasm with several DPRK delegations we have hosted, would involve combining provision of information materials (a process already begun by Nautilus and other), assembling assessment tools (such as measurement devices for wind and solar energy, and more basic measurement tools for temperature, pressure, heat flow, electricity, and other parameters), and, above all, providing training by experts in renewable energy and energy efficiency for DPRK actors who would then serve to further disseminate the information. This concept was, in fact, the topic of a partial proposal written jointly by Nautilus and an DPRK delegation in 2001, and still very much in favor in the DPRK, though political conditions since late 2002 have not allowed the joint proposal effort to move forward.
- **Center of Expertise for Building Energy Efficiency**. An important special case of an energy efficiency center, one worthy of standing on its own, is developing a Center of Expertise for building energy efficiency, including efficient building design, training of building energy auditors, provision of computer tools and analytical hardware related to building energy design and efficiency, and R&D on materials for energy-efficient buildings. The Center would also include a component related to the development and analysis of building energy codes (including a library of codes from other countries). Many US and Korean organizations, both governmental and non-governmental, exist that could be engaged in helping to provide training and materiel for such a center, and we are certain that DPRK counterparts are interested in this idea.
- **Center of Expertise on Environmental Management**. This concept would involve equipping a

DPRK center to do research on the environmental conditions in the DPRK, including, for example, monitoring of toxins in the environment, air and water pollutants, ecological health, and other parameters. Engagement options could include providing training on a variety of environmental issues for DPRK scientists and technicians, and carrying out pilot remediation projects, initially small, to address environmental concerns in local areas. This concept was originally suggested by Nautilus and others in the context of possible "repurposing" of the Yongbyon nuclear facility for peaceful purposes[2], but could be applied to existing research or academic centers in the DPRK, could involve creating a new center on a new site, or could be used to find new purposes for other types of industrial or military research units.

- **National Environmental Monitoring Center**: This Center could be a home to monitoring stations that are parts of international environmental monitoring networks, as well as to environmental monitoring of national concern. Examples of the former include monitoring of seismic activity (including, possibly, monitoring of seismic data to detect nuclear tests), monitoring of acid precipitation and other transboundary air pollutants, monitoring of atmospheric greenhouse gases and ozone, surveys of the number and health of migratory species of birds and other animals, and surveys/monitoring of the health of wetlands areas that extend across borders, such as the Tumen wetlands (probably in coordination with a branch Center in the Tumen area) and the DMZ. Avian Flu could be a focus of research for the international programs of such as Center, and this and other issues could be expected to be excellent candidates for collaboration from international agencies (such as the UN Food and Agriculture Organization, the UN Environment Programme, the World Health Organization, and others) and national/regional agencies. On the national level, monitoring of surface and groundwater for chemical and biological pollutants, monitoring of urban and rural areas for air pollutants, and, for example, testing of devices (autos, stoves) for emissions characteristics could be a part of this Center's activities. The Center could also be the institution responsible for maintaining, for example, national pollutant and/or greenhouse gas inventories. An Environmental Monitoring Center, focusing largely on monitoring and on international issues, could be either separate from, or a branch of, the Center for Environmental Management envisioned above.
- **Center for Reforestation Studies**: A Center focusing on reforestation and related geological and biological sciences could, in addition to monitoring reforestation and soil conservation efforts around a local area (and thereby teaching relevant skills for reforestation efforts and analysis to local staff), could serve in the following ways:

o As a clearinghouse for monitoring data and analysis on reforestation efforts in the DPRK as a whole, including, for example, mapping of soil types.

o As a center of expertise on the design and ongoing maintenance of reforestation efforts, perhaps in conjunction with forestry schools in the DPRK (and with the support of schools of Forestry in the United States, and elsewhere, for example).

o As a facility for research on, and breeding and propagating of, trees and other plants most suitable for reforestation in the DPRK, including as a teaching center for both traditional plant care and breeding and modern plant biotechnology. Research in the Center might include, for example, research on the use of trees to remediate soils polluted with toxic materials and otherwise compromised land areas (in coordination with the Center for Environmental Management, for example).

o As a nursery and seed bank for reforestation efforts, and perhaps (to help support the Center) commercial sales of trees for agriculture/forestry and for landscaping.

o As a source of experts who could consult on reforestation efforts elsewhere in the DPRK.

o As a Center of expertise on the global climate and regional acid rain dimensions of reforestation (again, in coordination with a Center for Environmental Management).

o As a venue where DPRK staff could learn to interpret remote sensing data to evaluate trends in forest health (though this would need to be designed carefully to avoid concerns about military use).

5.6. Pilot and Demonstration Projects

Demonstration projects have great value in the DPRK, where they serve as a key tool for dissemination of technologies, experience, and know-how in the country. A few of the many opportunities for such projects include:

- **Solar hot water heater deployment**: Solar hot water heating in China has proven very popular, and is likely to be applicable to the DPRK as well. Such a project could implement solar hot heating for humanitarian (school, hospital, nursery) and/or economic (tourist facilities) use. The project could start with imported solar water heaters, but could include a component for design and fabrication of solar water heaters in the DPRK (or improvement of existing domestic units for manufacture in quantity, if applicable).
- **Mini or micro-hydro system pilot project**: There are apparently many mini- and micro-hydro projects in the DPRK, but their level of performance is unknown, and thought to be suboptimal. Choosing a mini- or micro-hydro site, whether new and existing, and applying cost-effective construction methods to develop both the dam and generator and the systems to use power from the generator (probably including some local economic development and/or humanitarian project using the power) would provide a pilot facility that could, if well-designed, be replicated in many parts of the DPRK.
- **Wind power pilot projects:** Alternatively, a pilot project could be launched to assess the wind resource in one or more candidate areas where the wind power potential is expected to be good, followed by deployment, working closely with DPRK engineers and researchers, of (probably imported) wind machines, and follow-up monitoring of same. Here it should be noted that if the wind power project is to be stand-alone, it should probably be integrated with another renewable energy project, such as micro-hydro or mini-hydro, and an energy storage system, as well as a new distribution grid and related equipment for the area served. If the project is to be grid-integrated, a prior assessment of the local grid will be needed to see if it is adequate to support the wind machines. In the likely event that it is not, it may be necessary to build a new grid in the local area, supplied with power from hydro and/or diesel generation. In any case, a key part of such projects would be training on installation and maintenance protocols, in wind power technology and economics, and in monitoring and assessing wind resources. Wind power can also be interpreted more broadly to include water pumping windmills, which have many applications in the DPRK, and can be made locally[3].
    - **Development of new “green buildings” for use as clinics, schools, or for other purposes**: An activity that could involve and help to retrain DPRK workers in the building sector might be to work closely with international counterparts in the ROK, US, Europe, and elsewhere to design and build one or several highly energy-efficient “green building” incorporating, for example, solar passive or active heating, along with many energy efficiency measures. The idea is that the building would be a laboratory and showcase for building energy efficiency measures for the DPRK, and available for monitoring and study as a part of the work of the **Center of Expertise for Building Energy Efficiency** and/or the **Renewable Energy**

and Energy Efficiency Training Center described above.

- **Weatherization and energy efficiency in residential and institutional buildings**: More generally, existing residential and institutional buildings on a chosen site, which could possibly be the site of an existing institutes that might be a project partner, as well as nearby support buildings (child care centers, schools, cafeterias, and similar facilities) could be "weatherized" with modern insulation, weatherstripping, and windows, plus fitted with energy-efficient lighting systems and with building control and monitoring systems (heat, electricity, and temperature sensors, meters, and recorders) to allow the buildings to also be energy efficiency "laboratories" to help to advance energy efficiency practices in the country as a whole. This type of demonstration project could be an undertaking of staff of the **Center of Expertise for Building Energy Efficiency** and/or the **Renewable Energy and Energy Efficiency Training Center** described above. The buildings might well (almost certainly will) need to be largely rewired to take advantage of electrical system efficiency upgrades, which would provide an opportunity to wire the host institute campus for telecommunications (especially computer networks) as well. The weatherization process would be preceded by assessments of energy-efficiency needs for the targeted buildings, which would again provide an opportunity for initial training of DPRK expert trainers-to-be who might help to staff one of the Centers of Excellence described above.
- **Development of local power options and T&D systems**: This option would begin with an assessment of a local electricity grid and power supply system, and, depending on the findings of the assessment, could include partial or wholesale rebuilding of the electricity distribution grid in a local area, replacement of existing substations or transformers, and possibly the addition of new power generation, either in the form of combined heat and power systems (as above) and/or with independent power systems, probably, judging from the terrain and the presence of a river nearby, a mini- or micro-hydro system (as noted above), but possibly integrated with a small ridge-mounted wind-power system (and/or pumped-storage hydro system) as well (in part for demonstration/training purposes). Once again, energy supply assessment process, and the development of local power systems and T&D networks, can be expected to contribute to local and national expertise in these areas, and the new energy infrastructure set up as a result of this effort could/should be configured with sensors and other attributes so as to be used as pilot and demonstration systems for further training and study for researchers and technicians from throughout the DPRK.
- **Providing agricultural assistance for the local area**: Providing a combination of technical assistance, and improved implements (tractors and fuel, crop processing equipment, irrigation equipment) for one or more villages could help to boost local food production, providing both a humanitarian benefit and a demonstration of sustainable modern agricultural practices, as well as a way for foreign experts to learn about which practices are likely to applicable in the DPRK, and which are now. Monitoring of agricultural soils and products for soil composition and, if the area has a history of, for example, industrial pollution, for toxins, with remediation as needed, could also be a part of this type of assistance. Making sure that those in the project area have as much control as possible over their food security—by providing them with the wherewithal to produce their own food to the extent possible, would also be a goal (perhaps unstated) of this option.
- **Reforestation**: Reforestation efforts in a chosen area could improve the local environment, help to reduce erosion (including, for example, protecting watersheds used for hydroelectric generation, or preventing flood damage to buildings and agricultural resources in the area), and, eventually, provide a sustainable source of fuelwood for local residents. Reforestation efforts could involve locals both as laborers and for the long-term care and monitoring of reforestation efforts, including monitoring of soils and plants for nutrients and pollutants, and as such could lay the groundwork for the Center for Reforestation Studies concept described below.

- **“Energy Independent Village” Demonstration Project**: An “Energy-Independent/Green Energy Village” (GEV) project could integrate many of the pilot project concepts described above. Such a project would combine elements of renewable energy supply, rebuilt or replaced energy infrastructure, energy needs assessment/energy planning, deployment of building energy efficiency and other energy efficiency technologies, and local economic development opportunities, among others. A GEV project would meet the needs of DPRK by, for example, providing energy supplies and livelihoods for village dwellers that reduce their dependency on the state while demonstrating “green” technologies and green energy concepts that could be applied throughout the DPRK. A GEV project could also be a laboratory for applications of energy-efficiency and renewable energy (EE and RE) concepts developed in the ROK, as well as an opportunity to market ROK EE and RE technologies to other nations. A GEV project would also provide a demonstration of low-carbon development, thus it could be a useful illustration of approaches to global environmental problems, as well as an application of Clean Development Mechanisms (CDM) under the United Nations Framework Convention on Climate Change. The humanitarian benefits that an GEV project would be expected to provide will help to meet the political needs of groups in the ROK and elsewhere who would be called upon to support the project, and the economic development elements that must be incorporated in the project will be important in securing both the DPRK and ROK approval for the project[4].

VI. REFERENCES

[1] Korea Foreign Trade Association (1993), Major Economic Indicators for North Korea.

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

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

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

[5] Bank of Korea (2011), New Release: Gross Domestic Product Estimates for North Korea in 2010, dated November 3, 2011, and available as http://www.nkeconwatch.com/nk-uploads/GDP_of_North_Korea_in_2010.pdf.

[6] 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 [NP] 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…".

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

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

[9] N. Aden, "North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications", as prepared for the Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Dr. Aden's paper is available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/0679Aden1.pdf. Data for 2010 and 2011 from United Nations Comtrade Statistics database.

[10] 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 Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as http://www.nautilus.org/DPRKEnergyMeeting/Papers/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".

[11] As of 1995 the DPRK's trade deficit was estimated at $879 million, based on United States Department of Energy's Energy Information Administration (UDOE/EIA, 1996), Country Analysis Brief, North Korea.

[12] 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] For example, see Joongang Ilbo, Lee Young-jong, "North Korea Overseas Trade Reaps $1.97 Billion

For Last Year," Seoul, 06/04/01.

[14] 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.

[15] Bank of Korea (2011), New Release: Gross Domestic Product Estimates for North Korea in 2010, dated November 3, 2011, and available as http://www.nkeconwatch.com/nk-uploads/GDP_of_North_Korea_in_2010.pdf.

[16] 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.

[17] 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.

[18] 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).

[19] 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.

[20] 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 Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, William B. Brown discussed the state of DPRK energy markets, and noted 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://www.nautilus.org/DPRKEnergyMeeting/Papers/Brown.html and http://www.nautilus.org/DPRKEnergyMeeting/Papers/Brown.ppt.

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

[22] By contrast, the ROK’s per capita electricity consumption had more than quadrupled, to 8900 kWh per capita, by 2009, based on World Bank figures.

[23] 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.

[24] That is, for the most part, even as of 2010 and 2011, power was and is reportedly simply provided to consumers largely without metering, so “sales records” as such generally do not exist.

[25] The 2 x 1000 MW light water reactors (LWRs) previously under construction near Simpo in the DPRK by the Korean Peninsula Development Organization (KEDO), and the 2006 offer by the ROK to provide the DPRK with 2 GW of power through a transmission line across the DPRK/ROK border, are examples here.

[26] For example, as von Hippel, D.F., and P. Hayes (2009b), “DPRK Energy Sector Development Priorities: Options and Preferences”, in the Asian Energy Security Special Section on Asian Energy Security of Energy Policy, Volume 39, Issue 11, November 2011, Pages 6781-6789 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://www.nautilus.org/fora/security/07042DPRKEnergyBalance.pdf); von Hippel, D.F., and P. Hayes (2007), "Energy Security for North Korea", Science, volume 316, pages 1288 – 1289, June 1, 2007; and 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.

[27] Note that in this discussion we use the words "path" and "scenario" somewhat interchangeably. In general, we consider an energy "path" for the future to follow on to existing conditions, sometimes with a change in trends, and thus not take into account possible large dislocations or other events. Although we more typically refer to "scenarios" in the context of qualitative exercises designed to encourage participants to think broadly about how the future might look (see, for example, Nautilus Institute (2009), "Northeast Asia 2050: Is There a Role For Civil Society in Meeting the Climate Change Challenge?", available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Scenario_agenda.pdf), or for qualitative analysis of the type described below in the context of "collapse" scenarios, wet use the word "scenario" in this paper more broadly because "scenario" is the word used for energy path in the LEAP modeling software we use to quantitatively model the energy paths (see below).

[28] 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 activity, but force modernization accompanying redevelopment, including modernization of military buildings, communications, and other elements, might increase energy use per soldier even as the size of the armed forces decrease. Partial demobilization seemed to be under discussion in the DPRK as of about 2002, so should not be considered out of the question.

[29] 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.

[30] 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 https://nautilus.org/projects/by-name/science-security/workshops/2010-east-asia-science-and-security-meeting/.

[31] 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.

[32] 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.

[33]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.

[34] 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

[35] Energy sector policy options designed to help avoid DPRK collapse are presented later in this Report, as well as, for example, in von Hippel, D.F., and P. Hayes (2009), "DPRK Energy Sector Development Priorities: Options and Preferences", in the Asian Energy Security Special Section of Energy Policy, Volume 39, Issue 11, November, 2011, pp. 6781 – 6789**,** and available as http://dx.doi.org/10.1016/j.enpol.2009.11.068.

[36] See, for example, Peter Hayes and David von Hippel (2011), "DPRK "Collapse" Pathways: Implications for the Energy Sector and for Strategies Redevelopment/Support", Nautilus Institute Special Report, dated January 18, 2011, and available as https://nautilus.org/napsnet/napsnet-special-reports/dprk-collapse-pathways-implications-for-the-energy-sector-and-for-strategies-redevelopmentsupport/; and Peter Hayes and David von Hippel (2011) "North Korea's "Collapse" Pathways and the Role of the Energy Sector", Chapter 8 in The Survival of North Korea Essays on Strategy, Economics and International Relations, Edited by SUK HI KIM, BERNHARD SELIGER, and TERENCE ROEHRIG, McFarland & Company, Inc.

[37] Some would say that, due to the advent of cell phone usage and access to news from outside the country, particularly in the Chinese border region and in Pyongyang, the control of information in the DPRK is breaking down already.

[38] 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.

[39] For a more detailed presentation of how energy sector assistance activities for the DPRK might be phased, see David von Hippel and Peter Hayes (2010), DPRK Energy Sector Assistance: Options and Considerations, prepared for the Workshop on North Korean Economic Changes & Prospects, Organized by the Bureau of Intelligence and Research, U.S. Department of State, May 7, 2010, Washington, DC.

[40] Methane is the chief component of natural gas. Once processed to remove water, CO2, 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.

[41] Figure from David Von Hippel and Jungmin Kang, "Updated DPRK Energy Balance (Draft) and Work to Be Done" as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DvHKang.ppt.

[42] Photo by Nautilus Institute, 2000.

[43] Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DPRKBuilding.ppt.

[44] Figure from David Von Hippel and Jungmin Kang, "Updated DPRK Energy Balance (Draft) and Work to Be Done" as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA).

[45] 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://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Bentley.ppt.

[46] 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 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.

[47] 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.

[48] 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.

[49] Ji-Chul Ryu, “Energy Crisis in DPR Korea and Cooperation Issues”, presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Ryu.ppt.

[50] 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.

[51] Schipper, L. and E. Martinot (1993), Energy Efficiency in Former Soviet Republics: Opportunities for East and West. International Energy Studies, Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33929. Prepared for U.S. Department of Energy.

[52] 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 the Northern Part. 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

[53] Von Hippel, D. F., and P. Hayes (1995), The Prospects For Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options. Nautilus Institute for Security and Sustainable Development, Berkeley, CA, USA. December, 1995.

[54] 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.

[55] For more comprehensive treatments of these topics, please see David von Hippel and Peter Hayes, "Future Northeast Asian Regional Energy Sector Cooperation Proposals and the DPRK Energy Sector: Opportunities and Constraints", in ERINA Report, Volume 82, July, 2008, available as http://www.erina.or.jp/en/Publications/er/pdf/Er82.pdf; and David von Hippel, Ruslan Gulidov, Victor Kalashnikov, and Peter Hayes, "Northeast Asia Regional Energy Infrastructure Proposals", Asian Energy Security Special Section of Energy Policy, Volume 39, Number 11, November, 2011 Pages 6855–6866, and available as http://dx.doi.org/10.1016/j.enpol.2009.08.011.

[56] The reader is urged to consult the many papers presented during the 2001, 2002, and 2003 Workshops on Power Grid Interconnection in Northeast Asia, hosted by Nautilus and its partners in Beijing and Shenzhen, China, and in Vladivostok, Russia, respectively. These papers provide background both in regional interconnection proposals and on the many different issues affecting and potentially affected by Northeast Asian grid interconnections. See https://nautilus.org/projects/by-name/asian-energy-security/worksho--on-power-grid-interconnection-in-northeast-asia/.

[57] See, for example, Eui-soon Shin (2005), "Joint Stockpiling and Emergency Sharing of Oil: Update on the Situations in the ROK and on Arrangements for Regional Cooperation in Northeast Asia", prepared for the Asian Energy Security Workshop, May 13-16, 2005, Beijing, China, and available as http://www.nautilus.org/aesnet/2005/JUN2205/Shin_Stockpile.ppt.

[58] See, for example, J. Y. Yoon (2008), "Analysis on DPRK Power Sector Data & Interconnection Option", presented at 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/Yoon.ppt.

[59] 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".

[60] See D. von Hippel (2010), Possible Energy, Economic, and Other Engagement/Assistance Activities to Combine with Yongbyon Decommissioning/Conversion, dated January 2010, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Yongbyon-Decommissioning-and-Conversion.pdf.

[61] In our trip to the DPRK in 2000, we provided our counterparts with an example of a relatively easily-fabricated water-pumping windmill. Our understanding is that this design has in fact been replicated and deployed in some areas.

[62] Nautilus has prepared a detailed report on the "GEV" project concept for an organization in the ROK. The report has not yet, as of November 2013, been released.

VII. NAUTILUS INVITES YOUR RESPONSES

The Nautilus Peace and Security Network invites your responses to this report. Please leave a comment below or send your response to: nautilus@nautilus.org. Comments will only be posted if they include the author's name and affiliation.

View this online at: https://nautilus.org/napsnet/napsnet-special-reports/strategies-for-the-rehabilitation-of-the-dprk-energy-sector/

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