Renewable Resources in the Pacific
Proceedings of the 12th Pacific Trade and Development Conference, held in Vancouver, Canada, 7–11 September 1981
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Prospects for Renewable Energy Resources in South Korea

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The total energy supply and demand plan, which has been formulated by the South Korean government, is summarized, and potential sources and domestic quantities for each energy source are presented. The potential technology applications, implementation considerations, and research program are explained, as are the current status of renewable energy commercialization in Korea, the government's future plan, and current problems.

Korea has few energy resources. Consequently, imported energy, especially oil, plays an important role in meeting energy requirements. The demand for energy is expected to increase in accordance with the continuation of industrialization and social development. The government places great emphasis on enhancing energy supplies; developing new and renewable sources is one of its major strategies.

The annual growth of energy use in the next 5 years is expected to be about 7.7% (Table 1). During the same period, the economy is expected to grow annually at 8%. In 1980, total consumption of energy amounted to 38 Mt of oil equivalent (toe). Petroleum accounted for 62%, anthracite 26%, and fuelwood (a noncommercial source) 7%. Nuclear, hydro, gas (liquefied petroleum gas), and bituminous coal made up the rest.

By 1985, the energy consumption will increase to 59 million toe. With this increase, the configuration of supply sources will change significantly. Petroleum dependency is expected to decline markedly to 48% with rising substitution of alternative sources such as nuclear power, coal, and gas. The expansion of nuclear energy and bituminous coal will be particularly noticeable, each rising to 10-11% of total energy consumption.

Table 1. South Korea's energy consumption plan, 1980-85 (1000 toe).

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</tr>
</thead>
<tbody>
<tr>
<td>Petroleum</td>
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<td>25396</td>
<td>26916</td>
<td>28464</td>
<td>28027</td>
<td>27676</td>
<td>28667</td>
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<tr>
<td>Gas</td>
<td>458</td>
<td>569</td>
<td>622</td>
<td>700</td>
<td>788</td>
<td>1833</td>
<td>2904</td>
<td>38.5</td>
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<tr>
<td>Anthracite</td>
<td>9878</td>
<td>10198</td>
<td>10618</td>
<td>11235</td>
<td>11486</td>
<td>11740</td>
<td>12116</td>
<td>3.5</td>
</tr>
<tr>
<td>Bituminous</td>
<td>199</td>
<td>880</td>
<td>1467</td>
<td>2245</td>
<td>4474</td>
<td>6106</td>
<td>6154</td>
<td>47.5</td>
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<tr>
<td>Hydro</td>
<td>496</td>
<td>537</td>
<td>535</td>
<td>537</td>
<td>536</td>
<td>690</td>
<td>726</td>
<td>6.2</td>
</tr>
<tr>
<td>Nuclear</td>
<td>869</td>
<td>774</td>
<td>913</td>
<td>1484</td>
<td>3153</td>
<td>4561</td>
<td>6561</td>
<td>53.3</td>
</tr>
<tr>
<td>Fuelwood</td>
<td>2517</td>
<td>2517</td>
<td>2343</td>
<td>2260</td>
<td>2180</td>
<td>2110</td>
<td>2070</td>
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<tr>
<td>Solar</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>
Energy imports will play an increasingly important role in the next 5 years. In 1980, imports accounted for 69% of total energy consumption, with petroleum imports being the largest. By 1986, import dependency is expected to increase to 79%. Petroleum will still be the largest energy import, but its relative position among energy imports will decline. The imports of bituminous coal and anthracite will almost double, and imports of liquefied natural gas (LNG) will begin in 1985.

The prospective sources for new and renewable energy in South Korea are the sun, wind, biomass, tides, and inland waters. Research and development of all these sources are under way. Several hundred solar houses are under construction, and the interest in photovoltaic research is also high. The government is collecting data on wind power, with the intention of using it to supply electricity to remote islands and villages where high transmission costs make other energy supplies infeasible. Biomass studies in the country are primarily of forest products and crop residue conversion. These resources have some potential in South Korea, but their contribution to the total energy requirements of the country is small. The major increases in the utilization of biomass resources will come from improved efficiency in end use.

South Korea's small hydro resources are economically recoverable, and, currently, three small plants are operating. In addition, the government has started a feasibility study on the construction of a 400,000-kW capacity tidal power plant at Garorim Bay, and its construction is expected to be finished by 1988.

The country has invested only relatively small amounts in the development and utilization of new and renewable energy because of uncertain economic feasibility, engineering constraints, lack of capital for infrastructure, and unfamiliarity with alternative energy sources. Technical personnel and testing facilities for such work are scarce in this country. For example, mass construction of solar houses could only be undertaken if engineering design capability were improved substantially.

The potential for implementing new energy systems depends on how economic they are compared with other sources, whether they are marketable, and whether there are institutional or cultural constraints on their acceptance. Even if designs were possible, the infrastructure necessary to distribute them to the public and to ensure maintenance is at present not available.

To expedite the development of new and renewable energy sources worldwide, we suggest:

- Increased international cooperation and coordination in research, development, and demonstration in new and renewable energy (e.g., joint-venture and licencing arrangements between developed and developing countries);
- Strengthened information exchange systems in new and renewable energy (e.g., establishment of a data bank on sources of energy);
- A commitment to increased financial and technical assistance from rich countries; and
- An international commitment to expanded education and training in new and renewable energy.

Solar Energy

The direct solar resource base in South Korea is small in terms of both total and direct-beam insolation. During the course of a year, average daily insolation ranges from 180 cal/cm² (7.5 MJ/m²) to 318 cal/cm² (13.3 MJ/m²). These averages represent 25-45% of annual extraterrestrial radiation, indicating relatively few clear days and low direct-beam insolation. The high end of the range is comparable to insolation in New England and the north-central United States.

Because of the rugged terrain and complex weather patterns affecting the peninsula, there is also substantial variation in available insolation within regions. For example, Jeongeub and Buan, two cities near the western coast, fewer than 30 km apart, receive daily average insolation of 180 cal/cm² and 244 cal/cm², respectively — a difference of more than 30%.

Potential applications for solar energy in South Korea include water and space heating. Electricity-generating systems are also possible with photovoltaic and high-temperature thermal processes, the latter of which is less feasible at present levels of technology.

Photovoltaic systems, which directly convert insolation to electricity via semiconductor material, can be either flat-plate arrays or concentrating systems. The grid-connected, south-facing, flat-plate, nontracking array appears to be the most cost-effective configuration. Flat-plate arrays are particularly suited to the cloudy Korean climate, where most of the available solar radiation is diffuse insolation. The collectors maximize annual insolation if tilted from the horizontal at the latitude angle, which ranges from 33°31’ at Cheju to 37°34’ at Seoul.

The output is estimated to be about 8% of the total energy incident on the collector surface and is based on a photovoltaic-cell efficiency of 12%;
the estimate takes into account the effects of cell packing, angular sensitivity, and power-conditioning losses. The performance of the photovoltaic system was estimated for four sites in South Korea: Kyungju, Seoul, Kwangju, and Cheju Island. Estimated annual outputs range from 76 kWh/m² in Kyungju to 102 kWh/m² on Cheju Island.

In high-temperature thermal processes, concentrating collectors are used to produce high temperatures that operate a heat engine to generate electricity. The most cost-effective technologies for solar energy are the point-focusing distributed receiver (PFDR) and the power tower. The PFDR uses a field of hundreds of thousands of parabolic-dish concentrators, with a high-efficiency stirling cycle engine at each focal point. The power tower consists of a single receiver that is mounted on a tower surrounded by a large field of sun-tracking heliostats. Both systems are at present not technically or economically feasible in South Korea.

The economics of solar-energy systems cannot be projected with complete certainty but do not appear attractive for the most part; consequently, the potential market is expected to be limited. Despite government efforts to encourage solar energy, institutional constraints limit its potential.

The Ministry of Energy and Resources (MER) has announced plans to encourage the use of solar energy in new housing. MER projects annual construction of solar homes (estimated at 45 homes in 1979) to be 2400 in 1980, 4500 in 1981, and 250 000 by 1990. To encourage solar construction, MER has set up a special housing fund to provide loans of up to 9.5 million won per solar house, has introduced tax exemptions for solar home builders, and has waived the requirement to purchase housing bonds (amount to 2-7% of the price) for solar homes. These incentives decrease the initial costs of solar homes by 10-30%.

The government program for research on solar energy is under way in the Korea Institute of Energy and Resources (KIER). For 1980, it includes photovoltaic technology (67.0 million won), solar-thermal heating and cooling (62.0 million won), standard development (35.0 million won), industrial applications (14.5 million won), and house construction and information programs (223.0 million won). KIER has constructed three demonstration houses using active and passive solar-energy systems. It is also developing photovoltaic systems for use in remote areas, such as lighthouses, buoys, and pumping stations.

The Korea Institute of Science and Technology (KIST) is also involved in solar-thermal, electric-power systems development. It is installing a combined wind and solar-thermal electric system, using a parabolic-dish system (manufactured by Omnium-G), on an island off the west coast.

In addition to government-supported research, housing developers and other private entities have shown much interest in solar systems. The Korean Housing Corporation is particularly active and is now sponsoring a design competition to select three to five prototype solar homes, on which construction will start in August. In addition, several companies are manufacturing solar panels and complete solar-energy systems both for the domestic market and for export.

Wind

The characteristics of the country’s wind resource (estimated at $3.4 \times 10^{10}$ kWh) make it particularly attractive for electricity generation (19 900 MW capacity) either on a large scale, for interconnection to the mainland grid, or on a small scale, for local use on the islands to the west and south. In the late 1990s, wind-generated electricity will provide 2.5% of the total electrical needs, if sufficient land can be made available for large wind farms.

Wind velocity and direction are recorded hourly by the Central Meteorological Office at 86 stations throughout South Korea and are summarized monthly and yearly. Most of these stations are located on small hills in or near large towns and cities. Wind velocities are not available for the offshore islands or for peaks and ridge tops on the mainland, which are presumably potential sites for wind-generation systems. Average wind velocities are low to moderate (0.9-4.5 m/sec); the greatest average velocities are found along the southwestern and southern coasts.

Wind energy traditionally has been used on a small scale in South Korea to provide mechanical power for such uses as grinding and water pumping. Until 1975, wind power was not used for electricity generation, but, as a result of some recent developments by the Ministry of Science and Technology (MOST), the government is now considering wind machines for electricity generation on the islands, where wind is already competitive with alternative power systems such as diesel engines. In some regions (e.g., on the southwestern coast), average annual wind speeds are suffi-
sient to generate large quantities of electricity with large-scale wind machines.

Because most of the mainland is already connected to the main electric grid, the major market for wind systems smaller than 50 kW will be the offshore islands, which are too sparsely populated or too far from the mainland to make grid connection cost-effective. The government is currently preparing a census of the offshore islands to estimate the potential of small wind systems for providing electricity and mechanical power. The preliminary results of this census indicate that the optimal size for a small system is 10 kW.

A successful small-scale wind system must meet several technical and economic criteria. From a technical standpoint, these machines must be carefully designed to resist the frequent typhoons that destroyed previous wind-energy systems. Imported machines cannot be used because they are not adapted to Korean wind conditions. From an economic viewpoint, small wind machines on the island must be competitive with diesel for electricity generation.

For both small- and large-scale wind-energy systems, economics are the primary concern. The economics of the two types of systems are basically different. Unlike small-scale systems, large-scale wind-energy systems must be competitive with pumped hydro or thermal plants. On a cost-per-kilowatt-hour basis, wind systems would be competitive for average sites in South Korea only if large economies of scale could be achieved.

Small wind machines must compete with small diesel engines, which have high generation costs. Although generation costs for small wind-powered systems are generally highly competitive with diesel, the storage capacity that is needed for 2–3 consecutive days without wind, which occur fairly often, greatly increases costs and makes the economics of small wind systems less favourable.

The market for 10-kW wind machines is expected to be 1000 units in 1990. However, the machines, which are considered optimal for average electricity demand on the islands, cannot be standardized because of the variations in wind characteristics. For example, a 10-kW machine installed at Choonmu, where the average wind speed at 10 m is 2.73 m/sec and the maximum available power is 278 kWh/m² annually, should have a diameter of 12.6 m, whereas a 7.61-m diameter machine located at Mockpo, where the average wind speed is 4.37 m/sec and the maximum available power is 784 kWh/m² annually, would suffice. This simple comparison shows how difficult it would be to lower manufacturing costs by economies of scale.

In addition to economics and market potential, the potential for wind-energy systems will be affected by government policies, resource requirements, and environmental impacts. A major objective of the government is to provide electrical supplies to the islands. Alternative energy resources, especially wind, may play a major role in achieving that objective, because they will be economic in the near future. At present, however, there are no financial incentives to develop wind systems. Korea Electric Company (KECO), the state monopoly, has not pursued wind-energy systems because they are not competitive on a marginal-cost basis with alternative sources of electricity.

A small-scale wind machine industry would not be constrained by a shortage of materials, because the market for small-scale systems appears limited. Training personnel to design and operate the machines and to select the sites can be easily accomplished.

Wind power does not present major environmental problems; however, there is an aesthetic impact associated with installing large wind farms. Each large wind machine requires 0.3 ha plus land for access roads and transmission lines. Such extensive land use may not be possible, especially in the plains areas because of competing land uses, such as agriculture or housing. Finally, some preliminary studies suggest that large wind-powered generating machines have physiologic effects on nearby populations, because of their low-acoustic frequencies. However, such impacts have not yet been fully evaluated.

There is currently no research program on large wind machines in South Korea, but KECO has expressed interest in coupling wind-energy systems with pumped-storage hydro projects. The Korean Advanced Institute for Science (KAIS) and KIST are currently performing a limited research program on small-scale wind machines from 2 to 10 kW, for electricity generation, water pumping, and lighthouse operations.

**Biomass**

The country's biomass resources include human and animal residues; agricultural crop residues; and forest fuels and residues. Solid and liquid urban wastes do not appear to constitute a significant resource at present. The annual net energy recovered from these biomass resources is estimated to be 6.8 PJ; as much as 41.6 PJ were potentially available in 1978. By 1986, the potential is estimated to range from 50.7 PJ/year to 89.6 PJ/year, and by 2000, 42.6–115.0 PJ/year.
This estimated increase in the resource base would result if the expected switch from traditional fuels (wood, agricultural residues) to more convenient fossil fuels takes place and if expected increases in forest outputs are realized. However, available technology for the use of traditional fuels could provide convenience similar to that with fossil-fueled technologies and would have the advantage of using local resources.

Biogas from animal residues could replace about 32% (on a net-energy basis) of the coal used in the rural residential sector. By 1986, crop wastes burned in district heating systems and biogas from animal residues could replace about 67% of the coal, kerosene, and gas projected to be needed by the rural residential and commercial users.

A large percentage of the fossil fuels could be replaced if some of the residues not currently burned could be recovered without environmental damage or detriment to farming activities. The same resource base could replace more than 50% of the fossil-fuel requirements for the rural residential and commercial sectors by the year 2000. Wood-fired boilers or gasifiers could replace 3.6% and 5.7% of the energy supplied by oil to industrial users, by 1986 and 2000, respectively.

Direct combustion of biogas could supply heat for cooking or space heating. The useful energy potentially available from direct burning, at a heating value of 5500 kcal/m³ and a conversion efficiency of 60%, is 6.8 PJ/year. The energy required by a family of five for daily cooking has been estimated at about 3600 kcal. Therefore, the net energy recoverable from biogas combustion could supply the yearly cooking needs of 1.24 million households, or about 56% of rural households. Alternatively, biogas could supply the cooking and heating needs of about 150,000 households during the winter months.

Biogas could also be used to generate electricity. Experiments conducted in other countries indicate an efficiency of about 20%. In this case, the cooling water can supply the heat required to maintain the digester temperature and some process heat (hot water). It is assumed that 60% of the heat that would have been rejected can be recovered as process heat.

Grain straws can be used to produce energy through direct combustion, gasification to low-Btu gas, anaerobic digestion, or ethanol production. Of these processes, ethanol production, which involves preprocessing of the feedstock (i.e., chemical or enzymatic hydrolysis) to release the fermentable sugars, has not yet been commercialized. Gasification to low-Btu gas was extensively demonstrated during World War II for automotive transportation and is now being revived. The efficiency of anaerobic digestion of crop residues may be limited, because of the liquor content of the feedstock and its sometimes unfavourable ratio of carbon to nitrogen. This problem can be corrected in part through the addition of animal urine. Chopping the residues before they are introduced into the digester is recommended to increase digestibility. Chemical pretreatment can also improve digestibility but is probably justified only for large-scale operations.

Wood fuel can be used in direct combustion systems, converted to low-Btu gas through gasification, or converted to methanol fuel.

With the present technology in South Korea, residential direct combustion results in a net utilization of about 30% of the energy content of the fuel. With state-of-the-art technology, the efficiency of residential stoves could probably be increased to about 50%. Small industrial boilers that are wood fired could be used for process heat for small industries: they have overall efficiencies of about 70% — comparable with that of oil- or gas-fired boilers. Thus, forest products can be burned more efficiently by industrial boilers that have been converted from oil or gas fuel than by the stoves in most homes.

Gasification of wood to low-Btu gas for local use has been demonstrated. The current operations of pilot processes in the United States suggest that about 70% of the energy content of the wood can be recovered if the gasifier is closely coupled to the end user.

Methanol fuel produced from wood can be used directly in vehicles or converted to synthetic gasoline by the Mobil process, although there are currently no operations of this type. Analysis of the economics of this process indicates that plants with capacities to convert about 900 Mt of oven-dried wood daily would be required to achieve economies of scale. At present, annual productivity levels (i.e., 0.6 m³/ha), about 1 Mha of forest would have to be earmarked to sustain one such methanol plant, and such plants are not feasible for South Korea.

Biogas production technology is well established, the potential of the technology being based on adequate operation of the digesters. To achieve the full benefit, the government would have to introduce training programs for village leaders and employ the services of trained extension agents. Government incentives could also be offered to induce villagers to set up village-scale biogas digesters. The ongoing rural development
program could be a vehicle for such incentives.

Treatment of residues by anaerobic digestion reduces pathogen content while maintaining nutrient value. Collection of the residues within a village for delivery at the biogas facility may create a risk of disease, although it would probably be no more serious than that incurred by the spreading of raw manure on fields.

Biogas can be stored and distributed; it offers the same convenience as oil or natural gas and is more convenient than coal for household users. Therefore, the anaerobic digester should be readily accepted if its introduction is preceded by adequate information.

Crop residues could make a significant contribution to meeting energy demand in rural areas. Biogas derived from them is expected to compete well with energy from other sources and may have significant market potential. Institutional and environmental constraints should not present serious problems.

Both energy from combustion of residues and biogas produced from residues are best utilized in the rural residential and commercial sectors, because the feedstock resources are close to the users and because the technologies can be integrated into the agricultural environment (e.g., through the recycling of ashes and sludge to the land).

The implementation of heating systems may require the formation of cooperative utilities or the extension of the charters of existing utilities to provide this service. As with utilization of animal wastes, use of crop residues would require an infrastructure of trained personnel to maintain and operate the technologies. Also, incentives may be required to induce businesses to manufacture the appropriate technology and equipment.

The major environmental risk of using crop residues for fuel is the soil deterioration and loss of nutrients resulting from the removal of the residues. The risk may be decreased somewhat by the recycling of digested sludge to the land.

The best candidates for using the wood-to-energy technologies are industries in rural or semirural areas. Wood fuel could supply 3.6% and 5.7% of the net energy obtained from oil in 1986 and 2000, respectively. Oil displacement could be increased if the fuelwood resource base were expanded.

Except in the forest products industries, wood is not a common industrial fuel. Technology-transfer programs to promote use of fuelwood could be initiated. The best vehicle for such a program is likely the Office of Forestry. Tax incentives for promoting the use of renewable fuels may also increase adoption of the technology. Also, wood utilization is labour intensive, and a fuelwood program would create stable jobs in rural areas.

The major environmental concern is adequate management of the forests to sustain productivity and to avoid the environmental damage that results from deforestation. This concern is particularly acute in mountainous areas where the danger of erosion and runoff is great.

Geothermal Energy

The geothermal-energy resource in South Korea does not appear to be sufficient to make a significant contribution to the country's energy requirements. It is limited to low-temperature springs and wells. The Korean Institute for Geology and Minerals has identified 20 sites on the mainland with outflow temperatures greater than 20°C. The maximum temperature observed was 73°C, and only five sites have temperatures greater than 50°C. Moreover, all these resources flow more slowly than 8000 m³/day and exhibit moderate to severe drops in their water tables even at modest pumping rates.

Most of the hot springs identified are in southeastern Korea, although a survey indicated geothermal resources on the island of Cheju. The four volcanic eruptions on Cheju in the last 1000 years (in 1002, 1007, 1455, and 1670) suggest large volumes of hot rock and molten magma at shallow depths, good sources of geothermal energy. Similarly, the volcanic island of Ulreung-do may have potential.

High-temperature geothermal resources can be used for electric-power generation. South Korea does not appear to have exploitable resources of sufficient temperatures (200°C or greater) for these systems, although some may be discovered on Cheju. Lower-temperature resources can be used for space heating by "district-heating" systems, in which the hot water would be pumped to nearby residential and commercial buildings, and used for space and hot-water heating. However, district-heating applications are difficult at the low temperatures of most of the springs in South Korea because of the large volumes of water and the large, well-insulated, expensive piping required. In addition, geothermal use will accelerate the water-table drop at these sites.

Ocean Energy

The oceans can provide tidal power, thermal power, and wave power. The use of tidal power
for electricity generation at six sites along South Korea's northwest coast appears promising. These sites have a combined annual output of 12,000 GWh. Although a number of implementation issues remain unresolved, one of the six sites has already been selected for detailed study by KECO, with the aim of building a tidal power plant in the near future. Ocean thermal systems operating in the warm waters of the mid-Pacific about 2200 km south of Korea may also be economically used for ammonia generation, although electric-power production does not appear economically feasible. Wave-power systems may be economically feasible near Hupo, but the cost performance of these systems is uncertain.

KECO identified 10 sites for tidal power with a potential total of 7050 MW and potential annual energy production of 18,675 GWh. However, development of some sites would interfere with development of others. In addition, several other factors affect the utilization of the proposed sites. As a result, only 7 of the 10 sites can be used for tidal-power developments. The maximum potential of these is 5000 MW, and their maximum energy output annually is 12,000 GWh.

Ocean thermal systems are potentially usable only off the east coast in the Sea of Japan, where temperature differentials (ΔT) between the warm surface waters and cold depths can be as much as 25°C during the summer months. Normally, a plant cannot be designed to operate efficiently for a range for ΔT greater than 10°C; if the plant is designed for a maximum ΔT of 25°C, it will not operate if ΔT is less than 15°C. Such a plant would operate in South Korean waters only from June through November.

According to these assumptions, such a plant would have an annual output of 772.3 GWh. Each plant would require an area of about 2000 km² to operate in a renewable mode, i.e., without affecting the water temperatures significantly or interfering with adjacent ocean thermal plants. The sea within 200 km of the South Korean shore has an area of about 100,000 km². This area would support 50 plants for an annual output of 38.6 TWh, which is 1.7 times the country's 1977 electricity consumption.

Wave power may also become feasible along the eastern coast. A study estimated the total wave energy around the coastline and major islands to have a maximum potential of 8620 MW. The power availability has a marked seasonal variation, most of the power being available in the winter months and relatively little in June or July.

For a typical wave-power system having a conversion efficiency of 50% and a capacity factor of 50%, the estimated maximum extractable wave-power potential is 4300 MW capacity, with an 18,800 GWh energy output.

Tidal-power plants, formed by the damming of large bays or sections of the ocean, can be operated in several modes. The simplest tidal-power plant uses fixed-blade turbines to generate energy from the flow of water from the basin to the ocean. In certain cases, it may be possible to use variable-blade turbines, which pump water into the basin against a low head at high tide, using power generated elsewhere in the electrical grid. Such pumping increases the reservoir water level above the normal high-tide level; the extra water is then released at low tide, against a much higher head.

Tidal plants can also be designed to generate power from both ebb and flood tides, using bidirectional turbines with adjustable blades. This design would increase the time the unit is available to the grid. In studying the inner Asan Bay project, we found that this method increased the operation time of the generators from 43% to 68%. However, the annual power output increased only 1%, from 1466 GWh to 1480 GWh, because variable-pitch turbines are less efficient than fixed-blade turbines, the average head being lower. In addition, because the method doubles the number of output pulses, it may mean increased maintenance both for the tidal-power plant and for cycling units in the utility grid. However, the method may be justified on the basis of the increased flexibility in integrating the tidal plants and the utility grid.

The tidal plants can utilize double-paned basins. One is operated as a high basin, generating power from the ebb tides; the water level inside this basin is usually higher than that outside it. The other basin is operated as a low basin, generating power from the flood tide; the water level inside this basin is lower than that outside. Through coordinated operation of the two basins, power can be generated at almost any hour in response to system requirements. However, the low basin generally provides lower energy than it would if operated as a high basin. Depending on the shape of the basin, the loss in energy may be as much as 20%.

Finally, tidal plants can utilize double-linked basins. In this scheme, two basins are connected with the ocean and share a common dike. One basin is operated as a high basin, the other as a low basin. The main advantage of this mode is that the basins can produce energy at any time.
The most appropriate mode for operating a tidal-power basin depends on the load on the system and the mix of modes used in generating electricity. In the short term, while a significant portion of the generating capacity is oil fired, tidal plants will probably be operated in the single-basin, single-effect mode to maximize their energy output and minimize capital costs. After 1995, nuclear and pumped hydro will be most important and oil- and coal-fired generating units will represent a smaller portion of the total generating mix; then, the operating modes that allow retiming of the energy will become more important and will need to be examined as part of a comprehensive study of plans for utility systems.

Two major ocean thermal energy conversion (OTEC) technologies can be used to generate electricity from the ocean temperature differences. One uses a thermodynamic “open cycle,” in which the working fluid is sea water at 25–30°C pumped at the surface and then vapourized at low pressure. The vapour drives a large-diameter turbine. The cooler, deeper waters are brought to the platform by a long pipe and used to condense the turbine exhaust, producing fresh water as a by-product. This device is being studied by the French, who built such a plant off the Ivory Coast some 25 years ago. The other technology, a “closed cycle,” uses an intermediate fluid, such as ammonia, to drive a much smaller and less costly expansion turbine. The latter technology has received the most intensive study.

The electricity generated at the plant can be either transmitted to the shore by expensive submarine cables or used in situ to produce a valuable, storable, and shippable product, e.g., ammonia, aluminum, or chemicals that require electricity for production. The in-situ approach would rely on “grazing” plant ships cruising warm waters at reasonable distances from South Korea (e.g., off the Philippine Islands), producing a storable fuel such as ammonia, which can be used domestically as a fertilizer or a fuel or exported to other countries.

None of the possibilities for ocean thermal power have been commercially demonstrated. Several countries, such as Japan, the United States, and France, are entering the pilot phase of OTEC development and expect to prove its economic feasibility in the next 10 years.

Likewise, technologies for using wave power have not yet been demonstrated on any large scale. Many concepts have been described, but almost no data are available on performances because no pilot plant has yet been built. The dam-atoll consists of a large concrete dome with an open bottom. Waves are focused by the shape of the dome to the central point, where they form a vortex inside a tube that empties out the bottom of the dam-atoll. Inside this tube are vanes that are turned by the waves entering the top and used to drive a generator.

Development of all seven feasible sites for tidal power would require a capital investment of about U.S.$11.5 billion. Domestic portions of the project construction costs are estimated to be 95%: 25% for electrical machinery (primarily the low-head turbines, blades, and controls) and 70% for the civil works (dam, roads, and other infrastructure) and other items.

Tidal-power plants would interfere with land reclamation projects. The high-basin systems, which are most economic, would flood lowlands in the basin area; in addition, any reclaimed areas would reduce the volume and thus the potential energy output of the basin. However, low-basin schemes may not entirely preclude land reclamation. Selecting the optimal trade off between tidal-power production and land reclamation requires a careful cost–benefit analysis for each site.

Cost estimates of OTEC plants both for power generation and for ammonia production exhibit tremendous variation. A U.S. government design for a 325-MW power-generation plant is estimated to cost U.S.$2100/kW in 1993–95. In addition, a power-transmission cable must be constructed from the sites to the mainland, about 100 km. The cost of this cable would be U.S.$1 million/km. Therefore, the total plant cost would be U.S.$782 million. With an annual fixed-charge rate of 0.113 (6% capital cost, 30-year life, 4% annual maintenance costs), the energy cost would be 114 mills/kWh, or 55.4 won/kWh. This energy cost is not competitive with projected costs of oil-fired generating units.

Estimates of wave-system costs also exhibit tremendous variation, primarily because of the wide variety of proposed systems and the lack of actual operating experience. These estimates range from a low of U.S.$2500/kW for the Lockheed dam-atoll system (for the period 1990–2000) to $14000/kW for a proposed British system.

Although detailed data on the Lockheed system are not yet available because no pilot plant has been constructed, the estimated costs, if valid, indicate that only at one site, near Hupo, is wave energy economically competitive with oil-fired electricity generation in the near future. However, if wave-power systems were combined with breakwaters for harbour development,
other sites along the eastern coast would be practical.

A detailed feasibility study of a tidal-power plant for the Garorim Bay site is being carried out. This study will pave the way for construction of a tidal plant in Garorim Bay between 1982 and 1988. OTEC research and development are not currently funded by the government, although wave-power research is receiving assistance at 30 million won a year.

Small Hydropower

Development of small hydropower systems in Korea is technically feasible and economically attractive. The small hydro resource base of 596 MW represents 18% of the total hydro potential, with an annual output of 5.2 billion kWh. Of this potential, the use of 1.51 billion kWh is expected to be economically favourable in 1985, and 1.93 billion kWh in 2000. This potential is small relative to the total hydro development planned by KECO and will be constrained by KECO's purchasing practices and by local demand, which is not always near the small hydro sites.

More than 85% of South Korea's total area is at least 100 m above sea level. Although the average height of the mountains is relatively low (maximum of 2000 m), the terrain is rugged with many streams and rivers.

Rainfall ranges from 979 mm at Pohang Station to 1440 mm at Cheju Station. This rainfall, if harnessed in an optimal hydro system, could provide as much as 30.2 billion kWh/year at an average altitude of 100 m. Small hydro systems comprise facilities with a generating capacity between 2 and 15 MW. The total installed capacity of small hydro systems was 9.5 MW in 1978.

MOST recently conducted a nationwide study of the mountainous catchment area and identified 2600 potential sites for small hydropower development, representing a potential of 582 MW.

The hydro resource has two major characteristics. First, 43% of its potential is concentrated in one province — Kangwon — and more than 75% in three provinces. Second, the resource base is highly seasonal. More than 50% of the yearly total precipitation occurs during the rainy season, from June to October, creating a high hydro potential. The winters are dry and would not fuel production to meet the high demand for electric power in the colder months.

The discrepancy between hydro supply and power demand makes small hydroelectric projects unattractive for electricity generation unless they are developed — as multipurpose applications — in conjunction with other projects in water-flow management and control, irrigation, or land reclamation. However, small hydro applications are not basically oriented toward mass electrical generation anyway. Essentially, small hydro applications consist of limited electricity generation for local needs in remote areas, isolated from the grid, and multipurpose applications (e.g., electricity production and water management). Many technical features are similar for the two types of application, and, as a general rule, if a small hydro project proves economic for electricity generation alone, it will be economic for multipurpose applications.

A small hydroelectric plant consists primarily of electromechanical-equipment installation and civil engineering (i.e., construction of dams, spillways, etc.). The civil engineering is highly dependent on the physical qualities of the site, but the turbine, which accounts for the major part of the electromechanical equipment, is selected on the basis of hydraulic considerations.

The net head available (the head less losses from water flow to and from the turbine) dictates what type of turbine is suitable for use at a particular site. The rate of flow determines the capacity of the turbine. Several types of turbines are designed for operating under the conditions common in Korea (i.e., heads from 10 to 40 m, and flow rates up to 100 m³/sec). Two types of turbines are particularly adapted to South Korea — the Francis and the Tubular turbines.

In addition, limited flow variation and proper site preparation are essential for maximizing hydro output. The only way to limit seasonal and daily flow variation is to develop storage capacity, the optimal size of which will depend on such factors as the flow duration curve, the type of reservoir and dam, the evaporation, and the soil permeability. The optimal amount of storage capacity must be determined. Site preparation is aimed at maximizing the available hydraulic head at the site. Water heads of 9-11 m can often be obtained from 3000 m river loops, where the river slope is 3-4 m/1000 m.

The extent to which small-scale hydro plants will be implemented depends primarily on their economics but is also affected by local utility regulations and utility purchasing practices.

The systems affect local farming. For example, a small hydro project proposed at Nong-Won will provide an additional 528,000 m² of farmland valued at 6600 won/m². The project will allow upgrading of an additional 805,000 m² from dry paddy to wet paddy, increasing their value by 3300 won/m². The additional costs of these improvements (i.e., clearing, landscaping, build-
ing irrigation ditches) have not been estimated. Moreover, use of the site for irrigation may reduce its power output. There is no simple way to evaluate these peripheral impacts.

Local demand may be insufficient to utilize the total capacity of the plant. In Nong-Won, the local electrical requirements (primarily for lighting) are about 100 kW, while the plant capacity is 1000 kW. Attracting small-scale industry to local areas may be feasible, but this process is long and involved. Excess energy cannot readily be sold to KEKO, which is not interested in promoting small hydro systems for a number of reasons, e.g., powerline costs, synchronization system reliability, and maintenance. As a result, KEKO will pay only 15–20 won/kWh for excess hydropower; small hydro generation costs exceed this level.

The turbines and associated equipment may have to be imported. At present, the government is considering development of a domestic capability to manufacture Francis and Tubular turbines in sizes under 1000 kW. For higher power, the South Koreans will need to turn to imports, at least temporarily. In the absence of a domestic manufacturing capability, the cost of turbines will be increased about 30% (as a result of transportation costs).

The primary environmental impact of small-scale hydro development is the increased risk of flooding in the surrounding areas, which may be inhabited or devoted to agriculture. This risk must be assessed on a case-by-case basis. There is no formal research program for this energy source because small-head hydro technology is relatively mature. The government is financing studies of potential sites for small-scale hydropower development.

Conclusions

Keeping a proper balance between energy supply and demand is essential for the future economic growth of South Korea. As the country is poorly endowed with energy resources, all possible efforts for using renewable energy should be explored. For the optimal application of renewable energy, new technologies need to be developed, and older ones adapted. The development of a national renewable energy plan as well as the creation of laws to enforce it is essential. To broaden the opportunities for the use of renewable energy sources, the government must also enhance research and development programs.

Under the direction of the South Korean government, a vigorous solar-energy research and development program has been formulated, and substantial progress has been made in recent years. By July 1981, more than 500 solar-housing units had been constructed, and 25,000 have been projected for construction by 1986. Hundreds of lighthouses in remote islands already use photovoltaic cells for their power source, and the government is providing tax and loan incentives for solar houses in rural areas, tax incentives for imported materials to be used in solar systems, and loan incentives for solar products.

Wind energy traditionally has been used on a small scale in South Korea to provide mechanical power. Current development efforts are oriented toward electricity generation on the islands. At present, wind-energy installations in the country are relatively new. Most of these systems have been installed by the scientific organizations for demonstration purposes. The systems of small capacity (10kW) could serve as power sources in remote areas. The market for 10-kW wind machines is expected to be 1000 units in 1990.

Anaerobic digestion of animal wastes and gasification or pyrolysis of wood and agricultural residues are being examined for use in rural areas. The objective is to make more energy-efficient use of those materials and make rural areas more self-sufficient. These resources, however, have only limited potential in South Korea. The major increase in the utilization of biomass will come from improvements in the end-use conversion efficiencies.

Unlike biogas, ocean energy has considerable potential in South Korea, although only tidal power is feasible for use in the near future. The Korean government has started a feasibility study on the construction of a tidal-power plant with a 400-MW capacity, which is expected to be finished by 1988.

The contribution of small-scale hydro potential to the country's total energy needs is small. Nevertheless, such resources could play a significant role in the development of rural areas in South Korea. Currently, three small hydroplants are operating with a total capacity of 40 MW.

At present, the widespread use of renewable energy in South Korea is hindered by:

- Lack of a system-design capability, of a system-construction technique, and of system-maintenance personnel;
- High initial investments;
- High maintenance costs;
- Lack of knowledge among consumers and a need for education about renewable energy; and
- A bad public image caused by problem installations.