lation of the world economy, the levels of employment in both developed and developing countries, and the prospects for peace could well be involved.

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Energy Dilemmas in Asia: The Needs for Research and Development

Roger Revelle

Summary. Outside of China, the countries of southern and eastern Asia contain 30 percent of the world's population but only 2 percent of the known fossil fuel resources. Economic growth has resulted in increasing imports of petroleum and petroleum products. Because of the tenfold rise in oil prices since 1972, several of these countries are faced with two dilemmas—one short range and one long range. Unless they can discover more fossil fuel resources within their own borders, they must either incur dangerously growing foreign exchange deficits or drastically slow their economic growth. Research and development in energy production, conversion, and conservation should eventually allow local energy sources, of which the most promising is biomass energy, to be substituted for imported fuels. But diverting scarce land and water to plantations of fast-growing trees or other kinds of biomass may seriously limit food production in these crowded countries.

The 15 largest countries of southern and eastern Asia contain half the earth's population, but only 14 percent of its inhabited land area and about a fourth of the cultivated land (Table 1). Although these countries were originally heavily forested, the need for agricultural land to feed growing populations has resulted in a reduction of the forest area to only 11 percent of the world's total (*1*).

Energy Resources of the Asian Countries

Known or estimated energy resources for each country are shown in Table 2 in a common unit—millions of metric tons of coal equivalent (1 million metric tons of coal equivalent contains 27.8 trillion British thermal units or 7 trillion kilocalories, close to 1000 megawatt-years, or 10^{-3} terawatt years). In general, the location and extent of the nonrenewable fossil fuel resources (coal, lignite, petroleum, natural gas liquids, and natural gas), have been inadequately explored, and no more than guesses can be made concerning the fraction that could be recovered or the costs of recovery. For the potential "renewable" resources (hydropower and thermal energy in forest biomass), estimated maximum annual yields have been multiplied by 100 to give some measure of comparability with the total fossil fuels (*2*).

The People's Republic of China (China) has by far the most energy resources, both in total and per capita (*3*). Its fossil fuels and potential hydropower correspond to 868 tons of coal equivalent per person and make up about 13 percent of the estimated world total. Outside of China, the Asian countries, with 30 percent of the world's population, are endowed with only a little more than 2 percent of the world's fossil fuel and hydroelectric power resources. Even this small fraction is unevenly distributed. India, Japan, Malaysia, and the Republic of China (Taiwan) possess more than 100 tons of coal equivalent per person. So far as is known, the remaining ten countries have much less than 100 coal equivalent tons per person, ranging from 58 for Korea to 3 for Sri Lanka. On a per capita basis, Burma, Indonesia, Malaysia, Nepal, the Philippines, and Thailand have fairly extensive forest resources, with potential sustainable yields of between 0.5 and 3 tons of coal equivalent per person per year. Potential sustainable forest yields in the other countries are smaller, varying from 0.48 ton per person per year in Vietnam, to 0.06 ton in Pakistan and 0.03 ton in Bangladesh.

Present and Future Uses of Energy in Asia

Most available statistics on energy use refer only to so-called commercial energy, that is, energy from fossil fuels and hydroelectric installations. But for the poor countries of Asia, the figures on commercial energy are misleading. On the average, total energy use is about twice the amount of commercial energy. The major part of the difference is made up of biomass fuels—wood, charcoal, agricultural residues, and cattle dung—and a significant fraction is accounted for by energy expended in human and animal labor. Estimated use of biomass fuels, plus human and animal labor, corresponds to around 200 to 400 kilograms of coal equivalent per capita per year (Table 3). Most of this noncommercial energy is devoted to cooking and other household uses, and most of the remainder to agriculture.

In the past, the proportion of commercial energy has increased with time and economic growth. This increase re-

The author is professor of science and public policy at the University of California, San Diego, La Jolla 92093.

sulted chiefly from the growth of the industrial and transportation sectors and partly because convenient commercial sources were substituted for traditional ones as incomes rose and people migrated to cities and towns from the countryside.

The population of eastern and southern Asia, outside of Japan, in the first quarter of the 21st century is likely to be approximately 4000 million people—about twice what it is today. To achieve a leveling-off of population growth in the next 50 years, the incomes of most people in these countries must rise substantially; if this happens, the proportions of the populations living in cities and towns should also double. Demands for food, fibers, and energy should be much more than twice those of today.

Haefele (*4*) has estimated that per capita energy consumption in the developing countries of Asia, Africa, and Latin America should increase between three and five times over the next 50 years, provided normal expectations of economic and social development are realized. His conclusion is supported if we examine future energy needs in rural areas of Asia, which will probably contain about 2 billion people by the end of the first quarter of the 21st century (*2*).

To produce the needed food supplies for their own countries—approximately 1.7 billion tons of food grain equivalent, with an energy content equal to that in 800 million tons of coal—the energy required for irrigation, fertilizer production, and operation of farm tools and machinery would correspond to 350 million tons of coal equivalent. Thermal energy used in rural households would total 230 million tons, and transportation of agricultural harvests, rural industrial products, farm inputs, and human beings could use as much as 800 million tons of coal equivalent. Energy expenditures in rural industry would be between 400 and 800 million tons. Household lighting could add 1/4 kilowatt-hour per person per day or 20 million tons.

The maximum estimated rural energy use, not counting human energy in manual labor or thermal energy used to generate electric power, would be equal to 2.2 billion tons of coal equivalent. This is 28 percent of the entire world consumption of energy at the present time and twice present use in southern and eastern Asia, outside Japan. Per capita use would correspond to 1.1 tons of coal equivalent. It would be expected that rural incomes would still be considerably lower than those of the urban populations and, consequently, because of the close relationship between income and energy, urban energy use per capita would be between 1 and 2 tons of coal equivalent—say a total of 3 billion tons. Thus, the overall energy demand would be close to 5 billion tons of coal equivalent—4$^1/_2$ times present energy use.

For China, with its vast coal deposits and large reserves of petroleum and natural gas, such an increase in energy use would not be constrained by the availability of fossil fuels, though large capital investments and considerable development of energy technology would be required. India and Malaysia could turn to their coal and hydropower reserves, respectively, provided they could find the needed capital and technology. India has a sufficiently large and diversified science and technology establishment to be able greatly to expand its use of nuclear fission energy, in addition to developing its fossil fuel and hydropower resources. But for the other developing countries of Asia, known energy resources could not sustain the large increase required for economic and social development. These countries will either need to find and develop new energy resources within their own borders (including economical methods of conservation) or depend on large-scale imports of fossil fuels. For the first alternative, long-range research and development (R & D) will be essential. The second alternative is, of necessity, being followed on a short-range basis, with potentially disastrous results.

The Short-Range Dilemma—Worsening Foreign Exchange Deficits

Overall trade balances and petroleum imports of the Asian countries with developing market economies in 1972–1973, just before the first rapid rise in petroleum prices, and in 1978, before the recent 250 percent price increase, are shown in Tables 4 and 5. The comparative figures reflect the worldwide inflation of commodity prices, the strenuous efforts of the Asian countries to increase their exports, and their significant economic growth as well as the effects of the quintupling of petroleum prices during these 6 years.

The only countries with improved trade balances between 1972–1973 and 1978 were Indonesia, which is a large-scale exporter of its own low-sulfur oil and an importer of small quantities of petroleum products and low-grade crude oil, and the most rapidly developing countries of Korea, Taiwan, and Malaysia.

Trade balances (including external debt services) markedly worsened in the remaining seven countries. Bangladesh, Pakistan, the Philippines, and Thailand were especially hard-hit, in terms of the ratio of the trade deficit to gross national product. India also experienced a marked deterioration in its balance of trade in commodities, but this was more than made up for by remittances from In-

Table 1. Population, agricultural land, and forests in southern and eastern Asia.

Country	Population (× 10^6) (*38*)	Area (× 10^6 ha): Total (*38*)	Agricultural (*39*): Irrigated*	Agricultural (*39*): Total	Forests (*39*)	Hectares per person: Cultivated	Hectares per person: Forest
Bangladesh	85	14.4	1.2	9.1	1.5†	0.11	0.02
Burma	32	67.8	0.8	18.9	39.0	0.59	1.22
People's Republic of China	900	959.7	76.0	127.0	111.8	0.14	0.12
India	638	328.0	31.6	165.0	65.8	0.26	0.10
Indonesia	137	190.4	6.9	18.1	121.8	0.13	0.89
Japan	116	37.2	2.6	5.3	24.5	0.05	0.21
Korea	37	9.8	0.8	2.4	6.6	0.06	0.18
Malaysia	13	33.0	0.3	3.5	23.5	0.26	1.81
Nepal	13	14.1	0.2	2.0	4.5	0.15	0.32
Pakistan	77	80.4	14.0	19.4	2.6	0.25	0.03
Philippines	46	30.0	1.2	11.1	13.9	0.24	0.30
Sri Lanka	14	6.6	0.5	2.0	1.3†	0.18	0.09
China (Taiwan)	17	3.6		0.9‡		0.05	
Thailand	45	54.4	2.5	13.9	16.0†	0.31	0.36
Vietnam	50	33.0	0.6	5.3	13.5	0.11	0.27
Total	2220	1862.4	139.2	403.1	446.3	0.18	0.18
Percent of estimated world total	50	14		27	11		
Percent of world total, less China	30	7		19	8		

*Area irrigated about 1970. †See text. ‡Author's estimate.

dian citizens employed in Middle Eastern oil countries.

The total petroleum imports by the Asian countries represent only about 3 percent of the world oil production; thus, they play a minor role in worldwide competition for petroleum and petroleum products. Nevertheless, the ratio of the monetary value of oil imports to total imports rose from an average of slightly more than 6 percent in 1972–1973 to 16 percent in 1978, ranging from nearly 26 percent in India and 21 percent in Thailand to between 8.7 percent and 11 percent in Bangladesh, Indonesia, Malaysia, and Nepal. Indonesia and Malaysia are self-sufficient in petroleum, and Nepal and Bangladesh use very little of any form of commercial energy.

The probable impact of the sharp rise in import prices of petroleum and petroleum products in 1979–1980 can be easily seen in Thailand (*5*). With no change in the volume of oil imports (about 20 million tons of coal equivalent in 1978) or in the value of exports and imports other than petroleum, the oil import bill could be close to $2.7 billion in 1980, about 40 percent of the value of all imports. The trade deficit, plus services on external debt, could be more than $2 billion, on the order of 10 percent of Thailand's gross national product.

Under these circumstances, Thailand's recent rapid industrial growth is likely to slow drastically. Not only will growth be affected by rising energy costs, but the prices of the equipment and commodities Thailand must buy to increase industrial production will almost certainly rise, in large part because of rising energy costs in the supplying countries. At the same time, the need to channel a larger proportion of resources into oil imports will diminish the country's ability to procure other supplies and to make needed capital investments. Agricultural development will be adversely affected by the rising costs of transporting inputs and harvests and of manufacturing nitrogen fertilizer from oil products or natural gas.

The problem might be partially resolved by early development and use of Thailand's estimated reserves of coal, lignite, and natural gas. But these reserves, even if it were possible to substitute them for present oil imports, would be exhausted in 21 years. Thailand's hydropower resources could provide an annual energy supply equal to the thermal energy in 8.25 million tons of coal equivalent. But most of the unutilized hydroelectic potential cannot be exploited quickly. It depends largely on power development of the Mekong River, which, at present, faces severe political problems. In principle, the forested area of Thailand, which has a potential annual energy yield of 28.4 million tons of coal equivalent (Table 2), could meet a larger fraction of the country's energy needs than at present, but this would require a considerable increase in the sustainable annual yield of wood.

Energy Research and Development in the Asian Countries

Because their resources and problems differ in many fundamental ways from those of the developed countries, the poor nations of Asia, Africa, and Latin America need to undertake energy programs with a special thrust and emphasis. This is particularly true of the oil-importing countries of southern and southeastern Asia, with their extreme poverty and high, and rapidly growing, population densities.

We can conveniently classify energy R & D in six broad areas: production, conversion, transportation, storage, conservation, and economic and social issues. These categories are not exclusive; R & D in any one of them is likely to spill into others.

Energy production. The two most important energy production problems in Asia are (i) to find and develop reserves of petroleum, natural gas, and other energy resources and (ii) to increase energy yields from trees.

Systematic exploration for deposits of

Table 2. Estimated energy resources in southern and eastern Asia in millions of metric tons of coal equivalent.

Country	Coal and lignite* (*40*)	Petroleum and natural gas liquids (*41*)	Natural gas (*41*)	Hydroelectric power† (*41*)	Forests‡	Total	Metric tons per person: Total	Metric tons per person: Without forests
Bangladesh	1,187		290	10	270	1,753	20	17
Burma		12			6,920	> 6,932	> 217	> 0.4
People's Republic of China	719,000	17,300	26,500	18,000	19,850	800,650	890	868
India	85,800	3,000	9,800	730	11,680	110,010	172	154
Indonesia	2,520	2,300		410	21,620	26,850	196	38
Japan	8,760	11	150	7,950	4,350	21,221	182	145
Korea	1,515			615	1,170	3,300	89	58
Malaysia		630		4,915	4,170	9,715	747	426
Nepal				400	800	1,200	92	31
Pakistan	650	42	690	470	460	2,312	30	24
Philippines§	920 (*7*)	400 (*7*)		240	2,470	4,030	88	34
Sri Lanka				45	230	275	20	3
China (Taiwan)	450	2.5		1,280		> 1,733	> 102	102
Thailand	235	0.4	190	825	2,840	4,090	91	28
Vietnam	> 12			> 335	2,400	> 2,747	> 55	> 7
Total	821,049	23,687	37,620	36,225	79,230	996,818	449	413
Percent of estimated world total	16.2	5.3	10.9	30.7	12.4	16.5		
Percent of world total, less China	2.0	1.4	3.2	15.4	9.3	3.2		

*Total known resources of coal and lignite; economically recoverable resources may be less. †Hydropower resources taken as 100 times potential annual production of electric energy. Converted to coal equivalents, assuming one equivalent ton of coal = 3×10^{10} joules. ‡Forest resources taken as 100 times potential annual yield (= 22 percent of estimated net annual primary production of 8.07 tons of coal equivalent per hectare). §The Philippines also have significant geothermal resources. The planned electric generating capacity for geothermal sources may be nearly 1900 megawatts by 1988, equivalent to an annual combustion of 6 million tons of coal equivalent (*7*).

petroleum and natural gas, through the use of modern geophysical and geochemical tools and drilling methods and the geological concepts of plate tectonics, has not been undertaken on a sufficiently large scale in any Asian country. Such exploration is costly and risky and requires highly qualified technical personnel. In the past, the Asian countries have not been able to allocate the necessary capital, and they have lacked the trained specialists.

A systematic search for oil and gas deposits in the offshore areas on the continental shelves and slopes appears to be especially promising. Significant results have already been obtained. Thailand has discovered a large natural gas field in the Gulf of Thailand (*6*). The Philippines are now producing petroleum from an offshore field near Palawan (*7*), and India is obtaining several million tons of oil a year from the "Bombay High" southwest of Bombay (*8*).

Surveys of other kinds of potential energy resources are also needed. These include especially the possibilities for wind, small-scale hydropower, and geothermal energy.

The technology for extracting power from the wind is rapidly developing. But all wind systems are constrained by two relationships: the power produced varies with the cube of the wind velocity, and no power at all will be produced below a certain threshhold wind speed (*9*). Strong, steady winds are most likely near the seacoast; hence, a country like Sri Lanka, which has a relatively long seacoast compared to its area, may be able to meet a significant fraction of its energy demands by installing windmills (*10*). As surveys in Thailand show (*11*), there may also be large areas in the interior of a country where the winds are sufficiently strong and steady to provide a useful source of energy, at least to pump water for irrigation. In general, climatological data on the frequency distribution of wind speeds are not now adequate in the Asian countries to form a basis for extensive investment in wind machines.

Equally lacking are sufficient data on the annual variations in flow of small and medium streams in hilly regions where micro- or mini-hydroelectric generators might be installed. Such generators depend on diversion of a small quantity of water from a stream into a channel where the water can be carried nearly parallel to a contour until it can be dropped through a penstock that will provide sufficient head. To minimize costs of the "civil works," a high head (on the order of 100 meters) and a small volume of flow (a few liters per second)

Table 3. Approximate energy use per capita in five Asian countries, measured in kilograms of coal equivalent per person.

Energy source	China (1977) (*36*)	Bangladesh (1978) (*14, 28*)	India (1978) (*8*)	Sri Lanka (1975) (*10*)	Thailand (1977) (*42*)
		Commercial			
Coal and lignite		4	115	0.7	7
Oil		23	51	82.0	310
Natural gas	427	17	3		
Hydroelectric and nuclear power		2	8	8.5	33
Total	427	46	177	91.2	350
		Noncommercial			
Firewood and charcoal	57	46	238	163	370
Other biomass	103	187			41
Human labor	43	33	44		
Animal labor		17	111		
Total	203	283	393	163	411
Grand total	630	329	570	254	761

Table 4. Trade balances and petroleum imports in millions of U.S. dollars (1972–1973) for eastern and southern Asian countries with developing market economies (*38*).

Country	Imports: Total	Imports: Petroleum: Value	Imports: Petroleum: Percent of total	Debt service	Exports	Exports minus imports and debt service
Bangladesh	875	24	2.7	9	415	−469
India	3,210	264	8.2	652	3,325	−537
Indonesia	2,730	44	1.6	211	3,300	359
Korea	4,240	296	7.0	617	4,115	−742
Malaysia	2,510	156	6.2	85	3,315	720
Nepal	95	13	13.2	0.5	29	−66
Pakistan	980	65	6.6	187	1,130	−37
Philippines	1,800	188	10.4	214	2,465	451
Sri Lanka	430	38	8.8	55	425	−60
China (Taiwan)	3,796	100	2.6	180	5,140	1,164
Thailand	2,050	226	11.0	55	2,110	5
Total	22,716	1,414	6.2	2,265	25,769	788

Table 5. Trade balances and petroleum imports in millions of U.S. dollars (1978) for eastern and southern Asian countries with developing market economies (*38, 43*).

Country	Gross national product	Imports: Total	Imports: Petroleum: Value	Imports: Petroleum: Percent of total	Debt service	Exports	Exports minus imports and debt service
Bangladesh	7,580	1,555	175	11.2	94	550	−1,099
India	112,665	7,400	1,900	25.7	913	6,400	−1,913
Indonesia	48,530	6,650	580	8.7	1,388	11,200	3,162
Korea	39,000	14,970	2,312	15.4	1,795	17,100	335
Malaysia	14,545	5,920	627	10.6	705	8,000	1,375
Nepal	1,585	225	21	9.3	2.2	81	−146
Pakistan	17,525	3,325	495	14.9	316	1,840	−1,801
Philippines	23,080	5,140	1,030	20.0	646	4,715	−1,071
Sri Lanka	2,720	935	142	15.2	89	970	−54
China (Taiwan)	23,935	11,050	1,590	14.4	633	14,380	2,697
Thailand	21,790	5,355	1,125	21.0	171	5,015	−511
Total	312,955	62,525	9,997*	16.0	6,752	70,251	974
Percent of world total		4.7	3.0†			5.5	

*Volume of petroleum imports, 87.7 million tons. †Volume of total world crude oil production, 2903 million tons.

are desirable. In both Nepal and Thailand, it has been estimated that at least 500 megawatts of firm, year-round power could be generated in this fashion (*2, 11*). Extensive possibilities also exist in Sri Lanka, the Philippines, and the hilly regions of Pakistan and India.

A search for sources of geothermal energy has been notably successful in the Philippines (*7*). The planned electric generating capacity from geothermal sources may be nearly 1900 MW by 1988, equivalent to annual combustion of 6 million tons of coal equivalent. Geothermal energy resources in Indonesia could also be extensive.

Wherever fuel wood is available in less-developed countries, it is "the poorman's oil" (*12*). It is the principal source of energy for cooking and other domestic uses in Sri Lanka (*10*), Nepal (*2*), and Thailand (*11*), and probably in the Philippines, and it is an important fuel in the rural areas of all Asian countries (*8, 13*). In most of these countries, the forests are being rapidly destroyed as populations grow, not only because of the growing needs for fuel wood but also because of destructive logging for timber, clearing of land for settled agriculture, and shortening of the rotation cycle for "slash-and-burn" agriculture.

In the Chittagong Hill tracts in southeastern Bangladesh, about 40 percent (870,000 hectares) of the total forested area of the country is being rapidly destroyed by illicit timbering and by shifting cultivators who have reduced the traditional 10-year slash-and-burn rotation to 3 years (*14*). In the hills of Nepal, the 3.4 million hectares of forested land are being depleted for fuel and cattle feed at an annual rate of more than 3 percent. This could lead to total depletion within 30 years (*2*). Between 1963 and 1971 in Thailand, the total land area covered by healthy forests was apparently reduced from 53 percent to 39 percent (*15*). The forested area is now estimated as less than 30 percent—probably about 16 million hectares. In Sri Lanka, the forest cover has been reduced from 44 percent in 1956 to about 20 percent of the total land area by a combination of clearing for settled agriculture, slash-and-burn cultivation with progressively shorter rotation times, and illegal exploitation of trees for construction and household and industrial fuels [chiefly in manufacturing tea, ceramics, brick, and tobacco (*16*)]. Sri Lanka's major development program, the accelerated Mahaweli River development scheme, will reduce the forest cover still further to 16 to 17 percent of the total land area, or about 1 million hectares. In India, potentially usable forests are said to cover around 66 million hectares, mainly in mountainous regions, and in four states that have less than 20 percent of the population. The forests are being cut down faster than they can grow, partly to make room for new farmlands and partly for use as fuel. In consequence, the upland areas are subjected to destructive erosion, which results, in turn, in rapid silting of irrigation and power reservoirs and destructive floods in downstream areas (*17*).

The yield of wood for either timber or fuel from the natural forests of southern and southeastern Asia is extremely low. Estimates for Thailand indicate that less than 0.02 percent of the incoming solar energy is photosynthetically converted into wood that can be used for fuel and timber on a sustainable yield basis (*11*). In Nepal, the efficiency of photosynthetic solar energy conversion into fuel wood and animal forage is probably about 0.03 percent (*2*). The "Sal" forests of India are said to take 80 years or more to mature.

Higher yields can be obtained from several varieties of fast-growing trees that have been discovered in different parts of the world in recent years. One of these, the Hawaiian Giant, or Salvador variety of the evergreen tropical legume *Leucaena leucocephala*, is especially well suited to humid and semihumid lowland tropics (*18*). In dense plantations in the Philippines, this tall, virtually branchless tree, which can grow to a height of 20 m in 6 to 8 years, has produced between 12 and more than 50 tons of wood per hectare per year. At 25 ton/ha, about 0.7 percent of the incoming solar energy is converted into the chemical energy of wood.

Leucaena is able to withstand long dry seasons and to tolerate a wide array of soil conditions, owing to its deep, aggressive root system that reaches far below the soil's surface for water and nutrients. In energy plantations, it could be a continuously renewable source of fuel because the stumps readily regrow or coppice and thus "defy the woodcutter." However, it does not grow well in acid soils high in alumina or at elevations above 500 m, and the young trees must be protected against grazing animals, which eagerly browse on the protein-rich foliage (*19*). It is being widely introduced in Sri Lanka as a garden tree for rural households (*10*). In the Philippines, where it is called the giant ipil-ipil, an energy plantation of several thousand hectares of *Leucaena* is planned for electrical power generation (*2*), and a Japanese steel company has planted over 5000 ha as a source of smelting charcoal (*20*). The tree has been introduced in Thailand during the last 5 to 7 years and is also popular in Indonesia (*21*).

Other fast-growing trees for fuel production include *Acacia auriculiformis*, *Acacia albida*, *Acacia mangium*, *Casuarina equisetifolia*, *Calliandra callothyrsus*, *Eucalyptus camaldulensis*, and *Ecualyptus* spp. (*19, 21a*).

Much research, development, and demonstration should be undertaken in each of the Asian countries to determine the fast-growing species best suited to local climatic, soil, topographic, and social environments. The most productive and feasible cultural practices, including spacing, length of rotation, weeding and irrigation, and methods of protection against fire, insects, diseases, and browsing animals must also be determined. An important research problem is study of the ecological characteristics of the beneficial mycorrhiza fungi, which infect the root hairs of the trees and transfer phosphorus and other nutrients from the soil to the roots (*18*). The adaptability of the mycorrhiza to transplantation may determine the range of environments in which a particular tree species can be productively grown.

In Indonesia, Bangladesh, and Sri Lanka, trees for fuel wood and livestock forage are grown together with vegetables, spices, and fruits in small plots surrounding the homestead. The plants grown in these home gardens have a complex, three-dimensional ecology in which the tallest trees partially shade the lower trees and bushes and crops grown near the ground. Falling leaves and litter from the upper canopy are beneficial to the smaller plants. Research needs to be done on the most suitable fast-growing trees that can be introduced into these microecosystems. For example, introducing *C. callothyrsus*, which is a good producer of fuel wood, would not be desirable in many home gardens, at least in Indonesia (*21*). This bushy tree branches profusely from near its base and needs full sunlight, even though it is only 2 to 3 m tall. Consequently, taller trees would have to be removed, and cassava, coffee, taro, citronella, and other low-growing plants would be displaced by the profuse coppicing of *Calliandra*. On the other hand, *Leucaena* might be well suited because it can tolerate moderate shade, it does not excessively shadow lower plants, and its dropping leaves provide abundant nitrogen.

Wherever sufficient village land is available, it may be possible to establish managed "community woodlots," with one or more varieties of fast-growing trees. This is being attempted on a trial basis in Thailand, where the average household uses as much as 5 tons of fuel wood per year (*11*). Assuming an annual yield of 15 ton/ha, 0.33 ha would be required per average family, or about 30 ha for a village of 100 families. Annual costs have been estimated at $72 per hectare, or $4.80 per ton of wood, compared to a price of $6.25 per ton recorded in urban and rural areas of northeast Thailand.

To provide sufficient fuel wood for the present Thai population of 44 million would require 2 million hectares, assuming an annual yield of 15 tons of wood per hectare; this is 14 percent of the present cultivated area of Thailand (Table 1). It is unlikely that the rural people would be willing to devote such a large percentage of cultivated area to wood production when the average value of their rice crop is nearly $400 per hectare, with rice selling at $325 per ton.

With the severe pressure on agricultural land in all the crowded Asian countries, it will be essential to increase the yields of wood from forested areas that are not suited for agriculture because of steep slopes, irregular topography, rocky, thin soil, or other reasons. The average net primary production (photosynthetic production minus respiration) of Asian forests is believed to be about 7 tons of organic carbon per hectare per year (*22*), with an energy content of 5.6×10^7 kcal. Thus, the forests convert about 0.37 percent of the incoming solar radiation into chemical energy of organic matter. Yet, as we have seen, less than 5 percent of this quantity is being recovered for human use. Most of the net primary production is in the form of leaves and roots, but it is estimated that about 22 percent could be recovered on a sustainable basis as wood, useful for fuel and other purposes, in forests under intensive silviculture (*2*). In the tropics, this will undoubtedly require replanting of parts of the forested areas with those species of fast-growing trees that are most appropriate for each local environment. Such a transformation of the Asian forests will require a broad, sophisticated R & D program based on tree genetics (including genetics of somatic cells) and physiology, as well as on practical field experimentation. An international forest research center similar to the International Rice Research Institute at Los Banos in the Philippines, established in a southern Asian country by a consortium of multilateral and bilateral donors, could provide the focus for this urgently needed program of accelerated forest research.

Another long-range international research program related to energy production should also be considered. The Asian countries hold a relatively large share of the world's hydroelectric potential, but geologic and hydrologic conditions make the costs of development very high. One reason is that the rivers flowing from the great Asian mountains have some of the highest sediment concentrations in the world. Consequently, reservoirs for power and irrigation silt up very rapidly. It is expected that the reservoir behind the world's largest dam, Tarbela Dam in Pakistan, with an initial live-storage capacity of 12 billion cubic meters, will be completely filled by sediment within the next 40 years. Some hydraulic engineers have suggested that it should be possible to design a nonsilting dam, that is, a dam through which riverborne sediments would in some fashion be sluiced out instead of accumulating in the reservoir. This possibility deserves analytical and model studies and field trials on a pilot basis.

Energy conversion. Many R & D problems in energy conversion are especially urgent in the poor Asian countries, although they are not unique to those countries. These include problems of converting wood to charcoal, pyrolysis of organic wastes, wood combustion, the microbiology of anaerobic production of methane from human, animal, and vegetable wastes, small-scale hydroelectric power generation, nitrogen fixation, using solar energy for heating water and drying crops and wood, and integrating the use of different energy sources. Other problems (such as improving efficiency of microbial alcohol production, lowering the costs of photovoltaic conversion of solar energy, improving efficiency of electricity generation from fossil fuels, developing solar space heating and cooling and thermal electricity generation, and cogenerating electricity, steam, and process heat) are important for both developed and developing countries. Attaining a range of solutions may be facilitated by cooperative research by groups of scientists and technicians in different countries. A third set of problems is for the time being of primary concern to the rich countries because of the requirements for very large investments of capital and technical personnel. These include converting coal, oil shale, and tar sands to liquid fuels and safely managing nuclear power.

Wherever it can be obtained at sufficiently low cost in the poor countries, charcoal is preferred over wood as a domestic fuel. Charcoal braziers in Thailand have an efficiency of 15 to 20 percent (that is, 15 to 20 percent of the heat energy of combustion is actually utilized in boiling rice or frying other foods), whereas wood stoves are only 5 to 10 percent efficient. Because of its high energy density, charcoal costs much less to transport than wood with an equivalent energy content; it is generally considered that for transportation distances of more than 100 to 200 km, charcoal is a more economical fuel. Because charcoal burns without generating much smoke, it is especially preferred over wood and other biomass fuels in urban areas (*11*).

In Thailand, charcoal is made from rice husks and from the wood of the mangrove forests in southern Thailand. Coconut husks are used in Sri Lanka (*16*). Charcoal can be made from sawmill wastes, which constitute as much as 60 percent of the total quantity of harvested timber, and from logging residues. As much as 40 percent of the mass of harvested trees is estimated to rot in the forests (and even more in clear-cut areas) (*11*).

Highly efficient charcoal kilns consume 3 to 3.5 tons of wood to produce a ton of charcoal; 50 to 60 percent of the heat energy in the wood is converted into energy in charcoal. With the methods now used in the Asian counties, only about 30 percent of the wood energy is converted. Adaptive research is needed to produce charcoal kilns both for small-scale family or village operation (which can use wood or rice or coconut husks) and for larger-scale conversion of logging and sawmill wastes. A 30 percent increase in conversion efficiency appears feasible. Charcoal from rice and coconut husks can be made into briquettes for more economical transportation and easier final use (*11*).

Equipment for pyrolysis of rice hulls and straw developed in Indonesia can handle about 1 ton of feedstock per day to produce 0.25 ton of charcoal, 0.15 ton of pyrolytic oil, and usable quantities of gas. For a small rice mill, handling 3 or 4 tons of paddy per day, the operation can be highly profitable, with an estimated annual rate of return on investment of 50 percent or more (*11*). Most of the energy in the feedstock is captured in the pyrolytic products. The potential for adaptation of a device of this sort for use in the villages and small towns of other Asian countries should be explored. Presumably, sawmill sawdust and finely ground chips from logging operations could also be used as raw material.

The combustion efficiency of wood is low in Asian countries, in part because the wood is not dry when it is burned. Perhaps as much as 15 percent of the energy of combustion goes to driving off water as steam. Where wood can be used to generate electric power, higher temperatures of burning and more efficient heat exchangers are desirable to increase thermodynamic efficiency from the present estimate of about 18 percent (*2*). Research and development are needed on methods of drying wood, controlling the oxygen supply in combustion, and improving heat exchange.

So-called biogas digesters for bacterial production of methane from human, animal, and vegetable wastes are widely used in China (*23*) and are being actively promoted in several other Asian counties. While there are many technical and social problems associated with these devices—including those of lowering costs and increasing reliability of construction, determining appropriate sizes for community use and effective incentives for collecting feces and dung, and of ensuring equity when only richer families owning sufficient numbers of livestock can utilize family-sized digesters—there is also a set of basic microbiological problems. Needed are microorganisms that can function effectively over a range of temperatures from 5° to 45°C and that can utilize a high ratio of crop wastes to animal and human feces. Research should be undertaken to develop strains of methane-producing anaerobic bacteria with these characteristics. This is one of a large number of problems for research in applied microbiology that could be undertaken in the less-developed countries at relatively low capital costs for equipment and facilities (*24*).

Research on microbial production of ethanol as a vehicle fuel in the Asian countries, with their high population densities on cultivated lands, needs to be directed toward using organic materials that do not compete with human food production. The situation is radically different from that of Brazil (*25*), in which the amount of potentially arable land is about 0.7 hectare per person, compared with an average of 0.18 for southern and eastern Asia. In Brazil, annual production of 26 million tons of ethanol from sugarcane is planned by 1990, at which time it is contemplated that alcohol could be substituted completely for gasoline and diesel oil. At an assumed yield of 60 tons of sugarcane per hectare, and recovery of 70 liters of ethanol per ton, 8 million hectares—nearly 12 percent of Brazil's potentially arable land—will be needed for production of sugarcane. The estimated capital cost will be $15 to $30 billion. Even so, only about 1/3 liter of gasoline equivalent per person per day will be available in this large country in which transportation over long distances is essential for socioeconomic development.

The aim of microbiological research and development for ethanol production in the Asian countries should be toward developing organisms and chemical engineering processes that can convert the cellulose and lignins of agricultural residues and other plants to ethanol, leaving a protein-rich by-product that can be used as an animal feed. A second objective should be to minimize the water content of the fermentation product in order to reduce the energy required for distillation (*26*).

Small-scale "run-of-the-river" hydroelectric power generation represents a considerable potential energy resource in several Asian counties. Experience in the United States and elsewhere shows that the total capital costs for turbines, generators, and "civil works" can be as low as $1000 to $2000 per kilowatt for plants generating 3 to 20 kW (*2*). But there remain serious problems of operation and maintenance of the equipment and acceptance and use of the electric power in the hill villages of southern and southwestern Asia, with their low levels of mechanical skills and traditional lifestyles.

The high proportion of potential hydropower (and possibly wind power) to other energy resources in several Asian countries (Table 2) suggests that efforts should be directed toward converting electrical energy to nitrogen fertilizer. In Norway, this is accomplished by electrolytic generation of hydrogen from water, followed by catalytic combination of the hydrogen with atmospheric nitrogen to produce ammonia. The process can be carried out in relatively small-scale plants producing on the order of 10 tons of nitrogen a day (*23*) at a daily energy cost of about 175 MWh, but it is uneconomical at much lower production levels. For microhydroelectric plants generating 10 to 20 kW, recourse may be had to the almost forgotten electric arc process (*27*). Air is passed through a chamber fitted with electrodes that generate an electric arc that converts part of the nitrogen and oxygen to nitrogen oxide. The air is then passed through a water bath containing calcium carbonate, and the nitrogen oxide is captured as calcium nitrate, which can be precipitated and used directly as nitrogen fertilizer. The process is relatively inefficient, consuming 25,000 to 50,000 kWh per ton of nitrogen in fertilizer. But its simplicity and feasibility for small-scale operations may make it appropriate for village or small-town production, particularly in the isolated hill areas of Asian countries (*2*). Research is needed to reduce the energy requirement per ton of nitrogen and to develop simple, easily maintained and operated equipment for village use.

Sun drying of crops in the open air has always been practiced by farmers. It is particularly difficult during the monsoon season in Asia because of intermittent and unpredictable rainfall and almost continuous cloudiness. A large fraction of the nutrients in the grasses that grow during the monsoon in village pastures of the Nepalese hills is lost because hay cannot be dried (*2*).

Solar drying can be improved in a variety of ways, at different scales of volume and costs. In Bangladesh, for example, rice is spread out to dry on the earthen surface of homestead compounds. Covering the surface with an impermeable material and providing drainage would greatly speed the drying process and thereby reduce losses. Small flat-plate, plastic-covered solar "tent" dryers for rice, costing $10 to $20, have been used in Thailand (*11*). These are said to reduce losses of rice from spoilage, insects, and birds by 5 to 15 percent and to result in a product with both longer storage life and better milling characteristics, owing to its low moisture content. The farmer has more flexibility in timing the marketing of his crop, and he can expect a higher price because of its quality. Dryers of this type can also be used effectively for vegetables, fruits, and fish. Larger batch and continuous-flow solar dryers, with capacities of one to several tons, have been designed and built in Thailand. These can be used to dry crops and in such small-scale rural industries as curing tobacco, drying of export-grade lumber, and making noodles. Solar drying is also potentially applicable to distillation of water for salt harvesting.

Research and development are needed (i) to reduce the cost and increase the effectiveness of solar dryers for specific functions and (ii) to design equipment that could be constructed by village and small-town craftsmen using locally available or inexpensively transported materials.

To raise the incomes and improve the welfare of Asian peoples, more energy must be used in agriculture, industry, and transportation. Yet some energy sources such as petroleum products are rapidly becoming scarce, while others such as hydroelectric power are limited in quantity or, like forests, are being destroyed. One way to improve the situation is to use the different forms of energy in optimum combinations. In many cases, a modest increase in the use of one form of energy can result in a much larger increase in the supply of other forms. For example, application of more nitrogen fertilizer in the farmlands of Bangladesh would provide not only more food but also a larger supply of rice straw and other crop residues needed for cooking (*28*). About 15×10^6 kcal of fossil fuel energy, usually natural gas or naphtha, are required to produce a ton of nitrogen in fertilizer. Applying a thin amount of nitrogen can raise the energy content of the crop (in rice for food and in straw and rice husks for fuel) by at least 80×10^6 kcal. In the hills of Nepal, using electrical energy generated in microhydroelectric plants to pump water for irrigation and to produce nitrogen fertilizer would make it possible to grow two high-yielding crops per year on land that is best suited for cultivation and to convert cultivated, but rapidly eroding, hillside terraces into permanent pastures or village woodlots of fast-growing trees. The increase in human food and cattle feed or household fuel should have an energy content more than four times the electrical energy consumed (*2*).

Energy is required for many purposes in the rural areas of Asia: (i) in agriculture, for chemical fertilizers, lifting water for irrigation, cultivation of the fields, and crop drying; (ii) domestically, for lighting, cooking, and heating water and space; (iii) in transportation, for moving purchased inputs and harvests between farms and markets; and (iv) in rural industries, for shaft power, steam, and processed heat. In any specific time and place, different forms of energy will have comparative advantages for different uses. At present, manufacturing nitrogen fertilizer requires either fossil fuel hydrocarbons or electrical energy. Lifting water is commonly powered by animals, electric motors, or diesel-fueled engines, although pumps powered by windmills, biogas, or photovoltaic devices may be more widely used in the future. Traction for farm machinery is provided by livestock or by diesel-powered tractors. The sun's energy is used to dry crops, but heaters using fossil fuels, wood, or charcoal are often used for specialty crops such as tobacco. Kerosene is commonly, and electricity occasionally, used for lighting. Cooking and heating depend mainly on fuel wood, charcoal, crop residues, and livestock dung, the last sometimes (as in China) converted to biogas. Energy for transportation, which in the past came largely from animal power, depends more and more on trucks and tractors powered by liquid petroleum products. Shaft power for rural industry has in the past often used an internal-combustion engine as a prime mover, but electric power from a central station is becoming more widespread. In rural areas, heat for industrial processes is usually produced from wood or charcoal and sometimes from coal or bottled natural gas.

The rapid and continuing rise in the prices of petroleum products has given considerable impetus to attempts to substitute other forms of energy for that of petroleum fuels in as many as possible of the uses described above. As R & D on alternative sources proceeds, this may become more and more practicable. One of the tasks of national energy planners, now and in the future, will be to assess the benefits and costs of these alternative sources for different energy functions. All available energy sources and all energy uses within a particular geographical area must be considered as parts of an interacting system in which goods and services are produced on a sustainable basis to meet human needs.

Energy transportation and storage. The problem of energy transportation arises for two reasons: (i) Most commercial energy sources are highly localized in coal mines, oil fields and refineries, and hydroelectric power dams, whereas energy users are widely dispersed; and (ii) fuel wood, the principal traditional energy source, often can be found only at a distance from the places it is needed. Among the rural poor, much human energy and, commonly, the entire working time of one family member are expended in collecting and carrying wood. For both commercial and traditional energy sources, the transportation problem is basically the same—to reduce the costs in energy and other resources of moving energy from the point of production to the point of use. Converting wood to charcoal (and pyrolysis) can lower transportation costs of fuel in poor countries.

If coal, with its relatively low energy density and its inconvenience, is to be more widely used in the future, the problems of energy transportation will become more urgent in the developed countries and will be closely related to questions of conversion of the energy in coal to electricity or to liquid or gaseous fuels. The needed engineering R & D can be expected in these countries, with results that should be directly transferable to the poor countries.

Better and less expensive processes for energy storage at high energy densities represent the principal problem in developing solar energy and in widening uses of electricity for vehicle transportation. Here, too, R & D being vigorously pursued in the industrialized countries should provide technology applicable in the developing nations.

Energy conservation. In contrast to problems of energy transportation and storage, questions of energy conservation are not only urgent in the Asian countries, but many are specific to those countries. Both short- and long-term benefits of large magnitude can be expected from solving the problems of developing more energy-efficient stoves, fuel-saving motor vehicles, and energy-saving materials; instituting forest conservation; reducing the use of fossil fuels in nitrogen fixation; and lowering energy costs in lifting water for irrigation.

Fuel for cooking is just as essential as food in the Asian countries, and in many areas the costs are comparable. In rural areas, more energy is used for cooking than for any other purpose. One reason is the gross energy inefficiency of the cooking stoves. It is estimated that only 5 to 10 percent of the heat energy in wood and agricultural residues used as fuel is actually utilized in cooking rice (*17*). Inefficiencies arise from several sources. The heat from combustion is frequently unconfined, and only a small fraction is transferred to the cooking pot. The fire must be started before cooking begins, and it continues after cooking is completed. Means of controlling the air supply are lacking, and often the air : fuel ratio is insufficient to maintain complete combustion, so that considerable quantities of carbon monoxide are produced.

Many improved cookstoves have been designed in different parts of the world. Five of these have been described by Goldemberg and Brown (*29*): the Indian Hyderabad smokeless Chulah; the improved Egyptian rural stove; the Ghana smokeless stove; the Indonesian Singer stove; and the Guatemalan Lorena cookstove. All can be used either indoors or out, have multiple cooking holes, burn a variety of fuels, have an air-intake control, and are capable of 15 to 20 percent efficiency in rural households. All can be built by the user from local materials at very low cost. If they were universally substituted for traditional stoves, use of domestic energy could be reduced by perhaps 50 percent.

Improved stoves for rural household use have been available for some time, yet they are not widely used. One major R & D question is to find out why this is so (*30*). It has been suggested, for example, that the large quantities of smoke produced by present stoves are valuable for controlling insects and rodents in the thatched roofs of village houses and useful in curing meat and other foodstuffs. On the other hand, rural housewives exposed to the smoke frequently suffer from bronchitis, emphysema, and even lung cancer and partial blindness (*26*). Penetrating studies need to be made of cooking practices and of housewives' attitudes. Cooking is one of the most tradition-bound of human activities, and, in many Asian countries, the interests of women have been largely neglected by government agencies.

In Thailand, cooking is done over both open wood fires and charcoal braziers. The latter are much more energy-efficient, but even here, considerable room for improvement exists (*11*).

Since the onset of the oil crisis in India, a major effort has been made to promote the use of mopeds and scooters for human transportation in urban areas. Local transportation is one of the main users of energy in Indian metropolitan areas and of less importance in small and medium towns. The thrust of urbanization policy in India's sixth 5-year plan is therefore an attempt to slow the rate of growth of the largest cities and to increase the growth of smaller cities and towns (*31*). This will, of course, have many benefits for rural development, as well as conserving petroleum products. In the Philippine city of Manila, small minibuses called "Jeepneys" appear to be a principal mode of personal transportation (*32*). Studies should be made in other Asian cities to determine the potential social desirability and energy efficiency per passenger mile of these vehicles and of motor scooters. Bangkok, which has some of the worst traffic jams in the world, would clearly benefit in several ways from the reduced use of personal automobiles.

One of the main causes for the rapid destruction of forests in Bangladesh, Thailand, Sri Lanka, and probably in the Philippines, northeastern India, and the outer islands of Indonesia, is the increase in both the area and the intensity of slash-and-burn agriculture that has come with rapid population growth. New areas have been invaded by peasants using this method of farming, and in many places the fallow period between cropping seasons has been cut to only a few years, resulting in a vicious circle of decreasing yields and ever shorter fallow times.

Wherever the environment is suitable for a fast-growing leguminous tree such as *Leucaena* or *Sesbania* (*21a*) it should be possible to substitute settled farming for slash-and-burn agriculture. Half of each farmer's plot could be planted in these trees and the other half in row crops such as maize or upland rice. Lopped, leafy branches from the trees can be placed between the rows, or stripped leaves can be mulched into the soil. *Leucaena* leaves contain about 500 kg of nitrogen per hectare (*33*), perhaps 40 percent of which can be transferred to the cropped soil. Thus, a farmer having 2 ha could grow two high-yielding crops on a permanent basis on half of his land, with only a minimum of purchased inputs, provided water is available during both growing seasons. The weight of the harvest would be more than equivalent to that obtained from a single crop on 2 ha. This proposed farming method should be further studied and tested in the field (*21a, 34*).

Six bags of *Leucaena* leaves are said to contain as much nitrogen as one bag of ammonium sulfate produced from fossil fuels. Thus, wherever sufficient land is available, it should be possible to substitute the nitrogen fixed by these leguminous trees for nitrogen produced from fossil fuels. Experience in the Indian state of Tamilnadu demonstrates that Azolla, a small fern possessing symbiotic blue-green algae and grown in wet rice paddies, can also fix sufficient nitrogen to permit elimination of chemical nitrogen fertilizer.

Artificial fibers and synthetic rubber produced from petrochemicals require more than 40,000 thermal kilowatt-hours per ton, equivalent to the energy in nearly 4 tons of petroleum (*35*). Significant energy savings might be obtained worldwide by substituting natural fibers and rubber for some synthetic materials. R & D to increase the yield and quality of these natural materials and their range of uses can therefore be thought of as an important contribution to energy conservation. Metals used in building construction usually have high energy costs per ton, ranging from 13,000 thermal kilowatt-hours for steel to 91,000 kWh for new aluminum (*35*). The energy costs per ton for concrete and bricks are an order of magnitude smaller. Minimizing the proportion of metal in building construction might, therefore, conserve fossil-fuel energy. This question needs to be examined by careful economic and engineering analysis.

Lifting water for irrigation requires significant quantities of energy—on the order of 0.5×10^6 kcal per cropped hectare for water pumped from an average depth of 10 m. This is equivalent to the energy in 50 kg of oil. The amount of energy required varies directly with the depth of pumping. To meet the future food requirements of the Asian countries, it will be necessary to crop 750 million hectares; hence, the magnitude of the annual energy requirement for lifting water could be equal to the energy content of 25 to 50 million tons of petroleum. Careful water management to maintain a shallow water table by properly balancing pumping and groundwater recharge could significantly reduce this energy demand.

The need for biological research. Throughout this discussion, I have emphasized the need and promise of biological research: to increase forest yields and reduce forest losses through research in forestry and agro-forestry, to maximize production of household gardens through better understanding of their ecology, to increase the production and widen the uses of natural fibers and rubber, and to obtain more useful microorganisms for production of ethanol, nitrogen fixation, and mycorrhizal symbiosis with trees (*24*). These potential applications of biology to the solution of energy problems in the Asian countries give an added dimension to their already recognized importance in agriculture, food preservation, nutrition, health, and birth control.

Relative to research in physics and chemistry, the Asian countries have a comparative advantage in biological research. It is relatively inexpensive, requiring neither huge research establishments nor massive, highly complex equipment. It is in many ways a new science, a science of the future. Most discoveries in biology remain to be made. Hence, developed countries have a smaller head start than in physics and chemistry. At the same time, biological research is a most promising field for international scientific cooperation.

Social and economic issues. Many social and economic issues have already been discussed. They cannot realistically be separated from the "technical" issues of energy production, conversion, and conservation. But one set of socioeconomic research issues deserves special mention—those concerning problems of electrification and rural villages, towns, and small cities.

In the Asian region, agricultural modernization is, and will be, essential to provide enough food for growing populations, but it cannot provide sufficient employment for rapidly growing rural labor forces. In order to diminish rural poverty, new nonfarming jobs must be created. Considerable employment can be provided by developing small-scale rural industries based on processing and adding value to agricultural products and on meeting local needs for consumer and capital goods.

Rural employment is not an end in itself, but rather a means to more nearly equalize incomes, to enhance human dignity based on the freedom that comes from self-reliance, and to raise average income through fuller use of human resources. Empirical evidence indicates that equalizing incomes acts as a powerful force toward stabilizing population size (37).

Because of its flexibility and ease of use, electrical energy is probably more satisfactory than any other form to provide shaft power for rural industries. Many industries suitable for rural areas also require process heat, or process steam, (or both) as well as shaft power. In most cases, these can probably be obtained more economically by direct combustion of fuels rather than by electric heating.

Rural industries, helped by government or private agencies, have sprung up spontaneously in some small cities of the Indian subcontinent. Jobs in ferroconcrete construction, kraft paper manufacturing, diamond cutting and polishing, rug weaving, making of dry foods such as "papar," and production of brown sugar are among the industries established by rural development agencies. Some have been created at an average capital cost of $500 per worker.

Although electrification may often be necessary for the establishment of small industries in rural areas, experience shows it is far from sufficient. Other factors that are likely to be important are (i) actual or potential transportation facilities to and from markets and sources of raw materials; (ii) an adequate supply of other forms of energy needed for a particular industry or industrial complex; (iii) sufficient investment capital, in the form of either credit or savings; (iv) trained technicians and managers familiar with problems of marketing, cost accounting, personnel management, and business operation; (v) a market town or small city in which a complex of mutually supporting industries can be established; and (vi) the availability, skills, discipline, and comparative costs of labor in the rural areas compared with the labor force in large cities.

Important policy questions emerge in considering rural electrification. How much primary and secondary employment. what increases in incomes, and what multiplier effects can be expected from rural industrialization based on electrification? How can the load factors on electrical transmission grids from central station power systems be raised? What kind of public-sector intervention (such as credit for investments, technical training, road-building, construction of storage and market facilities, and subsidies for other necessary forms of energy for certain industries) should supplement electrification in order to stimulate rural industrialization? What factors need to be taken into account in appraising cost-benefit ratios? What types of data are needed for formal project evaluation?

The Long-Range Dilemma: Energy versus Food

The future sources of primary energy for generation of electricity and for motor vehicle transportation present many of the poor Asian countries with a cruel dilemma. With inadequate hydropower potential and small reserves of fossil fuels, they will be forced to import hydrocarbon fuels at very high foreign exchange costs to provide energy for central-power-station generation of electricity and liquid fuels for transportation. Yet the alternative of decentralized electricity generation and production of liquid fuels from locally grown wood and other biomass may seriously limit food production. In very large countries such as Brazil, where only a small fraction of cultivatable land has been required to grow enough food, production of alcohol from sugarcane as a vehicle fuel may actually raise the real incomes of rural people by providing increased employment. But in the Asian countries, with their high population densities on cultivatable land, using biomass fuels for transportation and electricity is likely to result in increased food prices and may reduce the real incomes of the poor, in spite of the added employment provided by rural industry.

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A Global and Long-Range Picture of Energy Developments

Wolf Häfele

Summary. Most studies of energy supply and demand ignore either global interdependence or the long time spans necessary to adjust to new energy sources. The International Institute for Applied Systems Analysis has therefore studied on a global scale, for seven major world regions, the balance between energy supply and demand for the next 50 years. Reported here are the results for two benchmark scenarios. In the "low" scenario world energy consumption increases from today's 8.2 terawatt-year per year to 22 terawatt-year per year in 2030; in the "high" scenario, consumption increases to 35 terawatt-year per year. The study showed that time will be the limiting constraint in adapting the energy supply infrastructure to changing resource availability; resources will be available until the second half of the next century, but a strong shift will be required to low-grade fossil fuels such as shale oil and tar sands. Each scenario studied indicated increased environmental problems associated with increased use of fossil fuels, and potential geopolitical problems associated with the world distribution of resources.

A Time Frame for Global and Long-Range Energy Developments

In the middle of the last century wood was the predominant source of energy, meeting roughly 70 to 80 percent of the demand. This meant large-scale gathering and led to a first energy crisis, which was overcome by a fundamental change in technology: Coal was used as a substitute for wood. The higher density of coal meant not only more energy but also easier storability and transportability, features that were essential for the first industrial revolution. Figure 1 shows the decline and rise of market shares of various types of primary energy in the United States. The data are plotted in such a way that a logistic curve becomes a straight line. It should be noted that there are remarkable regularities in the data over extended time periods. One such regularity is the slope of these curves. Its constancy means continued logistic substitution of one source by another over decades. For the United States it has always taken roughly six decades for a new energy source to conquer 50 percent of the market. For the world as a whole the figure is ten decades. The regularities of such market penetrations have been studied in great depth (*1*). What is concluded here is that it is appropriate to consider the time frame 1980 to 2030 when developments of energy demand and supply and their underlying infrastructure are to be discussed.

It also seems appropriate to consider the world as a whole. Indeed, today roughly 25 percent of the world's energy supplies come from one place on the globe, the Middle East, and this creates a strong technical and political linkage for almost all parts of the world. On the demand side the situation is similar. For instance, a political debate continues to focus on the notion of a "new economic order" viewing the world as a whole and addressing the problem of developing the so-called "South" of the world. Although political in nature, this debate nevertheless makes it plain that the demand for energy must also be seen in such a perspective. By contrast, most of the major studies of energy approach the problem on a national scale and use a short- to medium-range planning horizon, say 10 to 15 years. While this is clearly necessary, it is not sufficient. Often the result of such studies is the identification of required imports; the feasibility of such imports is left open. Indeed, others may have planned to import the same barrel of oil. It is thus global comprehensiveness and consistency that must come into focus, particularly when the time frame reaches out to the year 2030.

The IIASA Energy Systems Program

Such a global and long-range view characterizes the approach of the Energy Systems Program of the International Institute for Applied Systems Analysis at Laxemburg, near Vienna, Austria. IIASA was conceived in the late 1960's

The author is deputy director of the International Institute for Applied Systems Analysis, Laxenburg-Vienna, Austria, and leader of the Energy Systems Program at IIASA.

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