# Rural Energy Issues in Thailand

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## ABSTRACT

*Existing energy supplies and the uses of energy in the rural areas of Thailand are reviewed with attention to both resources and activities in the energy field. An assessment of the potential energy resources and a discussion concerning the available energy technologies, their technical, economic and social implications, and future trends, considers woodlot plantations, charcoal production, stove technology, direct combustion of agricultural residues, briquetting of agricultural residues, biomass gasification, dendrothermal power systems, biogas, solar heating, thermal refrigeration and water pumping, solar cooking and water distillation, solar drying, solar thermal electric generation, photovoltaic systems for communication, lighting, water pumping and refrigeration, micro hydropower, wind energy, and liquefied petroleum gas.*

*In the next two decades, biomass will remain the main source of energy for rural Thailand. Tree farming and reforestation programmes should be accelerated. With a very large surplus of agricultural residues, the development of technologies for efficient energy conversion of the residues should be promoted. Research and development of other renewable energy sources, such as solar and wind energy, should also be carried out in planning for long-term utilization.*

## INTRODUCTION

In the past, available patterns of energy consumption in Thailand did not include the use of non-commercial energy sources. As a result, the patterns of energy consumption were distorted, especially with regard to the rural areas of the country.

The development of rural Thailand has affected the patterns of energy consumption. For example, large rural industries, such as sugar mills and rice mills, appreciably increase the consumption of biomass; modern transportation is changing a self-sufficient rural lifestyle based upon renewable energy sources to increasing dependency on petroleum products.

This review paper on rural energy issues of Thailand is based on information and discussions presented at a technical meeting on "Energy Planning for Rural Thailand," organized by the National Energy Administration at the Indra Hotel in October 1985, and also upon research and development efforts carried out predominantly at Thai government agencies and universities – notably the National Energy Administration, the Electricity Generating Authority of Thailand,

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## EXISTING END-USE REQUIREMENT

### *General Pattern of Rural Energy Consumption*

In 1983, rural areas accounted for about 50% of the total energy consumption in Thailand.[1] The patterns of energy consumption in rural areas by sector and by fuel are summarized in Table 1.

**Table 1**
**Patterns of rural energy consumption in 1983[1]**

| | Quantity 1000 toe | % of total | Projected growth in %, 1983-2001 |
|---|---|---|---|
| **A. By Sector** | | | |
| Households | | | |
| Traditional fuels | 4180.3 | 93.4 | 0.5 |
| Modern fuels | 381.2 | 47.7 | 3.2 |
| Cottage industry | 380.0 | 100.0 | – |
| Industry | | | |
| Traditional fuels | 2363.0 | 100.0 | 2.2 |
| Modern | 229.2 | 8.8 | 6.3 |
| Agriculture | 449.9 | 100.0 | 4.9 |
| Transport | 1427.8 | 25.2 | 6.6 |
| Total | 9411.4 | 52.2 | 5.0 |
| **B. By Fuels** | | | |
| Traditional fuels | | | |
| Firewood | 2971.7 | 99.5 | –0.2 |
| Charcoal | 2219.7 | 88.8 | 2.5 |
| Agricultural residues | 526.9 | 100.0 | 1.8 |
| Bagasse | 1205.0 | 100.0 | 1.3 |
| Subtotal | 6923.3 | 95.9 | 1.3 |
| Modern fuels | | | |
| Petroleum products | 2259.4 | 24.6 | 5.7 |
| Electricity | 190.5 | 13.3 | 7.8 |
| Lignite/Coal | 38.2 | 21.2 | – |
| Subtotal | 2488.1 | 23.0 | 5.8 |

Several comments should be made on the figures given in Table 1. Firstly, energy consumption by commercial/government concerns and fisheries, at 615.9 and 680.9 thousand toe respectively, are not included in the rural energy consumption figures, though these activities also exist in rural areas. Secondly, the projected growth of energy consumption by cottage industry at zero percent seems to contradict the present trend and government policy of decentralized industries. Thirdly, the projected growth of lignite comsumed in rural areas at zero percent also contradicts

**Table 2**
**Percentages of energy consumption in various household activities[2]**

| Activities | Wood | Charcoal | Rice Husk | Palm leaves | Straw | LPG | Kerosene | Gasoline | Diesel | Electricity | Calcium carbide | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooking | 29.47<br>66.25 | 40.38<br>97.44 | 0.52<br>10.34 | | | 0.25<br>100 | 0.04<br>0.67 | | | 0.13<br>13.38 | | 70.79 |
| Lighting | | | | | | | 5.66<br>99.33 | | 0.22<br>59.32 | 0.35<br>37.64 | 0.16<br>100 | 6.39 |
| Personal heating | 7.71<br>17.34 | | | 0.15<br>41.18 | 0.23<br>20.69 | | | | | | | 8.09 |
| Insect prevention | 4.66<br>10.49 | | 0.20<br>3.91 | 0.21<br>58.82 | 0.88<br>79.31 | | | | | | | 5.96 |
| Cottage industries | 2.64<br>5.92 | 0.22<br>0.53 | 4.35<br>85.75 | | | | | | | | | 7.21 |
| Home appliances | | 0.84<br>2.03 | | | | | | | | 0.39<br>41.50 | | 1.23 |
| Water pumping | | | | | | | | 0.11<br>100 | 0.15<br>40.68 | 0.07<br>7.48 | | 0.33 |
| Total | 44.48<br>100 | 41.44<br>100 | 5.07<br>100 | 0.36<br>100 | 1.11<br>100 | 0.25<br>100 | 5.70<br>100 | 0.11<br>100 | 0.37<br>100 | 0.94<br>100 | 0.16<br>100 | 100 |

For each activity, figures in the top line indicate percentages of the activity, and figures in the bottom line indicate percentages of each source of energy.

the fact that lignite is a cheap domestic fuel and should be promoted. Fourthly, though non-commercial fuelwood *is* included, non-commercial solar and wind energy is not.

### *Household Energy Consumption*

Percentages of the household energy consumption in 1983 were 49% of the total energy consumption in rural areas and 25% of the total energy consumption of the country.[1] Household energy activities were classified in a limited survey conducted by the National Energy Administration of Thailand in 1980 as cooking, lighting, personal heating, cottage industries, insect prevention, and domestic appliances (including water pumps).[2] Sources of energy used in rural households were firewood, charcoal, rice husk, palm leaves, straw, LPG, kerosene, gasoline, diesel oil, electricity, dry batteries, and calcium carbide. Percentages of different sources of energy consumed in various activities are given in Table 2.

From Table 2, it can be seen that the energy required for cooking amounted to 70.8% of the total energy comsumed in rural households. Personal heating and cottage industries – the second and the largest activities in terms of energy – represented only 8.1 and 7.2%. It is worth noting that the main source of energy for the three largest activities was biomass, comprising fuelwood and agricultural and industrial wastes.

Since cooking represented the highest percentage of rural household energy consumption, a further analysis is given in Table 3, which shows that firewood and charcoal consumption, at 108 and 85 kg/capita, accounted for 97% of the total energy required for rural household cooking.

**Table 3**
**Pattern of energy consumption in household cooking in 1980**

| Fuel | Quantity per capita, kg | Heating value kcal/kg | $\eta$, % | Total quantity kcal |
|---|---|---|---|---|
| Firewood | 108.5 | 3896 | 12 | 50703 |
| Charcoal | 84.9 | 6823 | 24 | 139009 |
| Rice husk | 2.54 | 2963 | 8 | 602 |
| LPG | 0.33 | 11154 | 50 | 1840 |
| Kerosene | 0.06 | 9280 | 50 | 278 |
| Electricity | 2.1 kWh | 860 | 90 | 1625 |
| Total | | | | 194057 |

### *Rural Industries*

One of the government policies is to decentralize industry to rural areas. It is thus expected that rural industries will increase in the future. Table 4 gives the pattern of energy required for cottage industries in 1980.[2]

Cottage industries in the above table include charcoal-making fired by rice husk, commercial cooking for human and animal consumption, and other items. It should be noticed that rice husk

**Table 4**
**Pattern of energy consumption in cottage industries in 1980**

| Fuel | Quantity per capita, kg | Heating Value kcal/kg | % | Total quantity, kcal |
|---|---|---|---|---|
| Rice husk | 21.06 | 2963 | 8 | 4992 |
| Firewood | 9.67 | 3896 | 12 | 4521 |
| Charcoal | 0.46 | 6823 | 24 | 753 |
| Total | | | | 10266 |

used mainly in charcoal-making accounted for 50% of the total energy consumption for cottage industries.

Larger rural industries, such as rice milling, sugar milling, cassava processing, brick making and pottery, use by-product biomass and electricity. However, with the saturation of the world market for sugar, the growth of the sugar industry, and hence the use of bagasse, is expected to flatten off by 1990. On the basis of current trends, uses of modern and traditional fuels are projected at 6.3 and 2.2% respectively.[1]

## *Transportation*

The demand for transport fuel in rural areas is expected to increase more rapidly than the fuel demand for other energy activities in rural areas. In 1983, two thirds of petroleum product consumption was in the transport sector, with diesel oil accounting for 45% of the sector consumption. As a result of the relatively low prices of diesel, the demand for gasoline has stagnated, while the demand for diesel increased by 60% from 1977 to 1983.[3] Though transport fuels at present consist mainly of gasoline and diesel, the use of LPG, which is relatively cheap and indigenously produced, has been steadily increasing. With a projected growth rate of 6.6% annually, the demand for transport fuels will reach 4.5 million toe by the year 2001.[1]

## *Agriculture*

Information on the actual total energy consumed in agriculture is still sketchy. The wind energy used for water pumping in fields producing rice and salt has not been quantified. The same applies to solar energy used for desalination and the sun drying of agricultural and marine products. Mechanization in agriculture is expected to increase rapidly – at a rate of 6% – up to 1990, and then about 4% until the year 2001, when the total commercial energy consumption in agriculture should reach 1 million toe.[1]

# STATUS REVIEW OF RESOURCE POTENTIAL, AVAILABLE TECHNOLOGIES, THEIR TECHNICAL, ECONOMIC & SOCIAL PERFORMANCES AND TREND IN FUTURE

## Biomass Energy

### a) Woodlot Plantations

In 1983, the total sustainable supply of fuelwood was estimated at about 11M $m^3$, while 28M $m^3$ was supplied by overcutting the forests. It is expected that by the year 2001 the potential demand for fuelwood will reach 50M $m^3$.[1] The sustainable supply is however estimated to be only 6M $m^3$. Though more households in the central region of the country gather their fuelwood from private woodlots, the northeast and southern regions have higher percentages of households obtaining their supplies from natural forests. According to the 1982 base-line survey conducted for the National Energy Administration,[4] villagers in several districts have to travel over 3 km to collect fuelwood. With the present rate of deforestation, travel distances are expected to increase in the future so much that village or household woodlots will become economical.

Several species of fast growing trees, and notably eucalyptus, have been identified as suitable for different areas in Thailand.[5] It has been suggested that tree planting by two million households, each with about 50 trees, will provide 2-3M $m^3$ of fuelwood annually.[1] In addition, establishing of 450 000 ha of private fuelwood plantation would generate about 9M $m^3$ of fuelwood annually.

There are several possibilities for enhancing the economics of woodlot plantations. For example, other crops can be grown along with the fast-growing trees. Large tree trunks could be used as building materials, such as house poles, cabin walls, electric poles, and furniture. Branches and butt ends of the trees should be used as fuelwood.

### b) Charcoal Production

In 1983, some 3.7M tons of charcoal were produced from 26M $m^3$ of wood, which represented 67% of the total fuelwood consumption in Thailand. The energy loss in the charcoal-making process was estimated as being equivalent to 16M $m^3$ of wood.[3] The commercial production of charcoal has been most appropriately established in the southern region where mangrove resources exist. In other regions, mobile charcoal production often involves the illegal removal of wood from state-owned forests.

According to a charcoal improvement project conducted in Thailand from 1982-1984, thirteen charcoal-making methods were evaluated prior to improvements being undertaken.[6] Test results indicated that permanent kilns, with capacities ranging from 7 to 100 $m^3$, were superior to both metal kilns and non-permanent mound types in charcoal yield and quality.[7] After improvements developed in the project were introduced, notably on firing techniques and the method of kiln construction, the overall energy conversion efficiency increased from an average value of 39% to 55-60%. An accelerated dissemination programme for the improved design of charcoal kilns is recommended, and priority should be given to small charcoal producers because of their larger total output and less efficient operations.

The most important problem from the view point of charcoal producers is the increasing scarcity of wood sources. Since the consumption of charcoal for cooking is very high, and effective replacement by other fuels is unlikely within the next 10-15 years, government attention should be directed towards controlling illegal production, promoting woodlot plantations and further improvements in the production of charcoal.

**c) Stove Technology**

In 1980, the annual average consumption of firewood and charcoal for cooking in the country were estimated at about 108 and 85 kg per capita respectively. These figures represent about 40M $m^3$ of fuelwood per year, or 75-80% of all uses of wood. Fuelwood thus contributes significantly to the problem of deforestation in Thailand. Rice husk was also used in cooking stoves in rural areas at a rate of 2.5 kg per capita per annum.[2]

The main problems associated with biomass cooking are the use of inefficient stoves, a lack of knowledge of stove selection and maintenance, and a lack of understanding of fuel preparation.[8] An evaluation of the performances of existing stoves in Thailand from 1982 to 1984 showed that the average efficiencies of the charcoal bucket, the non-chimneyed and chimneyed wood, non-chimneyed and chimneyed rice husk stoves were 27, 20, 12, 16 and 5% respectively. Since then, better cooking stoves have been developed and the improved efficiencies are rated at 34, 27, 19, 19 and 10% for the charcoal bucket, non-chimneyed and chimneyed wood, non-chimneyed and chimneyed rice husk stoves respectively.

With these stove improvements, a considerable amount of biomass could be conserved if a stove promotion programme for about six million rural users is strongly supported with reasonable financial and human resources. To date, stove designs have not been optimized and further research and development to improve stove design will be beneficial to the domestic supply of energy and help reduce the rate of deforestation in the country. Rice husk stoves deserve special attention for research and development since the surplus of unused rice husk in the country is very large and the current efficiencies of rice husk stoves are still quite low.

**d) Direct Combustion of Agricultural Residues**

Though the amount of biomass residues generated from nine major cash crops in Thailand is estimated at about 50 million tons per year, bagasse from sugar cane and rice husk are, however, the only two residues currently used in significant amounts.[3]

In 1980, about 40% of 2.5M tons of rice husk produced by rice milling were directly burnt in rice mills to generate steam for power production, parboiling, and drying purposes. Based upon the present trend, it is estimated that by the year 2001, rice husk may amount to 3-3.5M tons. Hence a wider use of rice husk as an alternative energy source should be seriously considered. In addition to being used as a cooking fuel, the co-generation of process steam and power generation in rice mills using rice husk as the fuel can be a very efficient method of energy conversion. Co-generation would be further enhanced if rice mills were permitted to sell excess electricity to the national grid or to neighbouring villagers.

Bagasse from sugar cane has a similar potential as a fuel. In 1982, about 0.5M tons of bagasse were used as boiler fuel in Thai sugar mills. Cane trash, mainly cane tops, could add 2M tons of potential fuel yearly. Again, promotion of efficient co-generation in sugar mills could significantly contribute to the domestic energy supply for rural industry and electric generation.

**e) Briquetting of Agricultural Residues**

Briquetting technology has already been used in the country. Several private firms produce briquetted fuels from sawdust and rice husk for a limited market, since the price of briquetted fuels (at 0.7-0.8 baht/kg – approximately US$0.03/kg) is almost equal to that of low-grade charcoal. A pilot project to produce briquetted water hyacinth was recently conducted and results indicated that the briquetted fuel was more expensive than charcoal, and hence not feasible at present.[9] However, in the long-run, since the price of charcoal will increase as a result of wood scarcity, briquetted biomass fuels may become economically competitive.

**f) Biomass Gasification**

Several types of small gasifiers, fired by charcoal, wood, and agricultural residues, have been locally developed for the generation of electricity and water pumping, giving from 7.5 to 30 $kW_e$ output.[10] A few demonstration and field test units have been set up for long-term evaluation in rural areas, where results appear to be encouraging. In remote areas without an electricity grid, biomass gasifiers produced locally at a cost of below US$200/kW can provide a more economical alternative than diesel electric sets.[3] Though charcoal gasifiers present very few problems with regard to their construction and operation, charcoal is more expensive and less available than wood. Wood gasifiers therefore appear to be more feasible for applications which require a power output of up to hundreds of kW. However, since a large quantity of wood would be required for such gasifiers, wood production and the preparation system has to be carefully considered in the case of each wood gasifier. More efforts are also needed for the development of efficient wood gasifiers.

Due to the availability of agricultural residues, such as rice husk, bagasse, corn cobs, and coconut shells, the development of gasifiers fired by agricultural residues would be benefitial to the country and should therefore be promoted.[11] It should nevertheless be noted that other energy conversion technologies for agricultural residues (such as briquetting, direct combustion, and cogeneration) exist, and have been successfully used in a few specific applications, such as rice mills and sugar mills, as was mentioned earlier.

**g) Dendrothermal Power Systems**

Recent studies in Thailand indicate that the cost of electric generation by a small dendrothermal power system of about 3 $MW_e$ varies from between 1.7-2.8 baht/kWh (≈US$0.07-0.11/kWh) and that a larger plant would seem to be more economical.[3,12] With the shrinking market for cassava, some 160 000 ha of cassava farms can be made available for planting of fast-growing trees. Though the Philippines dendrothermal power programme may not seem to be econmical enough from the energy viewpoint, in Thailand dendrothermal power systems fired by fast-growing trees such as eucalyptus still appear attractive, since they can provide solutions to energy, agricultural and employment problems in rural areas at the same time.

Since a dendrothermal power system involves three sub-systems, namely tree planting, transportation of the wood, and the thermal power machinery, location-specific studies are required. One of the main problems to be studied is the management of very large tree plantation. For example, a 3 $MW_e$ dendrothermal plant will require a tree-plantation of about 5 $km^2$.[12] The cost of transporting the trees from the plantation is another problem which will need to be studied. Data from a few pilot systems larger than 3 $MW_e$ in the country will be very useful, and such data will be necessary before the implementation of a national programme on dendrothermal power systems is brought about.

**h) Biogas**

As the theoretical total potential of manure for biogas generation in Thailand is about 60M tons yearly, biogas from manure has been promoted as an alternative source of energy for rural households and farms. About 3000 family-size biogas units, each of about 4 $m^3$ capacity, have been installed – mainly with a government subsidy at 1/3 of the cost of basic materials. The gas production cost of the family-size units ranges from 5-10 baht/$m^3$ (≈US$0.19-0.38/$m^3$), which would be at best comparable to cooking with charcoal and LPG.[3]

Experience so far has shown that family-size biogas units intstalled in the country side face several problems. Firstly, owing to maintenance difficulties and changes in family lifestyle, 60% of the installed units were non-operational. Secondly, Thai families do not have a cultural familiarity with manure as do people in India or China. Thirdly, the investment costs of small biogas units are too high in comparison to other alternative cooking devices such as biomass stoves.

Larger-scale biogas plants for farms or industrial installations seem to be more economical because of the fuel generation benefits and the need to meet environmental regulations. Several types of feed materials are available for large-scale biogas plants, such as manure from livestock and poultry farms, tapioca waste, canning food waste, distillery waste, and dairy waste.[13] A few large-scale biogas plants using pig manure have been installed in the country. The largest industrial biogas plant, which was recently installed at a distillery, has a capacity of 400 $m^3$. A pilot biogas plant using pineapple skins has been investigated, and the results are so encouraging that a prototype is being designed for a pineapple canning factory.[14] It is recommended that more pilot projects to evaluate large-scale biogas plants should be continued prior to establishing a national dissemination programme.

## Solar Thermal Processes

Solar energy has several advantages over other energy sources. Firstly, its supply is inexhaustible; secondly, it is not subject do embargos; thirdly, its use creates very little pollution; and fourthly, several solar technologies exist for different applications. Unfortunately, the application of solar energy also presents one or two problems. For example, the intermittent nature of solar radiation requires some form of energy storage in most real applications. Its intensity is rather low, and expensive concentrators are thus required for high temperature applications.

### a) Solar Heating, Thermal Refrigeration and Water Pumping

Over ten private firms in Thailand manufacture flat plate thermal collectors for water heating. In rural areas, the main potential for solar water heating is in health clinics, hospitals, hotels, schools, and other provincial centres. With the recent development of selective coating in Thailand,[15] high performance thermal collectors can now be locally produced for solar thermal refrigeration and water pumping.

Though a few solar thermal refrigerators and water pumps have been locally designed, constructed and tested, their preformance is still not economical for field applications.[16,17] Even with additional research and development efforts, one cannot expect that solar thermal refrigerators and water pumps will be able to compete against existing alternative methods in the near future.

One of the strong competitors of solar thermal refrigeration is biomass thermal refrigeration based upon the same absorption refrigeration cycle. With the availability of biomass in the country at a relatively low cost, a biomass refrigerator is more economical than a solar one, though the latter is more convenient to operate as it requires less attention than the former.[18] In the case of solar thermal water pumping, the efficiency of the technology at present available is extremely low, and consequently photovoltaic pumping would seem to be more attractive technically and economically (as discussed below).

**b) Solar Cooking and Water Distillation**

Technologies for solar cooking and water distillation have been developed over several decades, and can now be considered as reliable. Their applications in the field have not however been successful, mainly on account of social problems.

Several designs of solar cookers are available, notably in the form of ovens, steam cookers, and parabolic cookers. Since solar cooking is hardly possible in the morning and evening owing to very low radiation, solar cookers do not fit the eating habits of most Thai. In rural areas, where biomass is readily available, it is almost impossible for solar cookers to compete against biomass stoves.

To overcome the problem of evening cooking, the development of a thermal storage unit was attempted.[19] Though the cooker with the thermal storage unit worked technically, the initial cost of the whole device was rather expensive and thus became unattractive.

Though solar distillation has been used for decades in salt production along the coastal districts, the use of solar energy for this purpose has not been quantified. It is a well-known fact that clean drinking water is scarce in many rural areas of the country. Though quite a few designs of solar stills, such as the portable type, the concrete basin type, and the modular type have been constructed and tested locally,[17,20] the popularization of solar stills in rural areas still requires considerable effort for the following reasons. Firstly, the initial cost of a solar still is too expensive for poor rural people; secondly the people themselves are not aware that drinking water is not clean enough, and thirdly, the operation of a simple solar still requires daily attention – which many potential users are not willing to give it. However, for health reasons, the application of solar stills in rural areas should be encouraged. It is worth mentioning that the quality of distilled water is good enough for filling batteries in trucks and cars. Additional income from the sale of distilled water for such purposes may enhance the use of solar stills in rural areas.

**c) Solar Drying**

One of the most attractive solar energy technologies for rural applications is solar drying. Sun-drying has been used for centuries with considerable success, but it still yields several undesirable results. Sun-drying is normally affected by rain, clouds, dust and atmospheric pollution, and is not safe from intrusion by people and animals. Moreover, the products to be dried are subject to infestation by insects. These problems will decrease or disappear if solar dryers are employed.

Several types of solar dryers have been developed in the country, such as the box type and the cabinet type free convection dryers for cash crops, meat and marine products; free and forced convection grain dryers; and solar assisted tobacco-curing barns.[21,22] Field tests have indicated several interesting results,[23,24] Firstly, initial costs of solar dryers seem to be too high for poor farmers; secondly, dryers will be attractive economically if they can be used all year round as multi-crop dryers or as storing barns as well; thirdly, the success of solar dryers depends also upon products and individual techniques in the drying processes; and fourthly, large-scale solar dryers are more economical than smaller ones. In addition to their rural applications, large solar dryers also have a high potential for industrial applications, and consequently the development of solar dryers should be accelerated at the national level.

A few approaches to popularize solar dryers should be considered. For example, demonstrations should be made of large and small solar dryers for various applications, and the dryers should be set up at different locations in the country. Also, incentives such as soft loans, subdidies, should be given to users of solar dryers.

**d) Solar Thermal Electric Generation**

Several types of solar thermal electric power systems have been installed abroad, with up to 10 $MW_e$, mainly in order to demonstrate their technical feasibility.[25] In Thailand, a small parabolic trough system has been designed, constructed and tested to assess the local technical capability. Two types of storage system were investigated, namely a steam accumulator and a phase change storage system.[26] In addition, a feasibility study based on a small physical model of a central tower system was conducted.[27] However, since Thailand has a rather high diffuse radiation, systems with concentrating collectors which accept only beam radiation yield low efficiencies, and thus seem to be uneconomical at present.

The recent development of several types of solar ponds which absorb both diffuse and beam radiation indicate that solar pond systems for electric generation are more economical than concentrator systems if they are installed for operation with high diffuse radiation.[28] A contributing reason is that the solar pond acts as a thermal collector and storage system at the same time. Heat from solar ponds has also been used for industrial processes in the USA, and at present two small experimental solar ponds are being investigated in Thailand. Further ressearch and development of solar ponds should be encouraged.

## Photovoltaic Systems

Direct conversion of solar radiation to electricity by photovoltaic cells offers a few advantages over other indirect solar electric generation methods. In general, photovoltaic systems are relatively easy to install, operate and maintain. On the other hand, the intitial cost of a photovoltaic system at present seems to be higher than other indirect solar electric power systems, especially for large power output. Present applications of photovoltaic systems may be broadly classified into three groups, namely communication, lighting and water pumping, and refrigeration — for which no storage is required.

**a) Communication**

Many successful applications of PV systems in Thailand are associated with communication facilities in remote areas, such as telephone repeater stations, and field radio communications of the armed forces and government agencies. In addition to the advantages already mentioned, their successful operations arise from the fact that in these remote areas electric generation by other methods would be more expensive, and in some cases less reliable.

**b) Lighting**

A few PV lighting systems have been installed in remote areas of the country mainly for security, and for political and social reasons. These systems have not, however, been properly analysed for their economic and social performance. It is suggested that if more PV lighting systems are to be installed in the future, economic and social assessment should be included as integral parts of the projects.

**c) Water Pumping and Refrigeration Systems**

Both applications of PV cells look attractive since they require no energy storage as a subsystem. Recent studies of two PV water pumping projects installed in remote areas of the country with capacities of 700 and 4300 $W_e$ indicated that though both systems were not economically feasible owing to the very high costs of the PV arrays, some indirect benefits had been achieved, such as cooperation between rural people and the government, and the application of a domestic energy resource in rural areas.[29]

A PV refrigerator has also been installed and assessed,[30] and the results of the project will be available in due course. It is envisaged that PV refrigerators could be very useful for medicine and food preservation in remote areas.

With the high initial costs of PV arrays at present, PV lighting, water pumping, and refrigeration systems are not feasible for applications in rural areas in general, since other alternative methods are cheaper, such as kerosene lamps for lighting, and diesel driven water pumps. Though the cost of the solar cell may decrease rapidly as a result of concentrated research and development efforts, especially in developed countries, costs of accesories for a PV system, such as a power conditioning device or battery storage, would decrease very little. With the exception of communication systems in remote areas and some other specific applications, such as hybrid systems with wind energy, other PV systems with large outputs would not seem to be economically feasible in the near future.

On research and development, two existing PV materials laboratories in two educational institutes are able to produce single crystal solar cells at laboratory scale.[31] A local company in a joint venture with a US company has produced PV modules for domestic demand and export since early 1985. A few government agencies, educational institutes and the armed forces have been developing and assessing PV systems for water pumping, lighting, refrigeration and communication.

## Micro Hydro Power

Small hydro power generation is one of the alternative energy technologies for decentralized power generation. With the exception of the control system, a micro hydro powerplant requires only intermediate technology, and this is locally available.

To date, twelve micro hydro powerplants, ranging in capacity from 5 to 200 kW, have been installed in the country and ten more are under construction or design. The total output from the small hydro powerplants in the country amounts to about 80 $MW_e$.[3] As the social and economic assessment of small hydro powerplants have to be conducted on a site by site basis, only a few of the existing plants have been thoroughly assessed.[32] Results from the assessed plants show that village participation in installation, operation and maintenance can be successfully utilized in micro hydro power projects for rural development. The economic feasibility of the plants, howeever, has yet to be demonstrated, since the government provided all of the materials and items of equipment which were not available in the villages free of charge.

It would be most useful to assess all the existing micro hydro powerplants economically and socially in order to obtain more complete information for the implementation of the national micro hydro power programme in the future. It should be noted that suitable sites for small hydro powerplants are rather limited, and installation of the plants in remote areas may have more social and political impact than economic consequences.

To lower the initial costs of micro hydro powerplants, studies should be made giving attention to simpler and less expensive design. Development of the control system and the use of cheap centrifugal pumps as turbines should be encouraged in the country.

### Wind Energy

Windmills have been used for water pumping in Thailand for decades. The wooden-blade type and the sail-type traditional windmills are used mainly in rice fields and salt production fields respectively. These windmills are normally constructed by village craftsmen at relatively low costs. Though their efficiencies are not impressive, they are economical to use. Steel multi-blade windmills are also manufactured in the country. In spite of their higher efficiencies, a recent assessment of two multi-blade windmills pumping projects indicated that the systems were not economically feasible.[29] One main reason was that their initial costs were rather high at 50 000-80 000 bahts (≈US$1923-3077).

It needs to be emphasised that hundreds of sail-type windmills are still being used for water pumping, and hence are economical enough. Unfortunately, the performance of these traditional windmills, and their contribution to the total energy consumption of the country, have not been properly assessed.

Another application of wind energy is electric generation. Wind electric power systems are manufactured in developed countries with an output of up to a few MW. A wind electric power farm in California generates more than one hundred MW by a few hundred wind turbines installed in one site only. In Thailand, small wind electric power systems are being developed,[33] and a few demonstration units of wind electric power systems are being monitored and assessed.[34] One of these is a hybrid system, with both wind and photovoltaic sub-systems. Though the potential of wind energy in Thailand is not high in general, a few sites with strong wind exist, and they could be suitable for wind electric power generation. A feasibility study on wind electric power farms in the country should be conducted.

### Liquefied Petroleum Gas

Owing to low LPG prices, the transport use of LPG has increased from the 0.47 Mbbl used in 1983, which represented 45% of the total LPG consumption in the country.[3] In 1985, the local LPG separation plant owned by the Petroleum Authority of Thailand will eventually produce 3.6 Mbbl per year to meet a large part of the LPG requirements in the country.

Six regional bulk storage and distribution centres are being set up by Petroleum Authority of Thailand (PTT), which will greatly facilitate supplies of LPG to up-country areas, especially for transport use. The use of LPG in rural households will, however, be constrained by the need to place a deposit on a gas cylinder as well as a lump sum for 50 kg of gas. As LPG is a high grade fuel suitable for transport use, the use of LPG in rural households should not be encouraged, since other cheaper alternative fuels, such as firewood and charcoal, are available unless the woodlot plantation and reforestation programmes discussed above seriously fail to reach the targets set for the future.

## CONCLUSIONS AND RECOMMENDATIONS

Within the next two decades, biomass – especially fuelwood – will still be the main source of energy for the rural areas of Thailand. Since the predicted consumption of fuelwood up to the year 2001 will exceed the amount of sustainable supply from existing forests several times over, woodlot plantations and reforestation programmes should be given top priority for implementation.

Though various bioenergy technologies are available for converting biomass into suitable solid, liquid and gaseous fuels for different applications, the efficiencies of bioenergy conversion and the uses of bioenergy remain rather low in general. Research and development on bioenergy conversion and uses should be accelerated in order to improve the efficiencies and thus help conserve biomass, especially fuelwood.

Bagasse and rice husk will remain the two largest sources of energy from agricultural wates. Improvement of fuel utilization efficiencies in sugar and rice mills should be urgently attempted in order to maximize their contribution to the energy supply of the country. In addition, since a very large amount of rice husk remains unused as fuel, more extensive use of rice husk stoves could be immediately promoted. Densification of crop residues still requires more development efforts to lower the costs of briquetted fuels, which are not economically competitive at present.

Though solar energy and wind energy have made considerable contributions to the non-commercial uses of energy in Thailand, in the next decade they will not significantly replace national consumption of petroleum-based fuels. However, with their numerous positive characteristics, such as being renewable resources, having little pollution effect, their domestic availability, research and development on suitable wind and solar energy technologies should be constantly encouraged so that their use can become economically competitive and eventually maximized.

Since LPG is largely produced from domestic natural gas and can be used in internal combustion engines, the increasing use of this fuel in the transport sector seems appropriate. Unless the woodlot plantations and reforestation programmes of the country fail to reach the set targets, the use of LPG for cooking in rural households should not be encouraged, since cheaper biomass fuels are available.

Though several energy research and development agencies exist in the country, exchanges of information among these agencies are rather inefficient. As a result, energy research and development efforts are sometimes repetitive and financially wasteful. A national energy information network should be set up with an emphasis on the efficient retrieval and dissemination of energy information.

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