Alternative Energy Development in Sri Lanka

S. Sivasegaram
Faculty of Engineering, University of Peradeniya, Sri Lanka

ABSTRACT

This paper sums up the experience of the past twenty years or so in the development of alternative energy resources in Sri Lanka, and highlights the major achievements and contributions of Sri Lankan research and development work. The paper mainly concerns the technological aspects of alternative energy work, although the comments do not entirely exclude socio-economic aspects of energy sources. Some critical comments are made about the present state of the art, and recommendations are made for future development priotities.

INTRODUCTION

Sri Lanka, located approximately between latitude 6° and 10°N and longitude 79.5° and 82°E, is an island of about 65,000 km^2 in area lying at the southern tip of the Indian subcontinent. The island has a mean annual rainfall of 2,000 mm, and its dry zone has a mean annual rainfall exceeding 1,200 mm. Only two narrow strips of land, one along the northwest coast and the other along the southeast coast, have a low rainfall (600-1,000 mm per annum). The land is very fertile and is served by hundreds of rivers and streams over its entire area, with the exception of the Jaffna peninsula at the northern tip of the island. Although the country has a long tradition of using canal irrigation, following a four and a half century long period of colonial rule the economy has become heavily dependent on plantation crops – namely tea, rubber and coconut. Paddy, however, still remains the main agricultural crop.

The island, although fortunate in its water resources, is poorly endowed with mineral resources (fossil fuels in particular). There is a modest deposit of high quality graphite, which has a very high value as an industrial material, and a small deposit of peat along the west coast. The quality of the peat deposit is too poor to be of much significance (37). Exploration for onshore oil deposits in the mid-seventies were unsuccessful and plans are a foot for exploring offshore oil deposits. At the moment, little is certain about the extent, if any, of the oil deposits and the quality of the deposits.

Firewood had from time immemorial been the major sources – and until recent times the only source of heat for domestic use. Even today, despite the rapid depletion of forests and the rapid rise in the price of firewood, the main domestic fuel is firewood. Even after reduction by a factor of 0.2 to convert heat energy from firewood to the equivalent electricity replacement, firewood accounts for nearly 85% of domestic energy needs and is used mainly for cooking.

Although the rapid urbanization in the years following national independence in 1948 contributed to a noticeable shift in the energy consumption pattern, the number of households with access to electricity is only around 10%. A considerable section of the urban population has shifted to the use of kerosene (paraffin) for cooking (accounting for about 5% nationally), and a very small section of the population use electricity or liquid petroleum gas (lpg) for cooking. Households without access to electricity use kerosene as their main source of energy for lighting – and, more often than not, the lamps are poorly designed and highly inefficient converters of energy to light.

Public transport is almost entirely dependent on petroleum fuels, and the use of animal muscle power for transport (mainly private) is rapidly on the decline, and is an insignificant factor in energy planning today. A fine network of canal transport was developed by the Dutch in the 17th-18th century, and was abandoned in the early part of this century. River transport of goods still exists, but is not a significant feature of the transport system. Coal was the main fuel for railway transport from the early days of the railway system until recent times. Coal-powered locomotives were completely replaced by diesel-powered systems by the end of the sixties. Electricity was used for transport in sections of the city of Colombo until the early sixties. Proposals exist for the revival of trolley buses, but the matter is yet to be approved by the government. Large sail-boats were used in coastal navigation until the middle of the century. Today, motorised fishing boats are rapidly replacing even the small sail-boats used for fishing.

Sri Lanka is by no means an industrialised country, and a great deal of urban activity relates to the commercial sector. Electricity and petroleum are the main sources of energy in the commercial and industrial sectors, with electricity having a slight edge over petroleum products when the latter are converted to equivalent electricity replacement.

The agricultural sector has witnessed considerable farm mechanisation, with a large number of activities (such as ploughing, threshing and transportation of produce) being carried out by two- and four-wheel tractors [13]. Although buffaloes are still used extensively, the animal population has declined by 35% in the twelve-year period between 1962 to 1973[23]. The use of human muscle-power for water-pumping to irrigate garden crops has also been replaced to a considerable extent by water-pumps, powered by petroleum fuels or by electricity.

The only two conventional sources of energy which the country can develop on a large scale are fuelwood and hydropower. The former has been badly neglected for decades and the alarming rate at which forests are being cleared without adequate replanting of trees poses a serious threat – not only to the availability of firewood but also to the condition of the soil. This circumstance, in turn, affects the reliability of water flow in the rivers, and hence the hydropower potential. It has been estimated that reafforestation of 55,000 ha/annum, with fast growing fuelwood trees to be cropped in a 5 to 10 year cycle, would be adequate to meet the demand for firewood. However, planned reafforestation is realistically estimated at 2,800 ha/annum[40]

The hydropower potential of the country was first recognized as early as 1918 by the Sri Lankan engineer-statesman Wimalasurendra. However it was not until 1950, two years after national independence, that a major hydropower scheme was undertaken in the country. Of the estimated potential annual yield of 8,000 GWh of electricity from major hydropower projects (i.e., those generating several megawatts or more), at present only around 1,500 GWh has been developed. On completion of the present Mahaveli project (which involves the largest river catchment area in the island) the installed annual yield is expected to reach 5,000 GWh by the end of the decade. Even when the entire available 8,000 GWh is developed the possible peak value of hydroelectric power available per head will be less than 100 W, a figure which is not very impressive even in the Asian context.

It is against this background, and in the context of the sharp increase in energy demand in the wake of the open economic policy of the government since 1977, that the development and the need for development of alternative energy resources should be studied. The main fields of Sri Lankan activity in alternative energy research and development are passive solar energy, wind energy and biomass. Besides these, proposals for developing ocean thermal energy (OTEC) and nuclear energy have been made in recent years and deserve some comment.

This paper briefly outlines the major areas of activity and achievements, in their historical context where relevant, and reviews the main contributions of Sri Lankan research and development in alternative energy. The paper is confined to work done in Sri Lanka and to work directly relating to Sri Lanka's energy problems. Some comments are made, where relevant, to activities relating to the use of alternative energy devices developed elsewhere and not relating to the mainstream of alternative energy work in Sri Lanka. An appendix listing the major institutions involved in alternative energy research and development is given at the end of the paper. It is perhaps necessary to mention at this stage that, in the interest of brevity and clarity, discussion is restricted to items which, in the author's view, are the most significant aspects of alternative energy work in Sri Lanka.

SOLAR ENERGY

It may be of interest to note that pioneering work on solar energy was carried out in Sri Lanka many years before the "energy crisis" of 1973. Chinnappa (5) initiated solar radiation measurements in 1957, and designed and tested the performance of a pipe collector with reflectors[6]. His work in developing solar refrigeration and air-conditioning system (Fig. 1) was of international significance[7 8 9]. He also developed a solar water heater system (Fig. 2) and tested its performance[10 11]. The pressurised water heater was capable of supplying hot water at 45 to 65°C. This work was followed by some unpublished work on the use of solar cells for pumping water, and a study of using solar stills for distilling sea water. It was Chinnappa's work which laid the foundation for the systematic study of solar radiation data and of the performance of solar devices in subsequent years.

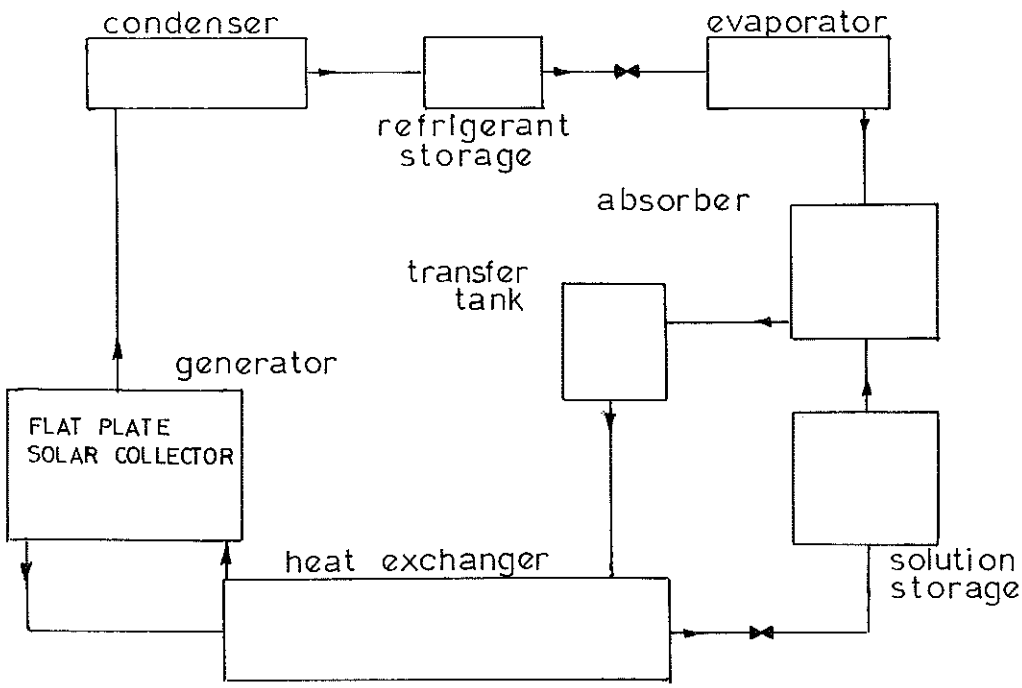

Fig. 1 Layout of vapour absorption refrigerator[9]

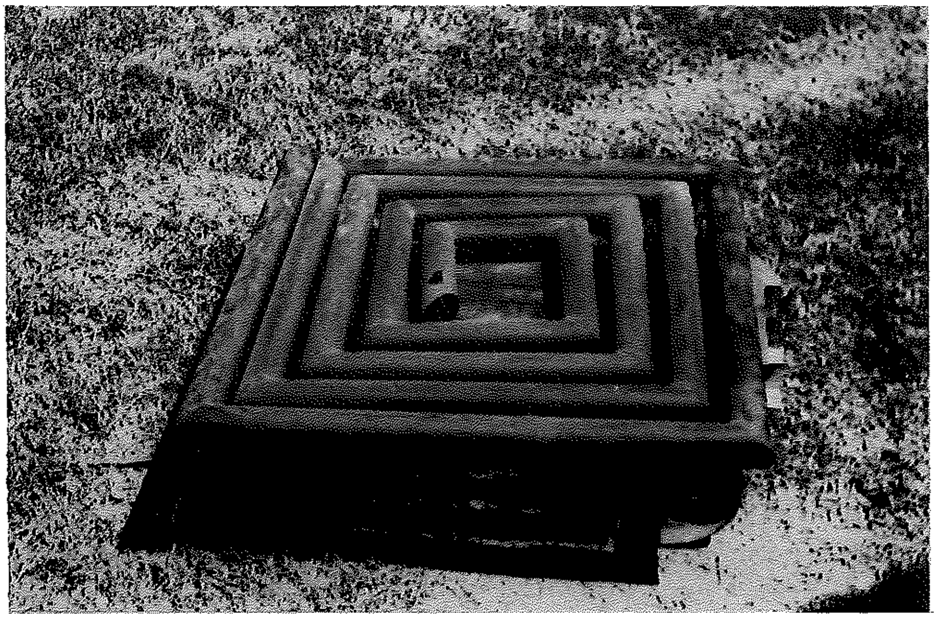

Fig. 2 Collector tube of pressurised water heater[10] (effective area 1200 mm x 1200 mm)

Solar energy studies were revived in 1973, and the seventies saw the development of a wide range of solar energy devices, largely solar collectors for cooking and for water heating. Some innovative work was done in the University of Peradeniya (UP) in designing and constructing conoidal reflector collectors (Fig. 3) and Winston solar collectors [46,47]. The perform-

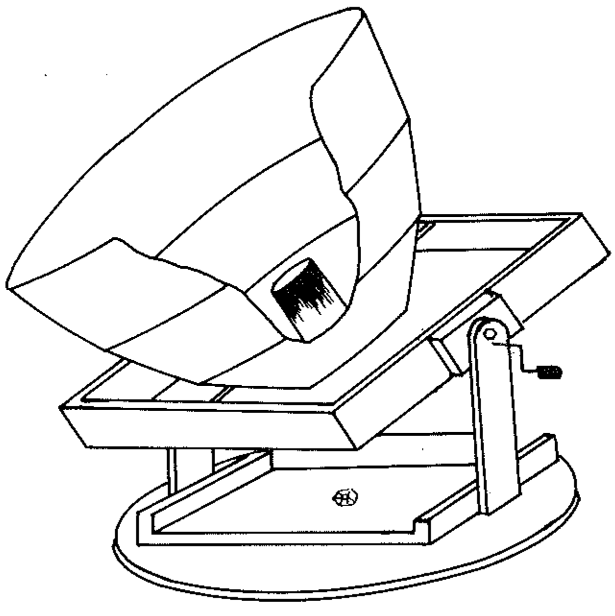

Fig. 3 Conoidal reflector collector[47] (reflector diameter 1430 mm, height 1300 mm)

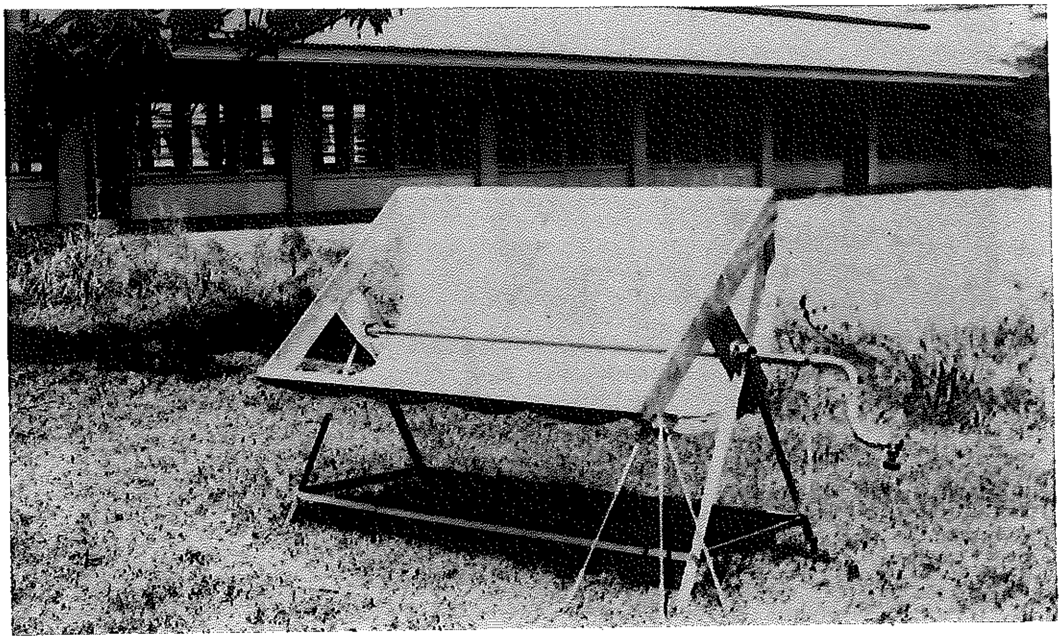

Fig. 4 Reflector-collector tube water heater, University of Peradeniya (effective area 2 m x 1 m)

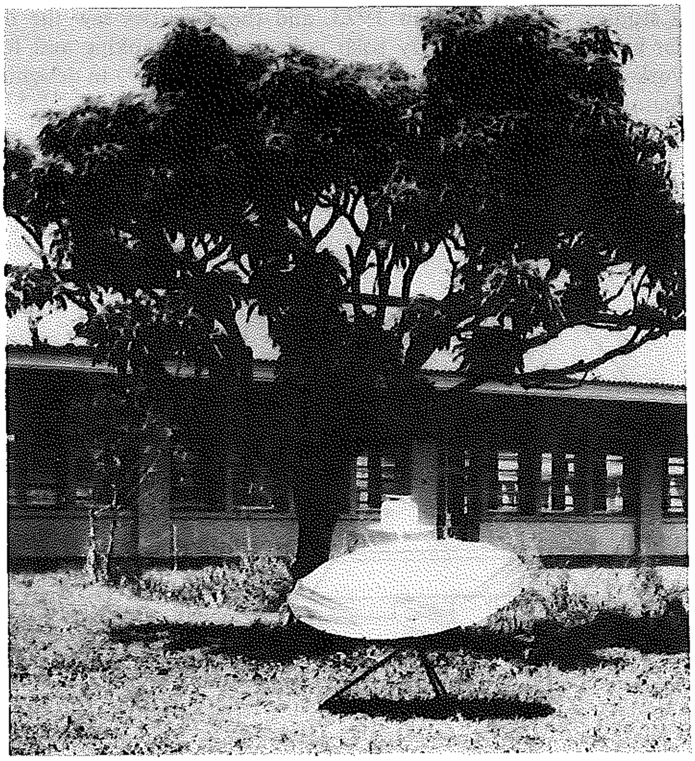

Fig. 5 An imported, commercial design of reflector-collector solar stove

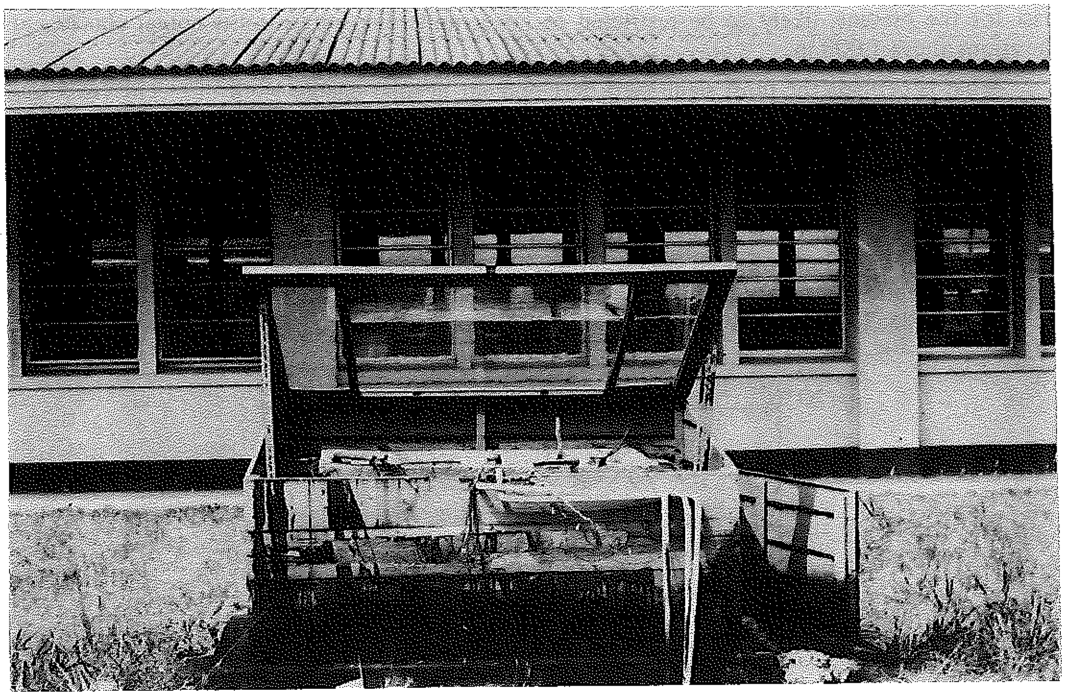

Fig. 6 Model pond for testing stability of NCSP[27]

ance of these reflector collectors was marred by the lack of availability of good reflector material, in place of which rather dull aluminum-paper foil was used. The devices gave satisfactory performance with a collection efficiency of the order of 40%. Unpublished work was done at the Ceylon Insittute for Scientific and Industrial Research (CISIR) and at the University of Moratuwa (UM) in developing paraboloidal reflector collectors for cooking purposes. The main emphasis of the work was on developing solar devices which were low in cost and could be fabricated with ease using locally available materials. There was a considerable slackening in innovative efforts relating to solar devices after 1976, when the emphasis shifted to the study of the physics and the analysis of the behaviour of solar energy systems.

Wijeysundera[41 45] made valuable contributions to the study of the transient behaviour of solar collectors and of the performance parameters of solar collectors. Theoretical studies of the thermal trap collectors of the non-convecting solar pond (NCSP) types were initiated by Samuel at UP [27 28 38] The studies were extended to the generalised behaviour of stable thermal trap collectors[29] and to investigations of the stability of the pond, using a model pond of 1 m^2 surface area and 0.3 m depth[27]. Proposals exist for the development of an experimental prototype pond at UP and for the setting up of soalr ponds close to salterns along the coast of Sri Lanka, where brine rich in $MgCl_2$ is available in abundance as a waste product[27].

Most of the development activity in solar energy relates to flat plate collectors. Experimental models of solar collectors with an area of 1 m^2 to 3 m^2 are being developed by the Department of Agriculture (AD) for crop drying using hot air. Use of flat plate collectors for heating water for parboiling paddy at 90°C is under exploration at UP. Commercial designs are available for reflector collectors for cooking and for flat plate collectors for domestic water heating. The technological know-how available for the design and manufacture of domestic appliances such as water heaters and solar cookers is good. However, the demand for these appliances is small – and is, at least for the present, likely to be restricted to larger units like hotels in the colder climates at elevations above 1,000 m.

What is perhaps the most significant development in solar energy work in recent years was the recognition of the need for a systematic survey of the availability of solar radiation throughout the island. The meteorological data available relate to records of sunshine hours at the various meteorological stations in the island. There are, in addition, records of sunshine hours collected at agro-meteorological stations. Although these figures do not correctly represent the net solar radiation at the stations, theoretical correlations do exist. Srikanthan and Samuel[26] estimated the mean daily radiation, averaged over a month and averaged over a year, on the basis of existing data and theoretical correlations [24]. The results, available in the form of annual mean values [25], are shown in Fig. 7. Monthly mean values are available in Ref. 25.

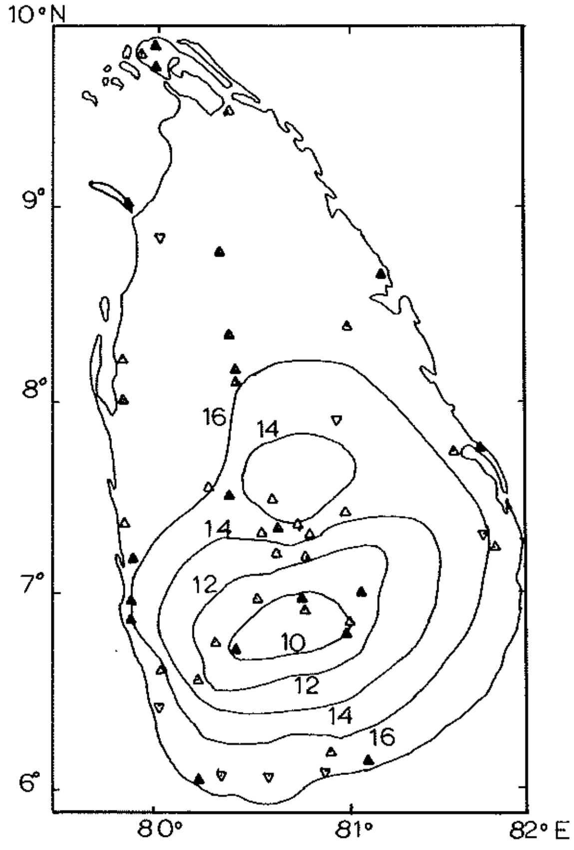

Fig. 7 Radiation map for Sri Lanka[26] (Contours refer to mean annual radiation in MJ/m^2. d). ▲ meteorological station; △ agrometeorological station; ▽ minor agrometeorological station.

The Energy Village project, sponsored by the United Nations Development Programme (UNDP) and managed by the Ceylon Electricity Board (CEB) in Pattiapola (see map, Fig. 8), encompassing solar, wind and biogas technologies, has facilities for recording both sunshine hours and radiation intensity. Some records are available for the diurnal and seasonal variations of solar radiation at the station.

The bulk of the work on solar energy in Sri Lanka relates to passive solar devices and to theoretical studies and radiation measurements. The lack of development of active solar devices is partly the result of the absence of an electronics materials industry. Imported solar appliances have been demonstrated [19] and occasionally tested without any significant consumer demand. The most important active solar equipment installed is at the Energy Village. A solar panel of 2 kW peak power has been installed and tested and a Rankine engine generator with a reflector collector, and eventually 7.5 kW peak power is to be installed. The solar panel is not used in supplying electricity to the village of Pattiyapola for want of an invertor to convert DC electricity into AC at 230 V and 50 Hz[31]. No serious study of the economics of solar energy equipment has so far been undertaken, and it may be reasonably expected on the basis of current activity that solar energy will for some considerable time be restricted to passive systems such as water heaters and air heaters.

WIND POWER

The available meteorological data for Sri Lanka suggests that wind speeds have an annual average value ranging from 2.2 m/s to 5.5 m/s[15] (see Fig. 8). There are, of course, locations

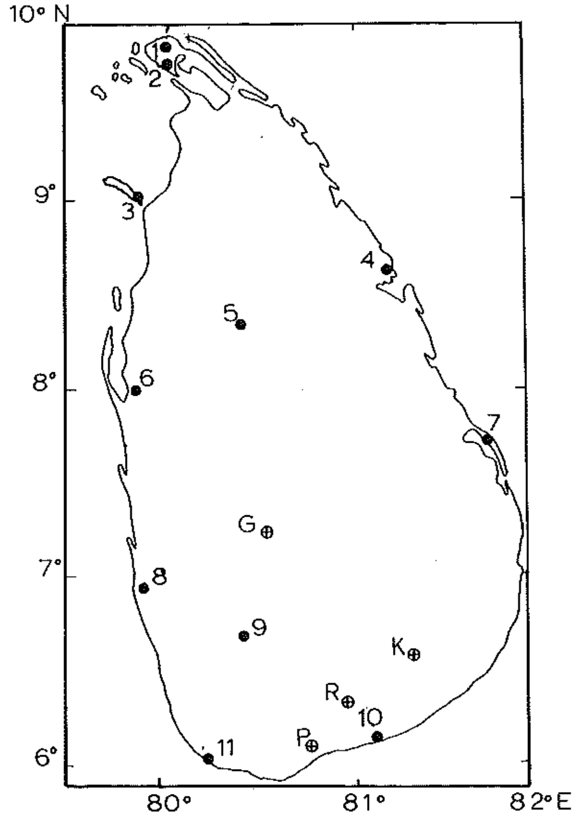

Fig. 8 Reference map for wind measuring stations and stations referred to in the text. (Wind measuring stations are referred to by number and others by letter. Annual mean wind velocities in m/s are listed below after name of station). 1-Kankesanturai, 4.1; 2-Jaffna, 4.2; 3-Mannar, 3.7; 4-Trincomalee, 4.5; 5-Anuradhapura, 2.2; 6-Puttalam, 3.2; 7-Batticaloa, 2.7; 8-Colombo, 2.3; 9-Ratnapura, 2.2; 10-Hambantota, 5.5; 11-Galle, 3.7. G-Gannoruwa; K-Kataragama; P-Pattiyapola; R-Ridiyagama.

in the central highlands where the wind speeds are in the region of 10 m/s or more. This, however, is of little significance in developing wind energy on a national scale. No systematic study of wind velocity variations has been undertaken so far, and the data available are for monthly mean values[15]. No studies of intermittency and of the wind boundary layer have so far been made.

Despite the generally low wind velocities available near Colombo, the Dutch colonial government (1658–1796) installed a windmill near Colombo for the purpose of pumping sea water to flush the streets of the city of Colombo. There was no serious interest in wind power until the middle of this century. In 1948 five horizontal-axis windmills were installed in a livestock farm owned by the government at Ridiyagama for water-pumping. In subsequent years windmills were installed in Tondamanaru and in Urelu in the Jaffna peninsula and near Kataragama in the south. The Tondamanaru windmill, 9.2 m in diameter, is so far the largest windmill to be installed in Sri Lanka. All these windmills were not in working condition and were considered too expensive to repair[20]. In 1979, one of the Ridiyagama windmills was repaired and put into operation by the Wind Energy Unit (WEU) of the Water Resources Board (WRB).

Active interest in wind power was revived in the seventies. Some Savonius-type windmills made from oil-drums were developed by the Industrial Development Board (IDB) in 1974. The National Engineering Research and Development Centre (NERDC) sponsored the development in 1975 of a slow-running 4-bladed horizontal-axis windmill at UM. The power coefficient of this windmill was below 5%, and despite some innovative features relating to the reciprocating mechanism and the pump design, the windmill-pump did not gain acceptance. The Department of Irrigation (ID) developed a larger water-pumping windmill of the American multiblade type.

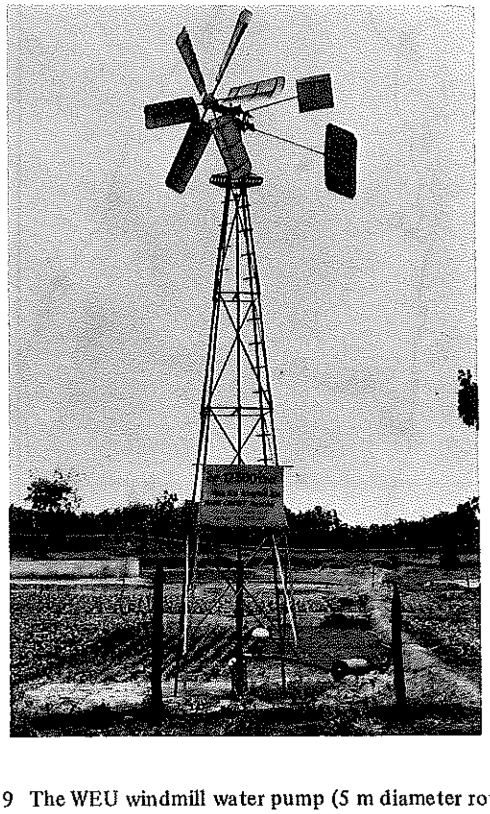

Fig. 9 The WEU windmill water pump (5 m diameter rotor)

But this project was abandoned after a few years. Imported windmills were installed in some parts of the island under foreign aid schemes by organizations such as the Sarvodaya Movement. These windmills failed to make any serious impact on the development of wind power.

The main thrust in developing wind energy in Sri Lanka came as a result of a collaborative programme between the governments of the Netherlands and of Sri Lanka. The WEU was set-up in 1977 at the ID and transferred to the WRB in 1978. After a considerable amount of work on a wide range of designs of rotors and reciprocating pumps, two sizes of windmill-pumps with rotor diameters of 3 m and 5 m (rated at 60 W and 150 W, respectively, at 4.4 m/s) were made commercially available. Between 1979 and 1982, over one hundred windmill-pumps have been installed throughout the island, and many of the pumps are in good working condition. The windmills, costing US$ 750 at present, are expected to cost considerably less when production is transferred to local smiths' shops. At present the consumers are given a 20% subsidy on the price of the windmill-pump.

Commercial designs of horizontal-axis windmills for water-pumping and for the generation of electricity have also been developed by the National Energy Research and Development Centre (NERDC). The rotors are rated for 50 to 100 W power output.

Four Dunlite-2000 windmill-generators rated at 2 kW at 11 m/s wind speed were installed at the Energy Village at Pattiyapola. The available wind speeds at the erected elevation of 20 m are much lower than the design wind speed. The output has not been measured and the power supplied is not available to the village for want of a DC to AC invertor.

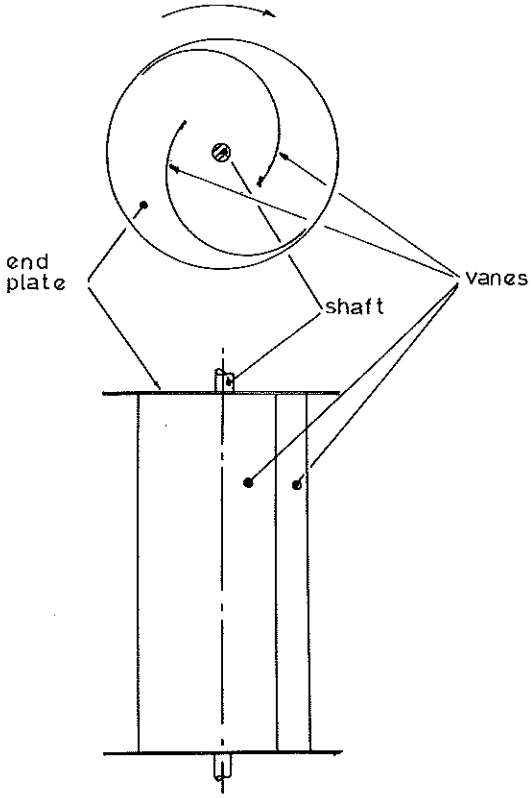

Fig. 10 Sectional plan and elevation of Savonius rotor

Work on Savonius-type rotors has been in progress at UP since 1974. The work comprised laboratory investigations and theoretical studies. Tests conducted on well over three hundred model rotors of the Savonius-type, with a number of blades ranging from two to six, resulted in improved sectional geometries for Savonius-type rotors, with power coefficients of 0.22 compared to 0.15 for the conventional Savonius rotors. Power augmentation in Savonius-type rotors using concentrator ducts, and the use of wind deflector vanes for power augmentation, were carried out by Sivapalan and Sivasegaram. The findings are presented in summarised form in Refs. 32 and 33. Subsequent investigations included the use of diffusers for power augmentation[34]. It has been shown that power augmentation by a factor of 1.7 to 1.8 is possible with the aid of simple and compact augmentation facilities. No prototype wind rotors have been developed at UP, although Tachi[39] has developed a wind-powered generator using a Savonius-type rotor of optimum sectional geometry determined by Sivasegaram at UP. The studies at UP also include the transient behaviour of wind energy systems[35] and the design of a self-regulating variable-stroke device for windmill water-pumps[36]. The system ensures that the windmill operates at peak power coefficient at all wind speeds, and permits the rotor to operate over a far wider range of wind speeds than is possible with a pump of fixed stroke.

Wind velocity data from meterological stations are generally obtained at 6 m above ground level. Following the cyclone which struck the east coast of the island in 1978, steps were taken to install anemographs for continuous recording of the velocity variation at 20 m above ground level. The two major meteorological stations along the east coast, at Trincomalee and at Batticaloa, have been equipped with these facilities since 1981. The WEU is planning an islandwide wind energy survey using all available data including that from the Meteorological Department. The WEU has its own wind recording facilities at several stations where WEU windmills have been installed. The records, however, are not always satisfactory[16].

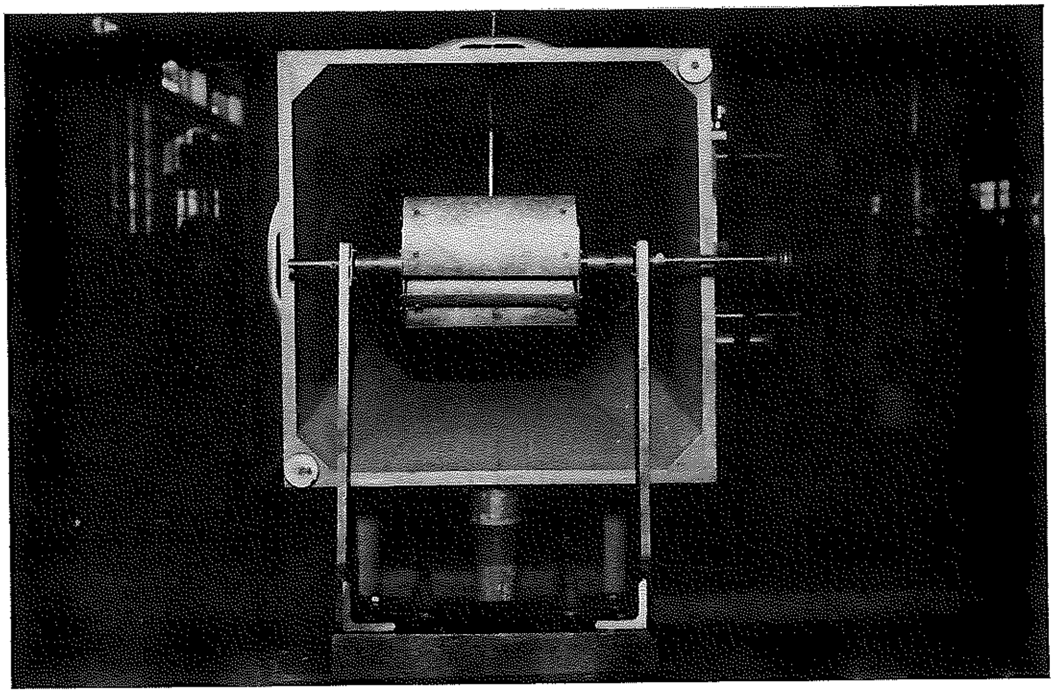

Fig. 11 Wind-tunnel tests at the University of Peradeniya

Although no extensive study of the economics of wind power has so far been undertaken, Buch-Larsen and Mueller[3] have made a case for subsidy for windmills on the basis of the state subsidy for kerosene, until recently sold at nearly half the price of other petroleum products, and often used in engines for operating water-pumps.

BIOGAS

Interest in biogas dates back to 1973, when an Indian design (Fig. 12) was first introduced into the country. Since then twenty-five digesters of the Indian type, with a gas storage capacity ranging from 1 m^3 to 85 m^3 have been installed. However, of these only five, including the 85 m^3 unit at the CEB Energy Village at Pattiyapola and the 20 m^3 unit at the Agriculture Department (AD) Research Station in Gannoruwa, are still in operation. The latter (see Fig. 13) forms part of an integrated bio-energy system.

Chinese-type digesters (Fig. 14) were first introduced in 1976 and have rapidly overtaken the Indian design because of their relatively low cost, ease of construction and ease of maintenance.

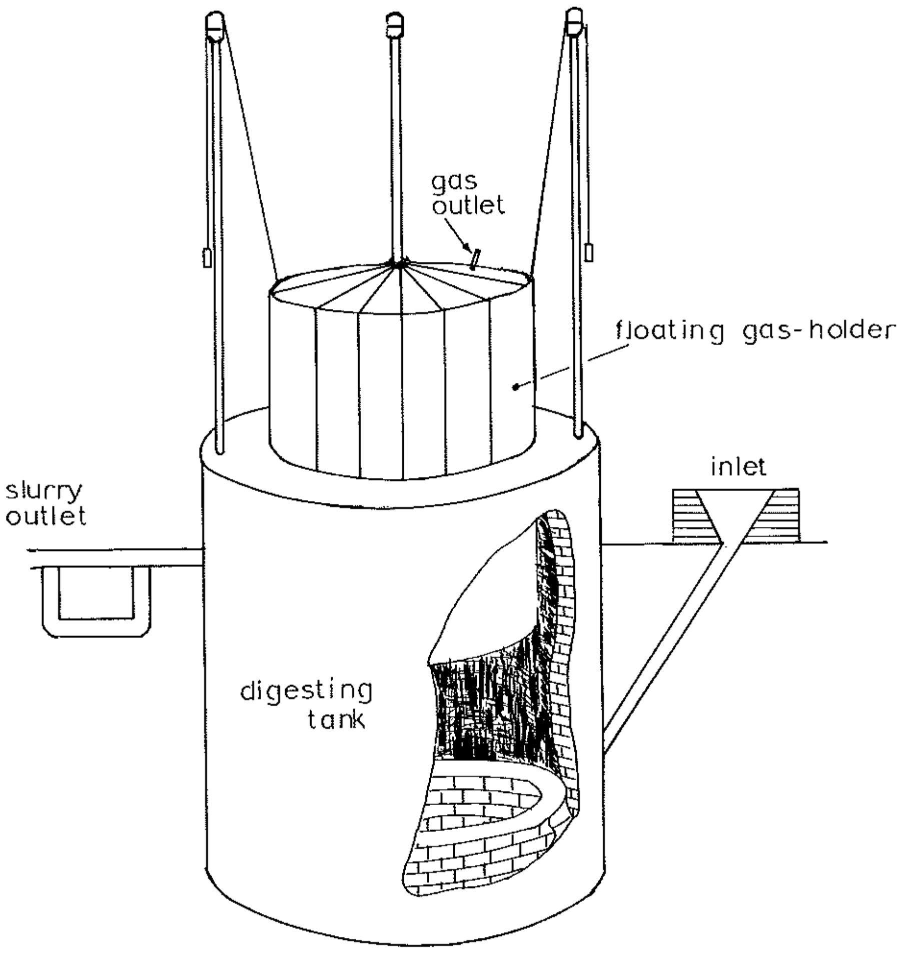

Fig. 12 Indian design of biogas generator

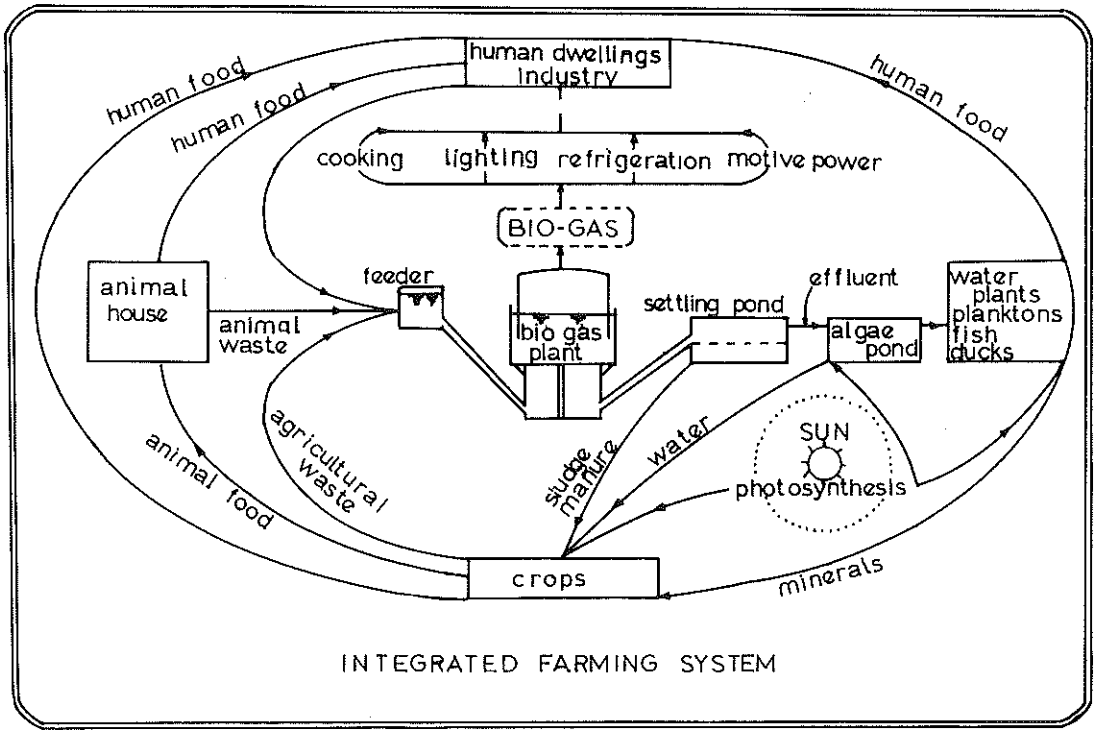

Fig. 13 Layout of integrated biogas system, Gannoruwa

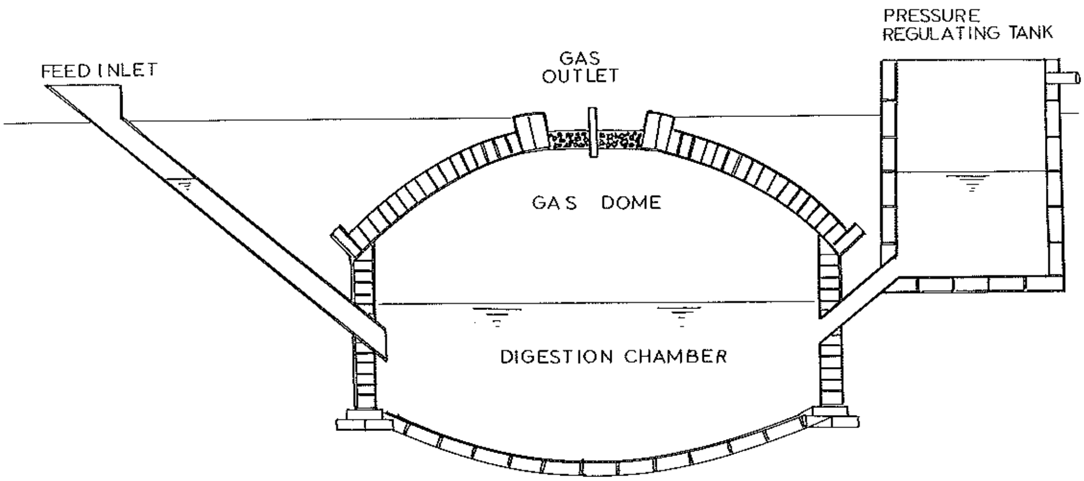

Fig. 14 Chinese design of biogas generator

The sizes of the units range from 2 to 10 m^3 gas storage. Larger units, although economical, do involve more sophisticated design of the gas dome, which in small units is a self-supporting structure like a masonary arch. Of over three hundred units installed, just over a hundred are in operation. The failure of the others is directly attributable to the fact that the bulk of the units were installed at state-sponsored institutions such as schools, where very little continued interest exists in the subject.

The bulk of the units installed were by the CEB and the IDB, and the AD has provided consultative assistance in several projects undertaken outside the state sector. Ameratunge at the UP, and the AD (Gannoruwa), have done considerable work in developing integrated energy systems [1, 2] and in the use of plant waste in biogas digesters.

The use of biogas is largely for cooking, and in some instances for lighting, especially where there is no access to electricity. The Energy Village in Pattiyapola uses its gas output entirely for generating electricity (50 kW, 230 V, 50 Hz). The gas stoves are generally made of cast metal. No attempts have so far been made to make them out of clay. The lamps are made by adapting kerosene vapour lamps, which are commercially available. The other major benefit from biogas, relating to hygienic disposal of human and animal waste, has not received much attention. Nor have serious quantitative studies of cost-benefit been undertaken.

USE OF AGRICULTURAL WASTE

Recycling of agricultural waste to produce usable forms of solid fuels (like briquettes) has been investigated since the seventies. In the early seventies some rice mills used the paddy husk waste from the mills as fuel in boilers for parboiling paddy. This practice has now gained wider acceptance. However, paddy husk is not a suitable fuel for use in conventional boilers for generaing steam.

Paddy husk, paddy straw, coir dust (from coconut husk used in coir-fibre industries), rubber and coconut tree-trunks and uprooted tea bushes are amongst major agricultural waste products. Coconut and rubber tree-trunks are used in several applications, including their use as fuels. Uprooted tea bushes are used as firewood in the plantations. Paddy husk and straw are not effectively used as fuels, and the high silica content poses some problems in industrial use. A portion of the paddy straw is used in making paper. Coir dust has for a long time been a waste product with some waste disposal problems.

Besides the major agricultural waste items listed above, a considerable amount of sawdust, wood shavings and chappings are available from saw mills and timber-related industries. Simple designs of sawdust stoves were developed in the seventies, and a wide range of designs are still in use. Some of the timber waste, in the form of large chips, is converted into charcoal and used in charcoal stoves, which are relatively free from soot and smoke.

Recently, Mannapperuma[22] successfully trial-produced briquettes out of coir dust and estimated that the coir dust available from the local coir industry, by and large a rural industry, is adequate to replace 80,000 t of petroleum fuel per year. Although this is equivalent to a third of the oil imports to Sri Lanka, the use of coir dust involves problems of transport and is likely to be confined to power plants of modest size[21]. The economics of briquetting is another aspect which has been overlooked.

Work on generating producer gas from coir dust has been in progress since 1978, and the CISIR and NERDC have developed producer gas units capable of developing 5-10 kW of power. Jayatilleke and Kulasiri at UP have designed and developed a larger unit for developing 40 kW[21]. The producer gas generated is used in petrol engines. Although many of the problems relating to the use of coir dust in gas producers have been successfully overcome in those of moderate size, the difficulties relating to tar, fine dust and removal of moisture are likely to be

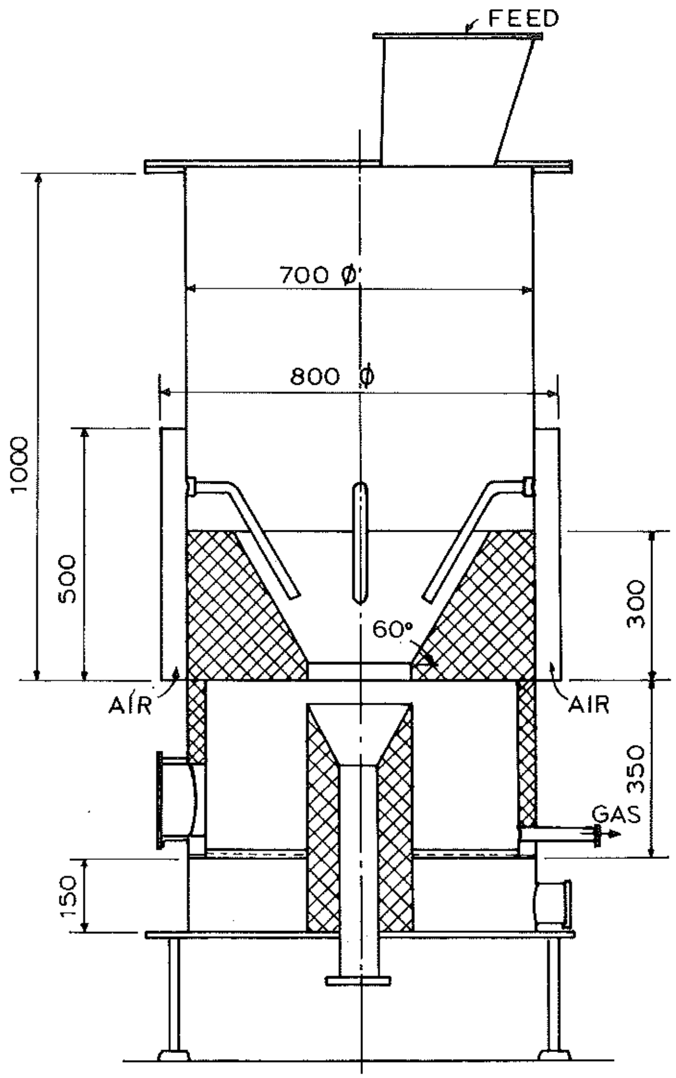

Fig. 15 Coir dust gasifier[21]

significant in larger units. The extension of this work to other forms of waste such as paddy straw has yet to be undertaken.

SMALL HYDROPOWER PLANTS

Small hydro-turbines were used in tea plantations in the hill country until two decades ago. Chandrasinghe[4] estimates that machines with a total installed power of 5.5 MW are still in existence, but in a state of disuse, in the plantations. The total power which can be effectively and economically extracted from small hydropower plants may be placed at a few hundred GWh per annum. (Estimates are rather subjective and vary widely from one information source to another).

The NERDC has developed some designs of the Banki cross-flow turbine for hydro-power generation[17]. Banki turbines are suitable for low power ranging from a few kilowatts to the order of a megawatt and have an efficiency of 60-65%, compared to over 80% for other designs which are more suitable for larger units. Chandrasinghe[4] advocates the use of Chinese designs which cover a very wide range of flow and head conditions and are backed by substantial experience in the field.

ON OTHER ALTERNATIVES

A revival of animal muscle power applications has been advocated since the seventies. However, this has failed to receive popular acceptance in the context of the relatively low cost of fossil fuel.

Reafforestation has been accepted in principle by all governments from the time of national independence as an essential requirement for the conservation of soil and water resources. Despite this recognition, the extent of forest land is continuing to shrink, and the completion of the Mahaveli project will lead to a further clearing of 25,000 ha[40]. The resources at the disposal of the Forest Department do not seem adequate to meet the crisis. The relevance of reafforestation to the hydropower potential of the rivers can hardly be overstated.

Ocean Thermal Energy Conversion (OTEC) was proposed as a serious alternative in the late seventies and the prospects of developing OTEC were studied by the Solar Energy Group (now defunct) of the National Science Council[14]. The existence of at least six suitable sites was recognised, between Trincomalee on the east coast and Dondra on the south coast (where the sea floor drops on a line to 1 km below sea level over a distance of 15 km from the coast). The available temperature difference was around 20°C, with the surface at 25°C. The economic feasibility of the project was found to be rather poor and the report ruled against the development of OTEC in the near future.

A case for nuclear power has been made for well over a decade[12]. The desirability of developing nuclear power was studied by a committee of the National Science Council[18], and the report recommended that nuclear power development is not desirable in the near future. The main considerations related to lack of trained personnel and to the possibility of accidents and problems in waste disposal and related risks. The report did not entirely rule out nuclear energy but left it as the last, if inevitable, option.

CONCLUDING REMARKS

Alternative energy work in Sri Lanka is at quite an advanced stage in matters relating to the availability of technical know-how and to research activity. The utilization of available alternative energy resources is poor: the total wind energy utilization amounts to 200 MWh per year, at most, and the energy from biogas (converted to the equivalent electrical energy using a factor of 0.3) amounts to approximately 1,000 MWh; solar energy utilization is insignificant. Little attention is paid to the conservation of natural resources, and there is very little public awareness about the economic use of fuel.

The need for developing alternative energy resources cannot be effectively communicated to a people who are not adequately aware of the economics of energy use. There is a serious need for a systematic economic assessment of each energy technology and energy conversion device. There is also a need to make a proper survey of the alternative energy potential in each area and have a realistic idea of the cost of the extraction of energy.

It is unlikely that solar energy and wind energy will play any significant role in solving the national energy problem. However, there are several rural and farm applications where these technologies can contribute to significant saving in fuel and to increased productivity. The use of biomass (both biogas and producer gas) has a greater potential. However, serious cost-benefit studies should be undertaken before plants are set up.

There is a wide communication gap between the planners, the reaseach workers and the manufacturers of alternative energy equipment. Better coordination and more collaborative effort could save both money and effort spent on unproductive projects.

The overall contribution of the past two decades of work on alternative energy is significant, and the experience already gained in applying the technology is adequate for avoiding unnecessary mistakes and for extracting the maximum from available energy resources.

ACKNOWLEDGMENTS

The author is grateful to Prof. M. Amaratunge of the University of Peradeniya, Mr. K.S. Fernando of the Wind Energy Unit, Mr. B.P. Sepalage of the Ceylon Electricity Board, and Mrs. I. Unamboowa of the IDB (Moratuwa) for their kind assistance in collecting some valuable information. The kind encouragement of colleagues at the Faculty of Engineering, Peradeniya, is also acknowledged with thanks.

REFERENCES

1. AMARATUNGE, M. (1977), A Rational Approach to Biogas Technology Based on the Concept of an Integrated Farming System, *Agricultural Engineering* (Sri Lanka), 1, p. 6 ff.
2. AMARATUNGE, M. (1980), Integrated Biogas Systems, *Reg. J. Energy Heat Mass Transfer*, 2, p. 45 ff.
3. BUCH-LARSEN, B. & A.M. MUELLER (1981), *An Economic Comparison of the Use of Windmills and of Kerosene Pumps*, WEU, Water Resources Board, Sri Lanka, WEU 81-4, 24 p.
4. CHANDRASINGHE, D.P. (1980), *Proc. Energy Policy Seminar*, Institution of Engineers, Sri Lanka
5. CHINNAPPA, J.C.V. & P. SELVANAYAGAM (1975), *Solar Radiation During the Solar Eclipse of Dec. 14, 1955 at Colombo*, Ceylon, *Solar Energy*, 1(4), p. 30 ff.
6. CHINNAPPA, J.C.V. & H. HEYWOOD (1958), Design and Performance of a Pipe Collector with Reflectors for Solar Energy, *Colloque International sur les Applications Thermiques de l.Energie Solaire dans le Domaine de la Recherche et l.Industrie*, Montlouis
7. CHINNAPPA, J.C.V. (1961) Experimental Study of the Intermittent Vapour Absorption Refrigeration Cycle Employing the Refrigerant-Absorbent Systems of Ammonia-Water and Ammonia-Lithium Nitrate, *Solar Energy*, 5(1), p. 1 ff.
8. CHINNAPPA, J.C.V. (1962) Performance of an Intermittent Refrigerator Operated by a Flat Plate Collector, *Solar Energy*, 6(4), p. 14 ff.
9. CHINNAPPA, J.C.V. (1968), Solar Operation of a Vapour Absorption Cycle Air Conditioner at Colombo, *Trans. Institution of Engineers, Ceylon*, 1968, p. 19
10. CHINNAPPA, J.C.V. & K. GNANALINGAM (1969), Pressurised Solar Water Heater of the Combined Collector & Storage Type, *Trans. Institution of Engineers, Ceylon*, 1969, p. 83
11. CHINNAPPA, J.C.V. & K. GNANALINGAM, (1973), Performance at Colombo, Ceylon of a Pressurised Solar Water Heater of the Combined Collector and Storage type, *Solar Energy*, 15, p. 195 ff.
12. DHAMAWARDENE, G. (1980), Nuclear Energy, *Proc. Energy Policy Seminar*, Institution of Engineers, Sri Lanka.
13. EKANAYAKE, A. (1980), Draught Power in Mahaweli, *Proc. Energy Policy Seminar*, Insti-

tution of Engineers, Sri Lanka.

14. FERNANDO, G.B.A., P.N. FERNANDO, J.A. GUNAWARDENA, D.B.J. RANATUNGA, S. SIVASEGARAM & H.S. SUBASINGHE (1980), A Preliminary Study of the Feasibility of OTEC for Sri Lanka, Report, National Science Council.
15. FERNANDO, A.D.N. & P.T. SMULDERS (1976), Wind Energy Utilization in Sri Lanka, Report SWD-76-1, SWD, Amersfoort, the Netherlands.
16. FERNANDO, K.S. & A. MUELLER (1981), Annual Report, WEU, Water Resources Board, Sri Lanka, WEU 82-2.
17. FERNANDO, M.A.R.V. (1982), Some Experiences in Rehabilitation of Mini-Hydro Plants in Sri Lanka, *Proc. Annual Winter Conf., Fluid Power Group, ASME.*
18. GUNAWARDENA, J.A., R.S. JAYATILAKE, G.A. DISSANAIKE, L. DE ALWIS, J.K.P. ARIYARATNE & P.L.T. FERNANDO (1982), *Report on Atomic Energy for Electric Power Generation in Sri Lanka,* National Science Council, Colombo.
19. HERATH, K. & H. FERNANDO (1980), Use of Photovoltaic Cells for Domestic Lighting in Sri Lanka, *Proc. Energy Policy Seminar,* Institution of Engineers, Sri Lanka.
20. JANSEN, W.A.M. (1977-1979), *Wind Energy Utilization Progress Reports* 1-8, Water Resources Board, Sri Lanka.
21. JAYATILLEKE, C.L.V. & G.D. KULASIRI (1982), Gasification of Coir Dust, *Proc. FAO/FHI Regional Technical Consultation on Agricultural Wastes and Solar Technologies for Energy Needs in Farms,* FAO, Bangkok, p. 185 ff.
22. MANNAPPERUMA, J.D. (1981), Processing of Coir Dust as Fuel, *Proc. 37th Annual Sessions, SLAAS,* Colombo
23. PILLANAYAGAM, M.G. (1980), The Source of Energy Available for Agricultural Use and Future Development Patterns, *Proc. Energy Policy Seminar,* Institution of Engineers, Sri Lanka.
24. SAMUEL, T.D.M.A. & R. SRI KANTHAN (1981), A Method of Estimation of Total Solar Radiation for Sri Lanka, *2nd Int. Symp. on Non-Conventional Energy,* ICTP, Trieste.
25. SAMUEL, T.D.M.A. & R. SRIKANTHAN (1981), *Estimation of Solar Radiation for Sri Lanka,* Report EM/81/02, Dept. of Engineering Mathematics, University of Peradeniya, Sri Lanka.
26. SAMUEL, T.D.M.A. & R. SRIKANTHAN (1982), Solar Radiation Estimation for Sri Lanka, *Trans. Institution of Engineers, Sri Lanka.*
27. SAMUEL, T.D.M.A., S. PARAMESWARAN & T. THIRUNAVUKKARASU (1983), Solar Ponds for Sri Lanka, *Trans. Institution of Engineers, Sri Lanka* (to appear).
28. SAMUEL, T.D.M.A. & N.E. WIJEYSUNDERA (1981), Optimum Performance of Thermal Trap Collectors, *Solar Energy,* 26, p. 64 ff.
29. SAMUEL, T.D.M.A. & N.E. WIJEYSUNDERA (1983) Performance of multiple-layer Thermal Trap Collectors, *Solar Energy* (to appear).
30. SANKAR, T.L. & G.B.A. FERNANDO (1977) *Towards an Energy Policy in Sri Lanka,* 1977-1982, Report, Ministry of Planning and Economic Affairs, Colombo.
31. SEPALAGE, B.P. (1980), *Introducing Solar Technology to Rural Communities,* Report, Ceylon Electricity Board, Colombo.
32. SIVASEGARAM, S. (1980), Wind Tunnel Tests on Slow-Running Vertical-Axis Wind Rotors, *Proc. 1st Asian Fluid Mechanics Congress,* Bangalore, India, paper A39.

33. SIVASEGARAM, S. (1982), Improvement of Performance of Slow-Running Vertical-Axis Wind Rotors, *Renewable Energy Review Journal,* 4, p. 36 ff.

34. SIVASEGARAM, S. (1983), Power Augmentation in Savonius-Type Rotors Using Diffuser Ducts, *2nd Asian Fluid Mechanics Congress,* Beijing (accepted for presentation).

35. SIVASEGARAM, S. (1980), Transient Behaviour of Wind Energy Systems, *Wind Engineering,* 4, p. 53 ff.

36. SIVASEGARAM, S. & T. VINAYAGALINGAM (1979), A Variable-Stroke Wind-Operated Water-Pumping System, *Wind Engineering,* 3, p. 127 ff.

37. SIVASEGARAM, S., N.S. JAYARATNE & M.C.M. BAHARDEEN (1975), Muthurajawela Peat: An Investigation of Some Problems Relating to its Use, *SLAAS Symposium on Student Projetcts.*

38. SIVASEGARAM, S. & N.E. WIJEYSUNDERA (1978), Transient Thermal Behaviour of Solar Ponds, *Reg. J. Energy Heat Mass Transfer,* 1, p. 7 ff.

39. TACHI, O. (1979), *Wind Power Generator,* Japan Wind Power Generator Co., Tokyo

40. VIVEKANANDAN, K. (1980) Wood Fuel, *Proc. Energy Policy Seminar,* Institution of Engineers, Sri Lanka.

41. WIJEYSUNDERA, N.E. (1975), *A Net Radiation Method for the Transmittance and Absorption of a Series of Parallel Regions, Solar Energy,* 1, p. 75 ff.

42. WIJEYSUNDERA, N.E. (1976), Response Time of Solar Collectors, *Solar Energy,* 18, p. 65

43. WIJEYSUNDERA, N.E. (1978), Geometric Factors for Plane Specular Reflectors, *Solar Energy,* 20, p. 81 ff.

44. WIJEYSUNDERA, N.E. (1978), Comparison of Transient Heat Transfer Models for Flat Plate Collectors, *Solar Energy,* 21, p. 517 ff.

45. WIJEYSUNDERA, N.E. (1977), Effect of Angular Misorientation on the Performance of Solar Concentrators, *Solar Energy,* 19, p. 583 ff.

46. WIJEYSUNDERA, N.E. & T.T. CHANDRATILLEKE (1977), Design and Performance of a Winston Solar Collector, *Engineer (Sri Lanka),* 5(4), p. 23 ff.

47. WIJEYSUNDERA, N.E. & S. SIVAPATHSUNDARAM (1976), Design and Performance of a Conoidal Solar Collector, *Engineer (Sri Lanka),* 4(3), p. 30 ff.

48. DE SILVA, N.A.T. (1982), *Compendium of Research and Development Projects in SRI LANKA on Energy Related Problems,* National Science Council, Colombo, 1982.

Appendix :
Current Research and Development Activities in Alternative Energy in Sri Lanka

Institution	Nature of Activity	Person in Charge
Department of Agriculture Sri Lanka School of Agriculture, Angunakolapelassa	low-cost biogas units; solar cookers and hot water systems.	Mr. G.K. Upawansa
Farm Mechanization Training Centre, Anuradhapura	crop drying using flat-plate solar collectors.	Engineer-in-Charge
Farm Mechanization Research Centre, Mahailluppallama	crop drying using flat plate solar collectors.	Engineer-in-Charge
Ceylon Electricity Board,	biogas for generating electricity; applications of biogas biogas from paper effluents; biogas from water plants, rural energy centres; solar energy laboratory; windmills for electricity and water pumping; producer gas.	Mr. H.S. Subasinghe
Ceylon Institute for Scientific and Industrial Research, Colombo	efficient use of wood fuel; carbonization of crop residue; producer gas from coir dust;	Dr. D. de Silva
	solar desalination; solar drying; solar steam cooker; solar refrigeration;	Dr. S.A. Abeysekera
	biogas from cellulosic material.	Dr. S.P. Amerakone
Coconut Research Institute, Lunuwila	coconut shell and trunk for thermal power; coconut oil as fuel.	Dr. S. Mohanadas and Dr. U. Samarajeewa
Colombo Gas and Water Company, Colombo	peat gasification.	Mr. U.C.S. Fernando
Industrial Development Board, Moratuwa	biogas development and appliances; efficient use of firewood.	Mr. I. Cooray and Mr. S.K. Rajapakse
National Engineering Research and development Centre, Ja-Ela	coir dust gasifier; biogas; hydrogen burner; improvement of bullock cart; banki turbines and propeller turbines for hydropower; solar hot-box domestic cooker; industrial preheating and steam from solar energy; evaluation studies on OTEC and on photovoltaic cells; windmills for water pumping and storage of electricity.	Dr. A.N.S. Kulasinghe
Rubber Research Institute, Ratmalana	solar drying of crepe rubber.	Mr. S.W. Karunaratne
State Timber Corporation, Colombo	charcoal from wood.	Mr. N.B. Jayasiri
University of Moratuwa (Dept. of Mech. Eng.), Moratuwa	windmill pump; solar refrigeration; solar cooker; solar water heater photovoltaic cells for lighting; solar tracking.	Mr. K. Herath

Institution	Nature of Activity	Person in Charge
University of Peradeniya (Faculty of Engineering), Peradeniya	biogas; feasibility of mini-hydro power.	Prof. M. Amaratunge
	solar pond; radiation measurements.	Prof. T.D.M.A. Samuel
	wind power studies.	Prof. S. Sivasegaram
	producer gas from coir dust; solar energy for parboiling paddy.	Prof. C.L.V. Jayatilleke
Wind energy Unit, Water resources Board, Colombo	windmills for water pumping and for electrical power; wind energy survey.	Mr. K.S. Fernando

Note:
The above data was obtained mainly from the findings of a survey on energy projects in 1981, by the National Science Council[48]. More recent information was compiled by the author. The list of activities is only an indication of the range of activities at instutions working on energy related projects.