Power Supplies

by E. W. Golding

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Power Supplies

Lack of mechanical power is not the sole cause of underdevelopment, but it is certainly one of the causes. This booklet examines the possibilities of providing more power for development, of distributing it to the potential users and of ensuring that it improves the national economy.

The implications of power supplies are also outlined – the social as well as the economic effects, the possibilities of establishing new rural industries, the credit facilities needed to finance small power plants, the transport of fuel and transmission of power, the national and local planning involved.

After defining power and explaining the methods of converting fuel, whether coal, oil, wind, sun or water, into energy, the booklet compares the costs and limitations of large and small power plants. So great is the cost of bringing power to vast and scattered populations that attention is given to the more unusual methods of generating power – solar generators, windmills and plants running on organic waste. But no attempt is made to gloss over the limitations of such methods; the sun only shines at certain times of day and at certain seasons, the wind may be strong enough only on exposed hills, water power may only be available at certain times of the year so that machinery lies idle during the dry period.

The booklet also covers questions of transport, power transmission costs, surveys, uses for electric power once installed, maintenance costs, location of plant and the training and education of technicians and public.

This outline of the possibilities and limitations of a variety of power plants is important not only to those in the immediate field of energy supply; it is useful also to people working in related fields such as community development, education, transport, finance and development planning. It is important, in fact, to all who wish to speed their country's development through the application of scientific knowledge.

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by E. W. Golding

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Foreword

by Sir William Slater

The speed and the efficiency of economic development in any country depend on the wise application of science and technology. The ill-considered use of these powerful tools will, with equal certainty, delay progress and lead to waste. Almost every step to improve the standard of living and the general welfare of a nation involves, in the modern world, the proper application of the basic principles of some branch of science or technology. It is not enough to *adopt* that which has proved successful elsewhere, it must be *adapted* to local conditions of physical environment, to the state of economic development and to the character of the people. It is vitally important, therefore, that the Ministers who decide national policy, the Government Servants who implement it and as many as possible of those who are affected by it, should have a broad general knowledge of what is involved in any scheme of development.

There is never enough either of money or of men to do at one time everything which seems desirable or even necessary. A choice must be made between rival plans, each appearing to offer advantages and each supported by technical evidence from the experts putting it forward.

A Minister, with the help of the senior administrators in his department must make the decision; to do so with reasonable confidence, he and his immediate staff must master at least the elements of the underlying science. He will, of course, have his technical advisers, but they are almost always involved as the advocates for one of the rival plans. Moreover, each speaks in his own technical language often only partially understood by those who listen.

Time is always pressing; a decision must be made, not some years ahead after careful study, but today or at best tomorrow. There is no time to browse in a library, to try to learn the technical language, to find amongst the great mass of scientific knowledge just those simple facts which will enable the conflicting evidence to be understood and fairly judged.

Those who have to make and implement major policy decisions need a simple chart, which will enable them to find their way with reasonable certainty in the complicated and changing world of science and technology. They must know the right questions to ask and be able to understand answers expressed in the language of technology.

It is the object of the series of pamphlets published by the Overseas Development Institute (of which this is the first) to provide such a chart. Each pamphlet will deal with a limited field of development explaining in non-technical language the scientific principles involved, the results which may be expected from the application of these principles, the order of the steps, which must be taken to achieve their successful implementation and perhaps most important of all, the pitfalls to be avoided.

No attempt is made to state any definite path to progress because this, in the end, must be determined by economic and sociological factors which differ for each nation. The way to success can be found only in the skilful use of science and technology to exploit the economic strength of the nation, its natural resources, its geographic position and the qualities of its people.

Rapid development often calls for sacrifices from the people. It may be that for a time harder living conditions must be accepted or that long cherished traditions and ways of life will have to be forgotten. It is vital that the people should know what is involved in any change and be able to weigh immediate loss against future gain. However wise a decision may be, if the people do not accept it, the plan involved is doomed to failure. To tell the people the full story in simple language the Minister must himself have mastered fully the details of any scheme of development. Those which arise from economic and other conditions peculiar to his country he will know, the basic science and technology he must learn.

His task, however, will be made far lighter if a section of public opinion is already well informed. Herein, it is hoped, lies the second and equally important use for the Overseas Development Institute pamphlets, in making available to the leaders of public opinion – politicians, professional men and teachers – in a cheap and easily comprehended form the basic knowledge required to form considered judgements on Government policy. These will help to prepare the people as a whole for policies, which although wisely chosen may at first seem to offer little or even to call for the loss of some of the advantages they already enjoy.

The production of these pamphlets has been inspired by the experience of some of those responsible for the establishment of the Overseas Development Institute. They know how the desks of every Minister and senior Government Servant are showered with papers which must be ready for tomorrow's meeting and how long reports and technical books lie collecting dust on the side table awaiting the spare day that never comes when they can be read. The aim has been to keep the pamphlets so condensed that they can be read virtually as committee papers immediately before the information they contain is required. It is hoped that they will find their place on a shelf in the office of every administrator, for ready reference when they are most urgently needed.

Introduction

Although it is only one of several basic needs in present-day civilised life, an abundance of mechanical power, in its different forms, is perhaps the most obvious mark of a developed society. Without power – for transport, for cultivation of the land, for industry and for domestic use, a community remains 'primitive'. In spite of some exceptions when communities, possibly for religious reasons, lead a fairly comfortable and healthy existence in complete simplicity, in the main, power is an essential ingredient of a good standard of living.

The annual amount of energy used, per head of population, has come to be accepted as a measure of development. A report prepared a few years ago by a group of experts for the Organisation for European Economic Co-operation (O.E.E.C.) began with the statement: 'Man's increasing use of energy in the provision of heat, light and power has characterised the development of civilisation' and later continued, 'Today manual labour supplies only one per cent of the energy used in the world and the amount of energy used per capita gives an accurate idea of the stage of development reached by different countries. In fact, the average income in each country, and thus its standard of living, is closely related to the consumption of energy per capita and productivity depends on the number of horse-power used per worker.'

The figures given in Table I illustrate the relationship between the use of electrical energy and the national average annual incomes.

TABLE I
ELECTRICAL ENERGY CONSUMPTION AND INCOME (1960)

Average annual electricity consumption	Countries grouped according to electricity consumption per head	Total annual consumption of group	Total population of group	Average income per head
kWh per head		Millions of kWh	Millions	£ sterling
Over 4,000	Norway Canada U.S.A. Sweden Luxembourg	1,024,744	209.9	780
2,000–4,000	Switzerland Iceland New Zealand Germany, E. United Kingdom Australia Austria	238,720	94.9	385

Average annual electricity consumption	Countries grouped according to electricity consumption per head	Total annual consumption of group	Total population of group	Average income per head
kWh per head		Millions of kWh	Millions	£ sterling
1,000–2,000	Germany, W. Finland Czechoslovakia S. Africa Belgium France Netherlands U.S.S.R. Japan Denmark Italy Israel Puerto Rico Korea, N.	728,614	530.3	240
500–1,000	Poland Ireland Hungary Venezuela Bulgaria Chile Spain Trinidad	67,730	95.5	175
250–500	Uruguay Yugoslavia Argentina Cuba Rumania Singapore Rhodesia Cyprus Hong Kong Brazil Costa Rica Portugal Formosa Mexico Peru Greece	82,779	221.5	96
100–250	Panama Columbia Lebanon Aden Congo Malaya Bolivia Albania Jamaica Iraq Dominican Rep. Nicaragua El Savador Algeria Turkey	14,942	98.8	53

Average annual electricity consumption	Countries grouped according to electricity consumption per head	Total annual consumption of group	Total population of group	Average income per head
kWh per head		Millions of kWh	Millions	£ sterling
50–100	Guatemala Egypt Philippines Morocco Syria Paraguay China Mauritius Equador Tunisia Korea, S. Libya Saudi Arabia Uganda Ghana Honduras	69,230	830.9	34
Less than 50	Angola India Iran Ceylon Pakistan Kenya Haiti Viet-Nam Liberia French Africa Burma Mozambique Thailand Jordan Sierra Leone Tanganyika Nigeria Indonesia Madagascar Afghanistan Cambodia Sudan Ethiopia	29,285	840.9	23
770	World	2,256,044	2,922.7	147

Notes (*i*) From columns 3 and 4 it can be seen that 28% of the world's total population of nearly 3,000 millions uses 88% of the total electrical energy.
(*ii*) The figures in columns 1 and 5 show the relationship between electrical consumption and income.

We see, therefore, that the implication is not simply that highly-developed countries use large quantities of energy but that their development is directly related to this use.

Is the converse, that under-development is due to insufficient use of energy, also true? It would be unrealistic to assert that lack of energy is the sole cause of under-development but it is certainly one of the causes and the purpose of this booklet is to examine the questions of providing more power for development, of distributing it to the potential users and of ensuring that it shall improve national economies.

There are no insuperable technical difficulties in providing power for any of the inhabited areas of the world: the deterrents are usually on the financial side. Capital investment for development can be applied in many directions – for the building of roads, the improvement of sanitation and health services, for schools and colleges to advance education, or for the establishment of industries. The capital needed for the provision of power is but a fraction of the total and demands for it are in competition with those for other means of raising standards of living.

As Sir Harold Hartley said in his address to the sectional meeting of the World Power Conference in Belgrade, 1957, 'Power is essential to progress but it is not an end in itself. It is a means to an end – the most effective utilisation of the indigenous resources of each country. Consequently, in making plans for power development, there are a number of possible limiting factors that must be taken into account, such as water, soil, raw materials, manpower and human skill, and last, but not least, capital. Each country has its own problems, conditioned by its special circumstances. For instance, there is the contrast between conditions in the more advanced countries with high wages, and often full employment, and in the less developed, often with teeming populations mainly engaged in agriculture on almost a subsistence basis. This contrast is so great that it must affect the pattern of development.'

When considering the question of providing power for a developing country it is thus important to view it realistically, taking fully into account all the relevant circumstances and the implications of introducing new possibilities for production to areas which have long-established traditions, perhaps of a somewhat primitive way of life.

There must be a proper balance between the functions of men and machines: while mechanisation may eventually have a major and lasting influence on the human way of life, its introduction must be carefully planned with full cognisance of its social, as well as economic, effects. On the other hand, profitability in the strict commercial sense should not be the criterion for investment in projects formulated in national plans. To quote again from the proceedings of the Belgrade conference, this time from an address by Gunnar Myrdal, 'The whole meaning of a national plan for the under-developed countries is to give investment such protection from the market forces as will permit it to be undertaken in spite of the fact that it may not appear to be remunerative according to private business calculations.'

1. Power and Energy: Men and Machines

Definition of Power

Before entering into a discussion on the problems involved in providing and using power for development, we must be clear about certain fundamental questions.

First, what is meant by 'power' – or 'energy' and how do these bear on the economic life of peoples? For precision, it is necessary to turn to the scientific definition of power as 'the rate of doing work, or expending energy'. Work is done when a force is applied through a distance, the force and the distance being in the same direction. Thus, as a simple example, if a mass of 5 pounds (which is being pulled towards the earth by gravity with a force of 5 pounds weight) is raised vertically through a height of 6 feet, 30 foot-pounds of work is done or, alternatively, 30 foot-pounds of *energy* is expended in the process. This quantity is the product of the force exerted (5 pounds weight) and the distance moved through in the direction of the force (6 feet). Note that this work done is independent of time: it is a simple product of force and distance. If, in this example, the mass is actually raised 6 feet in 1 minute, the *power* used is 30 foot-pounds per minute: this is the *rate* of doing the work, or expending the energy. For convenience in engineering work, a unit of 1 horse-power is used to measure power and this unit is equivalent to 33,000 foot-pounds per minute (or 550 foot-pounds per second which is, of course, the same thing). In electrical engineering the unit of power is 1 kilowatt which is almost exactly equivalent to $\frac{4}{3}$ of one horse-power. In other words, 3 kilowatts of electrical power is equivalent to 4 horse-power. (Because of power losses, which are inevitable in any machine, the power which has to be supplied to a 4 horse-power electric motor is rather more than 3 kilowatts but that does not affect the above-mentioned relationship between the two units.)

Forms of energy

Although the simple job of raising a weight is perhaps the most obvious illustration of an expenditure of energy, the energy expended being equal to the work done, in foot-pounds, energy can exist in many forms. A body possesses energy if it is capable of doing work, the scientific and everyday uses of the word 'energy' being closely the same. Thus, the water in a lake up in the mountains possesses energy, called 'potential energy' because it arises from the elevated position of the water. It can do work, perhaps in driving a water turbine, during its descent to a lower level. The water flowing in a river, or the wind, have 'kinetic energy', i.e. energy arising from their motion and they can do work by driving a water wheel, or a windmill, losing some of their speed – and therefore some of their energy – in the process. Heat is another form of energy: the heat may be used to raise steam which, in turn, can drive a steam engine. Coal, oil or other fuels possess energy in chemical form. This is converted into heat energy when the fuels are burned.

The different forms of energy can be converted from one to another – from chemical energy to heat, from heat to mechanical energy, from mechanical energy to electrical energy, and so on according to requirements. Nearly always some energy is lost in the conversion and the ratio of what is got out, to what is put in, is called the efficiency of the conversion. To produce power, some source of energy must be used and the greater the power needed, the greater the rate at which this source must be used up. For example, a steam-driven electric power station, burning coal, with an overall efficiency of 25 per cent, will use about $1\frac{1}{4}$ pounds of coal per hour for each kilowatt of its power capacity. Hence, a large modern power station, having a power capacity of 500,000 kilowatts, may use about 625,000 pounds (nearly 280 tons) of coal per hour.

Human and animal power

Now consider human labour – man-power. A man employed on mechanical work can exert, as a continuous average value, about $\frac{1}{10}$ horse-power. Thus, if he works for (say) 2,000 hours in the year at this average rate he can do 200 h.p.-hours of work, i.e. his annual rate of useful energy production is 200 h.p.-hours, or 150 kilowatt-hours. Incidentally, if his food intake is 2,600 kilo-calories per day (to use nutrition terminology) a man's efficiency, as a producer of useful mechanical work, is about 13 per cent. To do him justice it must, however, be added that his body does a considerable amount of work – for example in merely walking about – beyond the useful output of 150 kilowatt-hours so that his actual efficiency is probably nearer 20 per cent.

The commonly employed working animals – bullocks, buffaloes horses or camels – can produce between 600 and 800 kWh per year but they must be driven by a man or a woman or a child according to the work being done. These animals consume between 2 and 3 pounds (dry weight) of fodder, daily, per 100 pounds of their own weight. This corresponds to about $2\frac{1}{2}$ tons of dry matter (with a heat value of perhaps 2,000 kilo-calories per pound) consumed per annum. On a wet basis the annual consumption per animal is 10 to 12 tons of fodder. Their mechanical efficiency, based on useful annual output of work and on food consumption, is between 5 and 6 per cent.

As for the costs of human or animal labour, these naturally vary in different countries. In India, for example, a wage of 1 rupee a day is perhaps a fair average for a rural, non-specialised, worker engaged on manual work. In 250 working days a year he may produce 150 kWh so that the cost, per kWh, is $1\frac{2}{3}$ rupees or 30 pence. If a working animal costs £30 and has a working life of 5 years then, neglecting any interest charge on the capital cost of the beast, and taking a flat rate of depreciation, the annual fixed charge is £6. The cost of the fodder is very difficult to estimate; often it is without any specific cost because the animal may graze freely on common land, but a token figure of £2 a year can be taken. If one man is employed as driver for each 2 animals, his wages will add a further £9 to the 'operating costs' per animal, giving a total of £17 (or £15 without any charge for fodder). Taking an average annual energy output of 700 kWh, the cost of animal-produced energy is just under 6 pence per kWh. It will be seen that the wages of the driver constitute more than half of the total cost even though the rate is only 1 rupee a day. Wage rates, and the prices of the working animals, in different countries, will influence the cost of animal-produced energy considerably, but it is not likely often to be cheaper than 6 pence per kWh if realistic values are taken in its computation. A common argument is that animal power is cheap because the animals are raised on the agricultural holding where they work and their food costs nothing. Again, the cost of the human labour of the driver is often neglected because he is self-employed. Such arguments are really fallacious if the animals have market value or if the human workers have any source of employment which would give them a cash income.

It is interesting to note, from the above examples, that the cost per unit of energy produced by the combined efforts of man and animal is only one fifth of that for human labour alone. Obviously, if the animals were able (and willing!) to perform their tasks without a driver, the cost, per energy unit, would be lower still. The economic advantage of a combination of human labour with that of an animal, or of a machine, will, if the non-human source is cheaper than the man, increase as the capacity of the power unit increases. With a very large power plant the man-power component of the energy cost will fall to an almost negligible value. Continuous human labour may not be needed at all: the machine may merely be started and stopped by an attendant, running quite independently during its working period. Then the human-labour factor enters as a maintenance, or control, charge, not as a running cost.

Forms of power for different purposes

So far it has been assumed that the job to be done is purely mechanical in character, e.g. water pumping or corn grinding, and that different sources of power are simple alternatives. But for many jobs the number of practical alternatives may be reduced to no more than two. Factors other than straightforward costs, per unit of energy, clearly enter into the question. Size, or power capacity, is one of them: a small jaggery (crude sugar factory) dealing with the produce of perhaps only 2 or 3 acres could employ bullocks to crush the cane, but, if the area to be dealt with is several hundred acres, anything but machine power – from engines or electric motors – becomes impracticable.

The form in which the energy is needed is another limitation on the choice of power source. To operate a radio set one must have electricity – there is no choice of power supply. For domestic lighting or for refrigeration electricity or oil are alternatives as they are for many small-power jobs such as driving machine tools in rural workshops or mechanical appliances in small industrial plants. For these purposes human and animal power, if not impossible, are much less feasible.

Time may be another important factor. Let us consider, not a small, everyday, task like water pumping but a constructional job, of appreciable size such as the building of an irrigaiton dam or reservoir or, perhaps, a new road. There may well be a time limit: the job must be completed in, say, one year, or weather conditions in different seasons of the year may dictate the time during which the work can be done. The total quantity of energy involved in the mechanical work of earth removing, or building up, is calculable with a fair degree of accuracy. Suppose this total is 5 million horse-power hours. It is at least conceivable that the work could be done by man-power alone but, at the average rate of 200 h.p-hours per year for a man, the job would call for the employment of 25,000 men. Alternatively, using earth-moving machinery, working during 5,000 hours in the year, a net power capacity of 1,000 h.p. would be needed. Man power would not be entirely eliminated but would be greatly reduced, perhaps to that of a few hundred men instead of 25,000.

It is abundantly clear that, in a project of this kind, several considerations other than time must be taken into account in making the choice between men and machines.

Man power or machine power

Taking the man-powered case first, the labour cost in a district with an abundance of human resources may not be excessive. But, even for the simple work of earth moving, some equipment – picks, shovels, wheelbarrows or baskets, ropes, etc. – would have to be supplied. Probably a labour camp, to house most of the workers – for one year only – would be needed with its attendant medical services, lighting and cooking facilities, and other amenities. A good deal of organisation for this, as well as for the work itself, would be involved. There would be the advantages that the money spent on the work would go mainly into the pockets of the local inhabitants and that the satisfaction of having accomplished a major undertaking for the benefit of the district itself would have moral value. On the other hand, unless a succession of such tasks, employing the same group of men, could be envisaged, there would be the problem of re-employment at the end of this relatively short-period job: if the only possibility were a return to their former life as self-employed peasant farmers, the disturbance caused by this temporary work, with a cash income, might be troublesome.

Now consider the machine-powered job. The fuel consumption, as an overall average, might be 1 pint of oil fuel her h.p.-hour. So that the annual output of a man could be replaced by that of 25 gallons of fuel. Some 700,000 gallons would therefore be needed to replace the labour of 25,000 men – allowing for some non-useful running of the machines. The machines would have to be purchased and may have to be imported – as may the fuel – thus involving the provision of foreign currency. Depreciation on heavy work of this kind is high so that the fixed charges on the plant may approach 50 per cent of the capital cost. The machines must have drivers, and maintenance men with some engineering skill and, inevitably, a small number of unskilled workers would be needed for work which the machines could not undertake.

The 'working cost', for fuel, skilled labour and unskilled labour, would, however, be probably not more than one tenth of that for the job done solely by man power. This gain of nine-tenths in the working cost, on a big job, can easily absorb the fixed charges on the plant and still leave a handsome margin.

Calling for so much less human labour, the machine-done job would not be encumbered with a large labour camp nor would it bring about any serious disturbance in the life of the inhabitants of the area in which it was done. On the other hand, skilled labour for the operation and maintenance of the machines must be found and this may not be easy. There is also the question of the heavy capital cost of the equipment which must either be imported or built within the country itself if the appropriate manufacturing industry has been established.

This, admittedly sketchy and imprecise, comparison of work done by men and by machines, may be sufficient to show the complexities of the factors governing the choice of power and energy sources. Some of these factors are simply technical but others are social or political and the circumstances of the country or area concerned must obviously be taken into account in deciding which course to follow.

The assumption that there is a question of choice between one form of power and another implies that the onus of this choice lies with some authority possessing adequate financial status for capital equipment to be employed if this were thought most economic. One should not, however, overlook the fact that some very useful and successful development can be brought about by communities with few financial resources. There have been many instances of groups of people, in different developing countries, giving their labour for projects which will benefit them, as a group. Under such conditions the economics are quite different: the labour of the individuals is being put into something which becomes a capital asset communally held by the group and with the approval and encouragement of the governing authority responsible for the area concerned. Self help of this kind transcends the usual economic considerations.

Energy resources and their exploitation

Another factor which must have an important bearing on development, through the application of power, is the availability of energy resources. Such resources include the solid, liquid or gaseous fuels – coal, wood, peat, waste vegetable matter, oil and natural gas – all of which are exhaustible, and the inexhaustible energy sources – water in elevated lakes or rivers, solar radiation and wind energy. In some places there may be the possibility of exploiting geothermal heat (which is exhaustible at any particular place), marine heat (which derives from solar radiation) or tidal energy. Nuclear power is, of course, another possibility but its exploitation is so complicated that deposits of the basic radio-active materials can scarcely be regarded as a direct source of energy.

Possession of energy resources and their economic exploitation are different matters. Some resources can be used quite simply, for example, wood or peat can be cut and used as a fuel for heating and cooking or even for steam-raising locally without much cost other than that of the labour involved in the cutting. Coal, oil or natural gas, on the other hand, usually need mining or boring equipment calling for heavy capital expenditure which, however, results in a commercially valuable production available for export as well as for local use. The development of any form of water power demands high capital investment and the resulting power is most profitably used locally although it can be transmitted, in electrical form, over considerable distances if there is enough of it to merit the building of high-voltage transmission lines.

Solar radiation and wind energy are resources which occur over wide areas: they are not so confined to particular localities although some sites, especially for wind energy, are more favourable than others in a given area. These sources have, however, the disadvantages of discontinuity (so that they are not always available), and of diffuseness (which causes the equipment for harnessing them to be relatively large) partially counterbalancing the advantage of requiring no transport to the point of utilisation.

Storage of energy

Mention of the discontinuity of power supplies leads to the introduction of another very important aspect of the general question of power and energy, namely that of energy storage. For reasons which differ with the source, it would often benefit the economy of power generation considerably if the energy produced during one period of time could be stored for use later.

Thus, for example, any large power-generating plant is subject to periods – usually during the day time – when the demand for power rises to a high value. There is a daily 'peak' in the power curve. Taking a long period, e.g. a year, there is also a maximum 'peak' the actual date and time of which depends on several factors, including the weather, industrial activity, the occurrence of a public holiday, etc. To meet this 'greatest annual demand',

and also to cater for the daily peaks, a much greater capacity of plant has to be installed, at the power station, than would be needed if the demand could be levelled out to something near to its average value or, alternatively, if an adequate amount of stored energy could be drawn upon to meet the short-period need for power. Although some levelling can be done, on a long-term basis by encouraging the installation of equipment which takes power only at off-peak periods, or, on a short-term basis by (undesirable) restrictions or 'power cuts', this procedure cannot be relied upon when a large, multi-purpose, power network is being operated. Unfortunately, the storage of electrical energy, in directly usable form – as distinct from energy which still needs conversion into usable form – cannot be done economically on a large scale. It is usually cheaper to instal the extra capacity of generating plant required to meet the peak demands. Small quantities of electrical energy can, of course, be stored in secondary cells – accumulators – which are charged electrically at one time and discharged later. If the cost of the accumulator, and its fairly short working life, are taken into account, the energy so provided is considerably more expensive that that used in the charging process but convenience may outweigh this disadvantage.

Storage of energy in electrical form is not, however, the only possibility. Some other forms of energy storage are more economical. Solid fuels, for example, which represent energy stored in chemical form, may be stored with no greater difficulty than that of finding space on which they can be piled. The storage of liquid fuels demands barrels or tanks: to store gaseous fuels under pressure, a somewhat costly gas holder is needed as well as a compressor. The energy potential of water can be stored in a reservoir but, unless this happens to exist, naturally, in the locality in which it is needed, the cost of its construction may be high. In all these instances, there will usually be a question of converting the 'crude' sources of energy into a more refined, or usable form and then the question of an adequate installed power capacity – to meet peak demands – returns. But the purpose for which the energy is needed enters into the matter. If the fuels are needed only for heating, for example, the stocks can be drawn on, as required, without any problem. Again, stored hydraulic energy may serve the purpose of counteracting the effect of periods of low rainfall: the stored water can be used to ensure that the water power plant can be operated continuously, or nearly so, in spite of the variability of the rainfall.

There is the same need, but unfortunately not the same prospect of meeting it, with plant driven by solar energy or wind power.

Both suffer from the non-availability of their source of energy for lengthy periods but while storage of heat is certainly possible for short periods of time provision for it may be expensive. The kinetic energy of the wind cannot be stored for any significant length of time but only for very short periods in the form of kinetic energy of a rotating mass – the 'flywheel effect'.

With sources of energy which cannot be stored, although there may be a super-abundance of them at certain times, the best solution to the problem of their economic exploitation may be to store, not the original energy, but that generated by the power plant. An example of this process is the storage of the water pumped, from below ground, by a windmill. There is then 'inherent' storage of energy in the shape of the raised water. This whole question is so important to the economy of small power plants that it will be dealt with more fully in a later chapter.

By way of summary, the diagram of Fig. I shows the many different ways in which energy, from all the probable sources, may be used either directly or, at second hand, via various methods of storage to supply a variety of loads. Some sources lend themselves to storage more easily than others which, essentially, should be used directly. Clearly there are possibilities for the combination of several sources, with or without storage, to supply a mixture of loads and the diagram forms a basis for the consideration of such a combination.

The general principle to be accepted, whatever the source of the energy, is that the more directly it can be applied to a useful purpose, avoiding either conversion of its form or storage of its energy content the better will be the economy.

2. Large and Small Power Plants

If power is required in a developing area, the size, i.e. the power capacity, of the individual plants to be installed may appear to be a matter of secondary importance. It would be unrealistic to suppose that any plan for power development would envisage a target of some arbitrary quantity of horse-power, or kilowatts, per capita except as a very general ambition, but, if this were taken as a basis, the total power capacity needed to serve the population could apparently be composed of a few large units or a great number of small ones. Upon what factors does the choice of one or other of these alternatives depend?

First, to define what is meant by 'large' or 'small', although there can be no precision in such a definition, it may be accepted that the capacity of large power plants is certainly to be reckoned in thousands of horse-power, or kilowatts, whereas small plants are those of individual capacity from one or two hundred horse-power downwards. Much depends on the circumstances: a village power station of 200 kilowatts may be thought relatively large while one of 10 kW would be small. But power stations serving an industrial centre or supplying a wide area of a country, may have capacities of 100,000 kW, quite dwarfing the village plants.

Factors influencing the choice of size

Among the factors influencing a decision on size are: (i) the purpose for which the power is needed; (ii) the available sources of energy which could be used for the power production; (iii) the distances of these energy sources from the place or places at which the power is needed; (iv) relative costs of construction and (v) financial factors, including foreign currency requirements. It is difficult to consider these factors quite separately because, in fact, they may often be interdependent. As far as possible, however, let us take them in order.

(i) Purpose

Roughly the same total power capacity may be required for (*a*) the exploitation of a single industrial resource e.g. a mineral deposit, (*b*) an industrial load centre where it is intended to locate a number of manufacturing works, (*c*) a large urban area consisting of both residential and commercial premises or (*d*) an extensive rural area with many potential consumers engaged mainly on agricultural or rural industrial pursuits. But these four possibilities have different characteristics.

(*a*) A mineral deposit has a definite location which may, or may not, be close to a source of energy. Its exploitation must be undertaken on the spot but, even so, there may be two alternative methods of operation. The crude material must first be won, probably with the aid of power. Subsequently, however, assuming that further treatment is necessary, it can be transported to a point where ample power for such treatment is available or, it can be treated at source, leaving only the treated material to be transported. The method chosen will depend primarily upon relative transport costs – for the material or for the power – and upon the ultimate destination of the product. A large supply of power, in bulk, at some selected sites will be needed for either method but, in the first case, the total power demand will be divided between two sites (one of which might be extra-territorial) while, in the second case, only one site is involved.

(*b*) The availability of power, or of an energy source from which power can be generated, must obviously have a predominating influence upon the choice of site for an industrial centre. In the industrialised countries, manufacturing areas have always sprung up around coal or oil fields, or near hydro-electric stations. When new centres are to be established, therefore, they will be located at the most convenient places as close as possible to an energy source and the industrial scheme and power project may develop together. The distance over which the power will have to be transmitted will probably be short and the supply will be in bulk, with distribution to a fairly small number of consumers within the confined area of the industrial centre.

(*c*) While a new large urban area is unlikely to be established without consideration of the availability of a power supply, many old ones have been in existence from a time when power was not considered to be an essential service. They have arisen for reasons quite unassociated with industry: their locations have been dictated rather by geographical and commercial factors. The supply of power to urban premises in the older towns is likely, therefore, to involve the building of a local power station and an intensive distribution system.

(*d*) An extensive rural area presents quite a different problem. Although the total number of potential consumers of power may be great and their individual demands somewhat larger than those of urban consumers, there can be no general certainty of the existence of adequate energy resources within a reasonable distance. Often it may be necessary to import power in bulk to some central point, or points, from which it must be then distributed to very scattered consumers. Distribution, rather than bulk transmission of the power, is then the difficulty from the economic point of view.

Consider the differences, in plant capacities, which may be selected for these various purposes. For the exploitation of mineral deposits, or any other localised natural resource of significant magnitude, large-scale plants will be needed, the actual capacity depending upon whether power is needed only for the work of winning the crude material or, in addition, for its subsequent treatment.

An industrial load centre could take power from a large plant if the building of such plant were encouraged by the existence of an adequate supply of a source of energy or, alternatively, a number of small power plants, owned and operated by the individual industrial users could be envisaged.

An urban area would almost certainly require a central power plant for which a utility company or a municipal authority would be responsible, distributing the power to domestic and commercial consumers.

In a rural area with widely scattered communities, or even isolated single premises, the question whether a large power station with a distribution network is as good an economic proposition as a number of small power plants will usually be decided in favour of the latter, and succeeding chapters will be devoted to the possibilities of small plants for this purpose.

(ii) Available Energy Sources

The available energy source which could be used for the power production may influence the capacity of the power to be installed for one, or both, of two reasons – because of its nature or because of its magnitude. To illustrate this consider a few of the possible sources:

(*a*) *Hydro-power*. Both influences may apply with hydro-power. The source may be a small stream on which a generating plant of low capacity – perhaps only a few kilowatts – could be built. It would be useless to install a plant of a size larger than the known water flow and pressure (head) could drive, i.e. the magnitude of the source is then the limiting factor for the capacity of the installation. If, on the other hand, the energy potential of the proposed hydro scheme arises from a large catchment area at a considerable altitude, or from the fall of a big river, the possible capacity of the installation will be high – perhaps hundreds of thousands of kilowatts. It may be economically feasible to extract only a small fraction of the total possible power (as is done, for example, at Victoria Falls in Rhodesia where a power station of many times the power capacity of the existing station could be installed were the power required there) but often this is not practicable. Frequently the civil engineering work which must be undertaken if the project is to be carried through at all is so great that only a power station of large capacity can be economic in cost per kilowatt installed.

(*b*) *Geothermal energy*. Exploitation of this form of energy calls for very considerable expenditure on preliminary investigations – for sinking deep bore holes to locate the underground steam, or hot water, to test its physical and chemical characteristics and to determine, as accurately as possible, the probable reserves of energy stored in the source. Even more generally than with hydro-power, therefore, exploitation of geothermal energy can be justified economically only by a large installation: power plants of this kind are likely to have capacities of thousands of kilowatts although there have been a few instances of rather smaller geothermal plants (in Japan and the Congo where the conditions of exploitation happen to be especially favourable).

(*c*) *Fuels*. With the conventional fuels – coal, lignite, peat, oil or natural gas – there is usually a good deal of flexibility in the size of the plant that can be used. Unless the deposits in a particular area where local use for power production is envisaged, are quite exceptionally small any convenient capacity of plant up to very large capacities can be installed. There is perhaps more likelihood of an influence on plant size when peat is the fuel: it may demand a large station if expensive machinery is to be introduced to win the peat from the bog. On the other hand, a peat bog, of given area, represents a strictly limited, and calculable, quantity of stored energy which governs the capacity of the adjacent power station in relation to its economic life. Thus, for example, if the station is built to have an economic life of twenty years and the total quantity of workable peat in the bog represents an energy store of 1,000,000 kW-years (after allowing for the inevitable losses in the power-generating process) the capacity of the peat-fired station should not be greater than 50,000 kW. This assumes, of course, that there are no other nearby reserves of peat which could be worked later to supply the station without involving uneconomically high transport costs.

While the so-called 'fossil fuels' mentioned above usually occur as large deposits, so that they can be worked on a correspondingly large scale, other rather less conventional fuels, such as wood or organic wastes, are often subject to limitations in the rate at which they can be produced or used. Fuel wood may, in some countries, exist in such quantity as to appear virtually inexhaustible at any probable rate of use for power production but, as an energy source, it resembles peat in some degree. If the power station, built close to a forest, were to have an excessive capacity, the time would come when the wood fuel to feed it would have to be brought from a distance great enough so introduce a transport problem. Unlike peat, however, wood is a replaceable reserve: the felled areas can be replanted so that another harvest of fuel can be looked for after a period of years. The length of this period depends, of course, upon the climate and on the kind of timber grown. Some species (e.g. of eucalyptus) may grow fast enough to provide another crop within ten or twelve years.

Organic wastes such as bagasse (sugar cane waste), coconut shells, rice husks, corn cobs, etc. are used in some areas as power-producing fuels but, although they are almost valueless in themselves, they may have a disadvantage in an appreciable cost of collection. Fuels of this kind are seldom likely to exist, close to a power station, in sufficient quantity to justify the installation of a large plant capacity: they are essentially energy supplies for small plants. There are, however, some exceptional instances of fairly large bagasse-fired plants on sugar estates.

(*d*) *The inexhaustible energy sources.* In the present context, the most important of these are solar radiation and wind energy. With both of these sources of energy the limitation in the size of power plant is not brought about by any restriction of the quantity available (admittedly only at random times) but by their diffuse character. In spite of its vital importance to life, when one calculates the power which may be harnessed from it, the sun's energy proves to be somewhat thinly spread over the surface of the ground. The maximum power from the sun, at the surface of the ground, is not much more than 1 kilowatt per square metre, so that an extensive collecting surface would be required for a large-capacity power plant. A similar difficulty arises with wind power. The small mass of the air, per unit of volume, is responsible for the fact that a windmill designed to have a significant power capacity must tap the power from a big stream of air and must, therefore, have a rotor of large diameter.

Solar- or wind-power plants are thus likely to be limited in capacity to perhaps tens of kilowatts or, at most, a few hundreds of kilowatts.

(iii) Location of the Source of Energy

The effect of the distance between the source of energy and the point at which power is required cannot be separated from that of the nature of the source. As already seen, some energy resources, such as fuel deposits or hydro power, are fixed in location while others, e.g. solar or wind energy, are widespread in occurrence. For all those in the former group the important question is the cost of transporting them from their original location to that of the power plant. If this cost is low, relative to that of transmitting the power itself, there is little effect upon the size of the power plant: thermal stations, using coal or oil as fuels, can be large or small, the fuel cost being influenced only to a secondary degree by whether it is supplied in bulk or in small quantities.

Water, in the quantity required for a hydro-scheme, cannot be transported cheaply over considerable distances without a great loss of pressure so that it must be used, for power generation, quite close to the place selected for the scheme. This means that, if the area where the power is needed lies at a significant distance from the generating station, a high-voltage electrical transmission system must be built. Such a system may cost up to ten thousand pounds sterling per mile, or even more, and can be justified economically only if the quantity of power to be transmitted is large. The result is that hydro-electric power stations which are situated at a great distance from load centres are, inevitably, of high capacity – usually hundreds of thousands of kilowatts. If, on the other hand, the water power can be used close to the generating station the capacity may be quite low.

(iv) Relative Costs of Construction

The constructional cost of most kinds of power plants decreases rapidly as the capacity increases. Thus, for example, a diesel-electric generating set of 100 kW capacity costs, per kilowatt, only about one third as much as one rated at 10 kW and perhaps one sixth as much as with a 3 kW plant. For much larger power plants, e.g. hydro-electric stations, in the cost of which the civil engineering work is responsible for a major component, the effect of the size of the power plant itself may be even greater. An increase in capacity of several hundred kilowatts may have an almost negligible influence on the total cost of the scheme so that, beyond a certain point, the cost per unit capacity of the installation is virtually inversely proportional to the size. If the load requirements, the availability of an adequate source of energy, and other factors, permit an unlimited choice, the largest possible capacity should be installed.

(v) Financial Considerations

The financial aspect of the question is more complex than the technical aspects. So much depends upon the financial status of the person, or authority, to be responsible for the power installation, upon the industrialisation, capital resources, and economic policy, of the country concerned, upon the availability of foreign currency and other factors on which no general assumption can be made.

As already shown above, beyond a certain capacity the incremental cost, as the capacity is increased, may be small, so that, if use can be made of a larger plant, the expenditure of a few per cent more in the capital cost may have a disproportionately beneficial effect on the cost of the energy generated. But even this small increase in the initial cost may be beyond the resources of the purchaser of the plant if he has to pay cash for it immediately. Many facilities now exist, however, for some form of deferred payment, either by direct agreement between buyer and seller or perhaps through a government loan to the buyer, e.g. to a co-operative society established to undertake joint responsibility for repayment.

When consideration is to be given to a large-scale development of power production, catering for the needs of a whole country or, at least, of an extensive district, the financial question is of a different complexion. It may be assumed that the total scheme will cost millions of pounds which must be raised by governmental borrowing either within the country or extra-territorially – for example from the World Bank. Interest on the capital must, of course, be paid and there is an obligation to repay the loan. The development must, therefore, be planned to show a reasonable return on the expenditure, not perhaps immediately, but certainly within a period of a few years. Often there is a possibility of building a power scheme, e.g. a hydro-electric scheme of major importance and of very large capacity located at a particular site. For reasons already mentioned, a scheme of this kind may have to be big to be economic in unit cost (per kilowatt). Upon its completion, however, the problem of utilising its output effectively arises. To absorb power of such an order of magnitude a correspondingly large industrial plant, and an adequate supply of raw materials, will be needed. And this, in turn, may involve bulk transmission of the power over a long distance to the load centre.

In short, the completion of the power plant itself is but the beginning of the development required for full economy.

In most of the less-developed countries, agriculture has been for centuries, and remains, the means of livelihood of the majority of the inhabitants. The sort of large-scale power development just envisaged may well benefit the peasant farmers indirectly, and in the long term, but is not likely to help them immediately. The generation of the power is only one stage in the electrification of an extensive area with a scattered population: distribution of this power to the rural consumers presents a serious difficulty, so serious that the large industrial project may indeed be the best outlet for the power from the new development.

The question to be considered very carefully therefore, bearing in mind all the implications, is whether a single, large, power scheme is going to be as beneficial, on a national basis, as a number of small stations, strategically sited to serve rural communities. These may cost more, per unit capacity, but, instead of demanding one enormous initial outlay, with a subsequent problem of finding an outlet for the generated energy, they can be installed over a period of years, each suited to local requirements and each affording some experience as a guide to other installations of a similar kind. The total expenditure, spread over a number of years, may not prove such a burden as if it had to be made at one time and the early installations can provide some revenue while later ones are being made.

3. Networks or Small Power Plants for Rural Areas

Social Effects

In this chapter it is to be assumed that a decision has been taken to provide an electricity supply in the rural areas of a country which is mainly agricultural, which is thinly populated and in which the distances from the (presumably existing) main power stations are great. These assumptions are not unreasonable: such conditions exist in many under-developed countries. Nor is a decision to introduce rural electrification unjustifiable. Whatever may be the national benefit of a major industrial scheme supplied with power from a correspondingly large power project, there is danger that its effect may even be detrimental to the rural population. This may arise from the fact that the pay of the industrial workers will be higher than the incomes of the peasant farmers with the result that too many of them will be attracted to the industrial area with its amenities, as well as the prospect of a higher income. Only too often a large unemployed, or only semi-employed, population has thus congregated in newly-established towns. Rural electrification can act as an effective antidote, ensuring both amenities and an increased standard of living to match that of the industrial workers.

It does not, however, immediately follow that the electrification of rural areas should be through the medium of small power plants. Indeed it is not suggested that it should be so if a network, fed from a main power station is economically feasible. But when the distances to be covered are great, and the power loads relatively small, such a network is not likely to be economic. Consider the implied costs.

Costs of electrical transmission

First, a bulk supply of power must be transmitted, by a high voltage transmission line, from the generating station to some central point in the area and then it must be distributed to the rural consumers. Using 33 kV or 66 kV lines, according to the distances to be covered, the fixed costs on the lines, per unit (kWh) of energy delivered to different distances are as shown in Table II.

TABLE II

Maximum demand (kW)	*Cost, in pence per kWh, for different transmission distances in miles					
	50 miles	100 miles	150 miles	200 miles	250 miles	300 miles
500	2.3	4.7	7.4	9.7	12.0	15.0
1,000	1.2	2.5	4.0	5.6	7.5	9.5
1,500	0.8	1.7	2.7	4.0	5.0	6.0
2,000	0.7	1.4	2.2	3.1	4.1	5.0
2,500	0.5	1.2	1.8	2.5	3.2	4.0

* Based on 30% annual load factor, unity power factor of the load, 20% voltage drop in the line and a 15% annual return on the capital invested in the line.

It can be seen that the cost, per kilowatt-hour, for transmission alone, is very high – up to 15 pence – when loads of small maximum demand, of the order of 500 or 1,000 kW, have to be supplied over distances of two or three hundred miles. In fact, it is only when the maximum demand is several thousand kilowatts, and the distance no more than 50 or 100 miles, that the transmission cost per kWh becomes reasonably low.

To form an idea of the significance of relatively small maximum demands of 500 or 1,000 kW, consider the energy supplied annually when these exist with an annual load factor of 30% (which means that the annual energy is equivalent to that which would be supplied if the maximum power demand continued steadily for 30% of the year). With a 500 kW demand the annual energy would be over 1,300,000 kWh which could give 500 kWh per head for a population of 2,600. It would be equal to the work of about 9,000 men or 2,000 animals. A 1,000 kW demand would, of course, supply twice as much. It should be noted that an annual consumption, *per head of population*, of 500 kWh is much higher than that found in most of such areas now. From the statistics, given later in this chapter, for rural power stations in Sarawak it can be seen that the average annual consumption *per consumer* is not much more than 500 kWh and it may be assumed that, for each consumer, there are four or five inhabitants. The conclusion to be drawn, therefore, is that a demand of 500 kW is not likely to arise unless the village is large or the electrical load is well developed.

The Distribution Problem

If one supposes that the bulk supply of power can be transmitted, to a central point in the area, economically – either because the distance of transmission is short or the power demand is high – the next problem is that of planning an economical distribution scheme. Such a scheme involves a primary distribution network, probably of 11 kV lines which usually cost about £1,000 to £1,200 per mile. At points where loads are to be supplied there must then be transformers which reduce the voltage to a value suitable for the consumers to use in and about their premises. One transformer will usually serve a group of consumers, in a community, but sometimes, with isolated premises, it may supply only one or two houses.

The cost of each connection in the more remote rural districts of the United Kingdom and other electrically-advanced countries is now of the order of £400 – as an average value. In less developed countries it may, or may not, be less. Labour costs for erection may be lower but these form only a small fraction (perhaps 5 to 10%) of the total cost of the line, the electrical conductors being the major item in the cost. Again, the terrain over which the lines have to pass may be difficult: it may be mountainous, or dry and rocky, or very wet – as in the areas given over to rice cultivation – with consequent difficulties in making secure foundations for the supporting poles. Another trouble arises in thickly-wooded areas, or those devoted to coconut plantations, because unless the path out through the plantation is very wide, with consequent loss to the cultivators – who must be compensated – there is a danger of trees falling on the line. (Vegetation under the line also grows up quickly in tropical areas though its clearance forms part of the maintenance cost of the line, not of its initial capital cost unless it is considered desirable to clear the ground under the line thoroughly at the time of erection.)

The annual fixed charges, for interest and depreciation, on the cost of connection must be recovered from the 'profit' made on sales of electrical energy. It is always difficult to allocate the costs of the primary distribution system to different consumers but suppose the overall average capital charge, per consumer, is £400. Suppose, also, that the fixed charges are at the rate of 10%. Now, if a is the average price per unit, charged to the consumer, and b is the average cost of producing each unit and, again, if N is the average number of units used annually per consumer, the 'profit' to the supplier is N $(a-b)$. For economy, this must equal the annual fixed charges which are assumed to be 10% of £400, namely £40. For many consumers in the under-developed areas an annual expenditure of £40 would be too high. It is, however, an average figure and, if there were fairly large industrial consumers in the area, their annual payments would reduce those required from the small consumers. In a governmental scheme of rural electrification, something slightly less than 10% return on the capital cost might be acceptable and more thickly populated areas, in which the cost of connection, per consumer, is less than £400 might be selected initially. These measures may reduce the annual bill to the rural consumers to something nearer what they could manage to pay.

It is interesting to examine further the question of the 'profit' which pays the fixed charges. The number of units N used annually per consumer is obviously closely bound up, in economy calculations (of both the consumer and the supplier), with the differential between unit price *a* and unit cost *b*. Thus, if *b* is 1 penny, the annual number of units per consumer (to raise the supplier's 'profit' to £40) must be:

9,600 units if the price to the consumer is 2 pence per unit
4,800 ,, ,, ,, ,, ,, ,, ,, ,, 3 ,, ,, ,,
1,920 ,, ,, ,, ,, ,, ,, ,, ,, 6 ,, ,, ,,

If the differential between price and cost is low, the units used per consumer must be high and vice versa. But, when the price per unit rises to as high as sixpence, the consumer may have difficulty in finding applications for electric power which justify such a price.

From these elementary calculations, however far they may be from the precise conditions which may apply in a particular case, one can appreciate the difficulties facing any authority responsible for a new scheme of rural electrification in an untested area in which the inhabitants have little or no experience either of electricity or of mechanical aids to productivity. It is obvious that no such scheme can be expected to give an economic return on the capital expenditure for the first few years of its life during which every effort must be made to encourage the use of electrical energy for purposes which will *increase the income* of the consumers as well as giving them better amenities.

Local power stations

Let us now consider the alternative of a small local power station, of a capacity less than 100 kilowatts, to supply a village community. Later we will discuss the possibilities for locally-available sources of energy but, without doubt, the commonest form of small, up-country station is one driven by a diesel engine. The prime advantage is that the distances over which the power needs to be distributed are generally quite small, and that the capital cost of the installation is likely to be much less than that of an extension of the network to supply the same load from a considerable distance. The disadvantages are that the generating cost, per kWh, for a small diesel station are, because of heavy transport charges for the fuel, considerably higher than at a larger station which is more conveniently situated for transport of the diesel fuel to it. Maintenance costs, up country, are also heavy and stand-by plant may be needed to cater for breakdowns or for periods of servicing.

Two arguments, taking opposite viewpoints (though admittedly under different assumed conditions) have recently been advanced by engineers in under-developed areas. The first – stressing the disadvantages of diesel plant – was in a paper presented, by The Sarawak Electricity Supply Company Limited, to the ECAFE Regional Seminar on Energy Resources and Electric Power Development held in Bangkok, in December, 1961. The authors compare a 30 kilowatt diesel-electric station with an alternative electricity supply via an overhead 11 kV line costing £1,500 per mile. The generating cost at the small local station is taken (quite reasonably) as sixpence per kWh, and as 1.5 pence per kWh at the much larger station from which the 11 kV line would take its energy. They assume that the load factor is approaching 40% so that 100,000 kWh of energy, would be supplied. This would cost £2,500 to generate at the small station and £850 (allowing 0.5 penny per kWh for line maintenance) if supplied by the line. The conclusion is that the difference of £1,650 between these costs is sufficient to pay the fixed charges (at 10%) on rather more than 10 miles of line and, further, that the line would give greater flexibility of connection to consumers, through tappings, as well as involving none of the mechanical difficulties, maintenance and storage of spare plant, which would arise with the local station. Comments on this argument might be that transformers, representing increased capital cost, would be needed at the tapping points and, of course, that the argument fails completely if the distance to be covered by the line is much greater than 10 miles. In fairness to the authors it must not be suggested that they did not recognise the latter point: the comparison was made to urge the need for careful consideration when distances are such that the economy of a local station is marginal.

The second argument – in favour of local diesel stations rather than a network connection – was put forward by Ravi L. Kirloskar and G. N. Pakari in a paper presented, in July 1960, at the Silver Jubilee celebrations of the Institute of Engineers, Mysore centre. It relates to present conditions in India, and to the Third Five-year Plan in that country, in which only some 20,000, out of the 536,000 villages with populations under 2,000, had been electrified by March 1961. Under the current plan, a further 19,000 of such villages will be electrified (by 1966). Though this progress is doubtless creditable under the difficult financial conditions which exist in India it is, in fact, very slow.

The authors of the paper argue that the installation of small diesel stations in large numbers would be the best solution to the problem of advancing this rural electrification. They state the estimated average cost of electrifying an Indian village by a network as 65,000 rupees (£4,875). Their suggested alternatives are standard diesel-electric sets varying in total installed capacity according to the size of the village. Thus, the smallest local stations might have a 25 kW set with a 12.5 kW set standby. Others may have a total of two 25 kW units with 12.5 kW standby, while the largest stations might have 200 or 250 kW made up by various arrangements of 25, 50 or 100 kW units.

A detailed breakdown of the costs for a complete installation, including the power house itself, with an installed capacity of 50 kW and 25 kW standby, is as follows:

	Rupees
Complete 50 kW diesel-electric set	33,300
Complete 25 kW standby set	15,265
Freight and insurance charges at 12.75% ...	6,192
One 36 kVAr, capacitor	1,200
Power house, 30 ft. x 25 ft.	11,250
Erection charges	2,000
Distribution board	600
	69,807

With the rate of annual capital charges taken as 10⅝ per cent and 10 per cent for spares, tools and maintenance, the energy cost, with the station running continuously 12 hours daily, is estimated as 0.415 Rp (7.5 pence) per kWh when the load factor at the station is 30 per cent and 0.269 Rp (4.84 pence) per kWh when the load factor is 75 per cent.

India is thickly populated, with an average density of 315 people per square mile, so that the cost of connection of each village, at £4,875, is low. The plea, on the part of these authors, is that the necessary generating plants, in a small number of standard sizes, can be made in India with little difficulty in servicing them, and that local young men can easily be found to operate the stations – which could be owned by co-operatives with government subsidies and loans helping them. The idea is not that the cost of the energy would be lower than that from the network but that development of the electrical load would thus be quicker. When a village demand grows to 100 kW, with a load factor of 50 to 60 per cent, it should be connected to the network, its diesel plant then being moved to another, unelectrified, village.

Examination of the two sets of conditions envisaged in these two discussions shows that, in the first, the advantage of a network over a local station is essentially existent only when the distance to be covered is no more than a few miles. In the second the advantage of a local station is based on factors other than strict comparative economy – because, in India, the distance to be covered, for each village, is quite short. There are, however, so very many villages and such a limited coverage of existing networks that these short distances are, at the moment, and will be for many years to come, purely imaginary.

There is no doubt that, in many of the developing countries, the distances of many villages from main power stations and from networks can be reckoned not in tens, but in hundreds, of miles. Local stations can, therefore, provide the only possible means of power supply until the general development of the country, and of its electrification network, has advanced significantly through, perhaps, several decades.

Two further points should be noted, from the Indian paper. The first is that the power plants are assumed to run only 12 hours per day continuously, and the second that the achievement of a high load factor (75 per cent) during the running period reduces the cost, per unit of energy, to less than two thirds of that applying to a load factor of 30 per cent. To save labour costs in operating the station, as well as to reduce depreciation and maintenance costs, some reduced daily period of running – instead of a 24-hour service – may have to be accepted with small up-country stations. Again, the fullest possible utilisation of the power available during the running period, is necessary for economy. Fixed charges, for interest, depreciation and maintenance are responsible for about 53 per cent of the total costs when the load factor is 30 per cent but for only 33 per cent at 75 per cent load factor: at the higher load factor when much more energy is generated, the fuel costs form a larger part of the total. There is, of course, a much better prospect of obtaining a good plant load factor when the plant is run only during the period of the day when power is most needed, avoiding the night-time hours when the load would be almost zero.

The question of the required power capacity of local stations is, of course, an important one. Apparently even the larger Indian villages cannot be expected to be able to use much more than 50 kW with a good load factor, while many of the smaller ones would need no more than 25 kW.

Examples of the installed capacities and numbers of consumers for up-country stations in Sarawak are as follows:

TABLE III

STATISTICS FOR SMALL GENERATING STATIONS IN RURAL AREAS OF SARAWAK*

Installed capacity of station (kW)	Daily period of supply (hours)	Maximum demand (kW)	Energy generated (kWh)	Annual plant load factor (per cent)†	Number of consumers at end of year	Annual energy sales per consumer (kWh)	Increase in energy sales over period 1955–1960 (per cent)
12	12	11	14,084	14.7	42	328	107
100	13½	34	62,893	21.2	124	426	42
97	13½	39	55,081	16.2	114	424	65
100	13½	40	60,227	17.2	150	349	50
218	24	122	333,204	31.2	345	820	330
172	24	164	418,358	29.2	372	980	151
117	24	69	133,430	22.1	211	533	69
100	13½	50	96,150	21.9	143	573	125
132	18	64	134,139	23.8	192	624	39
125	13½	50	103,677	23.7	199	469	68
100	13½	70	92,193	15.0	165	455	119
154	24	85	159,464	21.4	244	553	348

* Based on the Annual Report of the Sarawak Electricity Supply Company Limited for the year ending 30th June, 1960.
† Calculated on a basis of 24 hour daily running period.

Probably an average simultaneous demand of around 100 watts per consumer is a reasonable estimate. Individual loads may be considerably greater than this but their diversity in time of occurrence pulls down the average. On this basis a 50 kW installation could cater for 500 consumers.

A paper presented by Electricité et Gaz d'Algérie at a conference in Paris a few years ago described their practice in the rural areas of Southern Algeria. There the centres to be electrified are rather more than mere bush settlements: they are small isolated centres which might be capable of economic development if given a supply of electricity. Total annual energy consumptions were estimated, as average values, as 50,000 kWh initially, 100,000 kWh after a few years and 500,000 kWh eventually.

Corresponding peak loads for the two limits of 50,000 kWh and 500,000 kWh were estimated as 40 kW and 160 kW respectively. The recommendation made in the paper was that, in such circumstances, standard generating plants of 40 to 80 kW capacity should be used, these being easily transportable so that the number of plant units used at any one time, at a station, could be related to the peak load to be met. A central depot, stores and workshop could be responsible for maintenance and for the installation of additional units as these became needed.

Before concluding this discussion of oil-driven power plants, the possibilities of even smaller plants, for individual users or for very small groups of people, should be mentioned. The cost of diesel-engines, per h.p. of capacity, rises steeply as the size becomes very small so that petrol-driven sets are then more practicable. The cost of the energy produced by such engines is, naturally, somewhat higher than that for larger plant. For example, a 3 h.p. petrol engine might have an initial capital cost of about £130 with annual fixed costs, for interest, depreciation and maintenance, of 20 per cent. It would use about 2 pints of petrol – at (say) 4 shillings per gallon – per hour. If it were operated at the equivalent of 3,000 hours full load during the year, the energy cost would be almost 5 pence per horse-power-hour. The power from the engine might be used directly without conversion to electricity, for such a purpose as water pumping. If it were to be coupled to an electric generator (for which the fixed costs might be about £12 per annum) the output of electrical energy would cost about 8 pence to 9 pence per kWh.

Very small plants of this kind are, of course, under the close control of their users who can shut them down, or run them, according to the power demands throughout the day. This gives the possibility of extending their working life – and so reducing depreciation – and also allows a deliberate choice of use to be made according to the probable economy.

4. Small Power Plants Using Local Energy Resources

Possibilities of local energy sources

In the preceding chapter the arguments for or against local power plants rested basically on the costs of transporting energy, in electrical form or in the form of fuel, from some main centre, where it may be cheap, to a distant point where it is needed. Both methods of energy transport are expensive when the distances are great but it is usually much cheaper to transport oil fuel than to carry electric power over the same distance by a transmission line.

But if some usable source of energy is available at, or close to, the place where the power is needed, transport costs do not arise. Other questions crop up. Will the power plant needed to exploit this local resource cost more in fixed charges, for interest, depreciation and maintenance, than the more conventional fuel-driven plant? If so, will the increase more than outweigh the saving on transport of energy from a distance? How dependable is the local energy resource as a basis for a continuous supply of power?

Clearly, if there had not been some doubts on the answers to such questions, local energy resources would already have been developed on a major scale. The truth is that not enough serious attention has been given to them in the past. It has been assumed, too easily, that if conventional means of power supply show no prospect of economy, nothing else can do so. This attitude of mind can be shown, quite simply, to be unrealistic. For example, extensive arid or semi-arid areas depend entirely upon wind-driven pumps for water supplies for human beings and domestic animals. At one of the UNESCO conferences of their Arid Zone Research Advisory Committee a few years ago, a lecturer from South Africa stated that, in his country, one million people, and twenty million animals, were completely dependent on wind power for their drinking water.

During the last decade much more serious, and widespread, interest in the possibilities of local energy sources has been shown.

A good deal of research has been done and it has led to the conclusion that the prospects for the use of such sources are, in fact, better than had been thought. It is not to be suggested that the wholesale introduction of power plants using local energy supplies should be undertaken without careful consideration of their economic potentialities but, on the other hand, they do deserve such consideration.

The forms of locally-available energy most likely to be usable, in different degrees in different localities, are:

(*a*) water, from fast-flowing streams, or from high-altitude lakes,
(*b*) wind energy,
(*c*) solar energy,
(*d*) organic wastes.

All of these are of fairly widespread distribution and can be exploited by means of small-scale power plants. They will be examined in order.

(a) *Water power.* Scattered over the world there must be many thousands of sites where small quantities of power could be obtained from falling water but the economic prospects for their exploitation vary greatly. There must be an outlet, for the power, within a fairly short distance – perhaps three or four hundred yards – because it must be remembered that the power lost in low-voltage transmission, which is all that could be justified in a small-scale scheme, is roughly 1 to $1\frac{1}{2}$ per cent for each hundred yards. Again, longer distances will add appreciably to the cost of the installation.

The quantity of power available from this source is proportional to the product of the effective head (or pressure), expressed in feet, and the water flow, expressed in cubic feet per second. A rough rule is that the horse-power is one eighth of this product, e.g. a flow of 10 cubic feet per second with an effective head of 20 feet would represent an available power of $\frac{1}{8}$ (20 x 10)=25 h.p. Only a fraction of this power – perhaps $\frac{2}{3}$ to $\frac{3}{4}$ – can be extracted by the water turbine and the electric generator which it drives, but it is clear that measurements of flow and of the head which might be obtained, must be made before any reliable estimate of the power obtainable can be made. Another essential study is that of the dependability of the flow throughout the year, or even from year to year. Most small water power sources vary: some, in dry areas of the world, fall to zero during parts of the year. It is obviously important that water should be flowing for most of the year although combination of water power with that from another source – perhaps a diesel engine, used mainly as a standby plant – could overcome the difficulty presented by lack of water.

If the flow régime of the water supply is sufficiently dependable to allow full power capacity of the installation to be generated at any time during the year, the annual output of energy, in practice, is governed only by the use which the consumers make of the electricity supply. Small plants of this kind can run automatically with only a small amount of – relatively unskilled – attention so that the running costs are very small. The main costs are the fixed charges, for interest and depreciation on the capital outlay. The greater the use made of the supply, therefore, the lower the cost per unit of energy. There is, indeed, with water power installations having adequate reserves of water, and with other small power plants, e.g. wind power plants, a good argument for running them at full output throughout the annual period for which their source of energy is available to them, devising useful loads which can absorb the power at any time of the day, month or year. There is no point in regulating the power output to suit some demand lower than the full capacity: having installed the plant, only very small extra costs are involved in operating it continuously on full load.

As for the capital costs of small water power plants, these are always difficult to state with any useful degree of accuracy. So much depends upon the relative magnitudes of the two prime factors, the water flow and the working head and upon the site

TABLE IV

Power	Head	Flow	Pipe diameter	Type of Turbine	Cost of plant*	Total cost*
kW	ft.	cu. ft. per min.	ins.	F = Francis I = Impulse	£ per kW	£
10	25	400	–	F	200	2,000
10	100	100	9	I	165	1,650
10	300	35	6	I	140	1,400
50	25	2,000	–	F	75	3,750
50	100	500	15 to 16	F or I	60	3,000
50	300	166	10 to 12	I	45	2,250
100	25	4,000	–	F	65	6,500
100	100	1,000	21	F	55	5,500
100	300	330	12	I	40	4,000

* Including rotating plant, switchgear and pipe but excluding transmission and civil engineering works.
Note: The length of pipe is assumed to be three times the operating head.

itself. The topography of the site must always have a major influence on the cost of the civil engineering work needed to make the installation.

Several potentially cheap small-capacity plants have been put on the market, in different countries, during the last few years. One important feature, as in the French 'bulb' units which can be completely immersed in the stream so that they need little constructional work for their installation, is the reduction in installation cost.

Some actual costs for small water turbine plants by a British manufacturer are given in Table IV. It must be emphasised that these costs are for the machines only and do *not* cover civil engineering and other associated work.

Even though, due to the need for civil engineering construction, the initial cost of a hydro-electric station may be high, per unit of power capacity, the length of life can usually be taken as much greater than for most other forms of power plant. The fixed charges for depreciation are, therefore, low although those for interest will be at normal rates. It may be accepted that, if a water power scheme has been given adequate preliminary study and has been considered to be justifiable, the cost of the energy produced from it is likely to be low. But – and this is a serious qualification – the energy is only cheap if it can be used near to the site of the installation: and there is usually little choice in this site which must be at a technically favourable point on the stream or water course.

(b) *Wind energy.* The power in a stream of air having a cross-section of 100 square feet is 4 kilowatts (about 5 horse-power) when the air is moving at 20 miles an hour and this rises to 13.5 kW (or 18 h.p.) for a speed of 30 m.p.h. The power in the wind is proportional to the *cube* of its speed and also, of course, to the cross-sectional area of the wind stream considered.

A windmill erected to tap this source of power, and to produce electric power, cannot extract all of it: an efficient machine might harness up to 40 per cent of the power in the wind. But this relative inefficiency is not serious because the power input is entirely without cost. An efficiency of only 40 per cent is easily counterbalanced by making the rotor of the machine tap a cross-section of 250 sq. ft. instead of 100 sq. ft. This means that the rotor diameter must be about 18 feet instead of 11 feet. A larger diameter means an increased cost of construction though this increase may not be very great because the cost of the rotor is only a fraction of that of the complete machine and, for a given power capacity, the rest of the cost is not influenced very much by the size of the rotor.

To allow for an efficiency of something less than 40 per cent the rotor diameter of a machine to produce 13.5 kW (or 18 h.p.) at a wind speed of 30 m.p.h. might, in fact, be 20 feet. Wind-driven electrical machines of this size have not yet been produced in sufficient quantity for a firm price to be quoted but several, of different makes, in the range of capacity 4 kW to 100kW, are under development and prices quoted indicate that they may cost £50 to £60 per kilowatt for the larger sizes and up to £200 per kilowatt for the smaller ones designed to run in low wind speeds. That maintenance costs for windmills are undoubtedly low has been shown by long experience with them in Denmark where many of capacities up to 70 kW have been used for a number of years. Maintenance has averaged between 1 per cent and 1½ per cent of their capital costs. The machines can run unattended and, if well designed and made, should require little more than routine attention for lubrication and general inspection. The operating costs, therefore, are mainly those for interest and depreciation and the annual rates will vary from perhaps 10 per cent to 12 or 13 per cent depending on the design of the machine (as affecting its working life), on any provisions which may be made for energy storage and, of course, upon ruling interest rates.

Annual operating costs can thus be taken as between £5 per kW and £25 per kW according to the capacity and design of the machine and the rate of the capital charges.

Having dealt with probable costs, we must now consider the annual output of energy likely to be obtained as a return on them. The annual output, per kilowatt of installed capacity, depends upon (*a*) the annual average wind speed at the site of the installation, and (*b*) the 'rated' wind speed at which the machine is designed to give its full power output. The higher the average wind speed the higher the rated wind speed chosen by the designer and the smaller the windmill rotor for a given power capacity, i.e. the cheaper the machine. (To show the effect of rated wind speed upon the probable cost per kilowatt of capacity, considering a fixed diameter of windmill rotor, the costs, per kilowatt, for rated wind speeds of 35 m.p.h., 25 m.p.h., 17.5 m.p.h. and 15 m.p.h. will probably be in the ratio 0.5: 1.0: 2.0: 2.75).

Annual average wind speeds are measured at meteorological stations all over the world and they range from only 1 or 2 m.p.h. to perhaps 20 m.p.h. But these observation stations are not located at especially windy places and, by specially selecting well-exposed sites – on smooth hilltops and near the coast when possible – average wind speeds over 50 per cent higher than those at the meteorological stations can be obtained. It must be clearly understood that, in spite of popular ideas about the wind blowing 'all the time', there are probably no places in the world for which this is literally true. Always there are some periods during the year when the wind drops to a complete calm though, at very windy sites, these periods amount to only a very small total of hours in the year. On the other hand, even at places with a low average wind speed, gusts of up to 80 or 90 m.p.h. may sometimes occur. A windmill has therefore to be made strong enough to withstand strong winds even though it is to be installed at a site which is not very windy. At windy places these gust speeds may rise to well over 100 m.p.h. For the assessment of the potentialities for wind power at a particular site, hourly wind speeds throughout the year should be available. These speeds are classified to show the annual number of hours duration for each wind speed, at 1 m.p.h. intervals.

Now, a windmill cannot be designed economically to use all the windspeeds that occur. A particular machine will begin to produce an output of power at some 'cut-in' point, e.g. 10 m.p.h. The power will increase rapidly as the wind speed rises to the 'rated wind speed' of perhaps 20 m.p.h. and, for higher wind speeds, it will give its full power capacity – but no more than that because its output is regulated for its own safety. The annual energy output can be expressed in terms of an equivalent number of hours per year running at full output. Thus, for example, if during the year (of 8,760 hours) the wind speed is equal to, or higher than, the cut-in point of the windmill for 6,000 hours (so that it is producing *some* power for the whole of that time) and if it produces full power output for 3,000 hours, the energy produced is, approximately, that corresponding to full power output for $\frac{6{,}000 + 3{,}000}{2}$ hours $=$ 4,500 hours. In other words, the annual output would be 4,500 kWh per kilowatt of installed capacity.

To calculate the cost of the energy under these conditions, suppose that the cost of the windmill installation is £100 per kilowatt and that the annual fixed charges are 12 per cent. Then the annual operating cost, per kilowatt, is £12 and the energy output, per kilowatt, is 4,500 kWh. The cost per kWh is thus $\frac{£12}{4{,}500}$ or 0.64 pence. For a large (say 100 kW) machine, the energy cost could be lower than this because its capital cost, per kW, might be less than £100. The output of 4,500 kWh/kW is, however, fairly high and would be achieved only at a site with a high annual average wind speed of 20 m.p.h. or more. As a guide to the probable costs of energy at sites with lower wind speeds, Table V has been drawn up.

TABLE V

Annual average wind speed (m.p.h.)	Capital cost of installation per kW. (£ sterling)	Annual output in kWh, per kW	Cost per kWh* (pence)
15	†100	2,680	0.9
	†200	4,500	1.1
12.5	150	2,800	1.3
10	200	2,440	2.0

* Assuming 10% annual charges.
† These capital costs correspond to different rated wind speeds.

In calculating these energy costs the fixed capital charges have been assumed to be 10 per cent: a rate of 12 per cent would, of course, increase the energy costs by 20 per cent. Even so, the highest cost would be only 2.4 pence per kWh. Figures for two different rated wind speeds have been given for the case of an average wind speed of 15 m.p.h. to show that, although a lower rated wind speed leads to a higher capital cost of £200, it also gives a much greater annual output per kW. Thus the cost per kW is not much increased while the annual period during which power output is being produced is much greater – the equivalent of 4,500 hours full output instead of 2,680 hours Under some circumstances this longer annual operating period might be a better economic proposition than a smaller output at a lower cost per kWh.

The costs of wind-produced electrical energy indicated in Table V often compare favourably with those for alternative methods of generating power in up-country districts. For example, in Chapter III the cost of generation by small diesel-electric sets was given as 6 pence per kWh. It is important to realise, however, that these windpower costs are for random power which, if it is to be so cheap, must be used as and when it becomes available: the costs do not take into account any means of storage to cater for calm spells. As a rough estimate, energy stored in an electric battery would cost about twice as much as the random energy, so that only a fraction of the energy output – such as might be needed to supply electricity for top-priority purposes – should be stored. The question of utilisation of wind-generated energy will be discussed further in Chapter IV.

Lest it be thought that this random nature of wind power is an intolerable disadvantage, it should perhaps be pointed out that, while the occurrence of usable wind speeds is rather unpredictable temperate zones, this does not apply with equal force in the tropics and sub-tropics. During quite long periods in the year high winds at certain times of the day can be predicted with some confidence: the diurnal variations of wind speed are regular. Seasonally, too, high winds can be depended upon and, in the very large majority of places in the world, the annual average wind speed – and therefore the available energy – varies little from year to year. Although, therefore, one cannot place one-hundred-per-cent reliance on the availability of wind power at a particular time on a particular day, there is near-certainty of a predictable total of energy from this source during a full year. Simple and easily-maintained instruments (anemometers) for wind measurements are available and the installation of a few of these at selected sites, in an area where wind power might have good possibilities, can provide invaluable information both on the relative favourability of the sites and on the annual wind régime. From the data obtained, annual energy outputs can be estimated with some precision, the daily and seasonal variations of wind speed can be determined and the maximum periods of calm weather can be measured.

Before concluding the discussion of wind power it must be emphasised that the production of electricity is not the only possibility. Non-electric windmills – wind pumps – are very commonly used for water pumping in dry areas. These machines are of very simple and robust construction and are designed to run in quite low wind speeds. They have a low rotational speed, in contrast to the electricity-generating windmills which are fast running, and they have a lower efficiency. Nevertheless, they are very effective as providers of water from underground sources. An obvious disadvantage of this type of windmill is that it must be located either immediately above the well or, at least, very close to it. There is thus no possibility of selecting a specially windy site and the energy output is restricted to that corresponding to the site of the well itself.

Wind pumps of this kind are made in a range of sizes with wind wheels varying in diameter from 6 feet to perhaps 18 or 20 feet. Assuming an efficiency of 20 per cent (which is probably the maximum likely to be obtained) the outputs, in gallons of water when pumping against a 'head' of 100 feet, would be as shown in Table VI.

TABLE VI

Wind speed (m.p.h.)	Pumping rate, in gallons per hour, for windmills having different rotor diameter				
	6 ft.	8 ft.	10 ft.	12 ft.	14 ft.
7	25	42	72	102	138
10	75	132	200	300	400
12	128	230	360	520	700
14	204	366	580	820	1,120
16	306	546	860	1,220	1,660
18	436	778	1,220	1,740	2,400
20	594	1,060	1,660	2,380	3,200

As for the probable costs of water pumped in this way, a representative price for a 10 ft. diameter wind pump, installed at a well, is £200. Taking the rate of annual fixed charges as 10 per cent, and assuming that pumping is against a head of 100 feet as was assumed in calculating the figures in the table, the annual costs would be £20 and the rate of pumping, at full capacity, might be 600 gallons per hour which corresponds to a rated wind speed of a little over 14 m.p.h. If the wind régime at the site were such that the annual output corresponded to 3,000 hours of full-capacity running, this output, in terms of water pumped, would be 3,000 x 600=1,800,000 gallons. The cost, per 1,000 gallons, would therefore be $\frac{20 \times 240}{1{,}800} = 2.7$ pence.

In spite of the impressive quantities of water pumped per hour the power capacities of these windmills are, in fact, quite small. In the above example the maximum power is just under one third of a horse-power, or ¼ kilowatt. The price per kilowatt of capacity can be seen to be very high, namely £800 but this fact does not appear to affect the popularity of such machines in dry areas. After all, if one must have water, for human beings and animals, in a dry area who is to say that 2.7 pence per thousand gallons is too high a price to pay.

(c) *Solar energy.* Like the energy from wind, that resulting from solar radiation is free, needs no transport to the site where it is to be exploited, and is inexhaustible. Also in common with wind energy, though perhaps in less degree, it is random in occurrence and cannot be depended upon to produce power whenever the power is needed. The sunshine régime in the tropical and sub-tropical countries in which this energy is most likely to show promise of economy is, however, more dependable than wind régimes are usually found to be. Except in the rainy seasons, bright sunshine continues for long periods each day although, of course, the daylight hours during the year constitute only 50 per cent of the total. As examples of the annual duration of bright sunshine, in central arid zones of U.S.S.R., south of 50° N, this is continuous for 150 to 200 days, while the sunshine records for New Delhi show that there are usually over 170 days with more than 9 hours of bright sunshine, giving a total annual duration of around 2,700 hours which is 60 per cent of the total possible. Although, in many areas, ample solar radiation is known to occur, precise long-term records for different districts are not as commonly available as might be expected and measurements of the intensity and duration of this radiation could usefully be made as a basis for calculations of the useful energy which might be obtained from solar-operated power plant.

The annual total of solar energy which arrives at the outside of the earth's atmosphere is about 1.6 million, million, million kilowatt-hours and the rate of this arrival is close to 1.35 kilowatts per square metre or nearly 2 gram-calories per minute per square centimetre. Some of this energy is absorbed in the atmosphere and is scattered by gases, by water vapour and by dust. Cloud and haze also reduce the amount penetrating to the surface of the earth.

The solar radiation which actually arrives at this surface may therefore be direct or diffuse radiation: the former may be 90 per cent of the total on a clear day but only 50 per cent, or even zero, on cloudy days.

In spite of these losses, however, and of the variability of the radiation received at different places and at different times of the day and year, a maximum direct radiation of over 1 kW per square metre can be obtained. The annual (24 hours per day) average for areas between 60° N and 60° S lies between 0.1 and 0.2 kW/sq. metre. Yearly averages of daily solar energy received on a horizontal surface in the sunny areas of the world range from about 4.5 kWh/sq. metre/day to nearly 7.5 kWh/sq. metre/day.

The equipment used to capture the solar radiation and to apply it to different purposes takes various forms, according to the actual application but most solar devices are based on either a flat-plate collector or a concentrating collector. Both can have collecting efficiencies of over 50 per cent.

The flat plate type of collector usually consists of a flat surface, blackened or otherwise treated to make it a good absorber of the radiation, and covered with one or more sheets of glass or translucent plastic material. There is then the well-known 'greenhouse' effect in which the heat is 'trapped' inside the glass cover. The blackened surface usually forms the top of a shallow tank containing water or any other fluid to be heated. The advantages of this kind of collector are that it can absorb diffuse radiation as well as direct radiation, so that it does not need to be continually held in a position facing the sun, and also that it is cheaper, per unit of surface, than the concentrating type. The main disadvantage is that the temperature attained by the heated fluid is generally rather lower than the boiling point of water – perhaps 180° F – although this boiling point can be achieved by the use of a surface specially treated with deposits of certain metallic salts.

The concentrating type of collector has a somewhat higher efficiency than the flat-plate type but is more expensive per unit of surface because it consists of a paraboloidal or parabolo-cylindrical surface which reflects the radiation and concentrates it at a focal point, or line, where the temperature is very high – several hundred degrees Fahrenheit or, in some solar furnaces even several thousand degrees. It is necessary that the reflector should face the sun continually and this calls for some mechanism which can slowly rotate the equipment and change its angle of elevation. Again, concentrating collectors can use only direct radiation: bright sunshine is needed for their operation and a cloud passing over the sun immediately stops their functioning.

Both of these kinds of collectors utilise the solar radiation directly for heating. Any further purpose, such as the production of mechanical power, involves the use of an engine or other device which can be driven by the heated fluid. There are, however, two methods by which the solar radiation can be converted directly to electric power. The first is by the use of thermo-couples – junctions of two dissimilar metals which, when heated, give an electrical potential difference, or voltage, in a circuit which must also contain a similar junction maintained at a lower temperature. The second is by the use of photo-voltaic cells which also produce a voltage through the influence of light on certain specially-prepared metal surfaces which are incorporated in the cells. Much research work is being done on these direct means of conversion of solar energy into electrical energy. Newly-discovered semi-conductor materials are being employed to make thermo-junctions which can be located at the focal points of concentrating collectors and, for photo-voltaic cells, new materials are being tried and improved methods of manufacture are being developed. Up to the present, however, although conversion efficiencies as high as 15 per cent have been achieved, these methods are too expensive – in first cost of the equipment – for use as producers of any significant amount of power. They are used to operate electrical instruments and equipment needing only very tiny quantities of power but for which, as in space vehicles and missiles, any other means of power production would be difficult to provide.

Flat plate collectors are used in solar water-heaters, solar stills (for the production of distilled water from saline water), space heating and air-conditioning installations and for solar-operated engines. The uses of concentrating collectors are for solar cookers, steam raisers and related applications such as distillation and ice-making, through an absorption refrigeration plant, and perhaps for the production of motive power using some form of heat engine. Solar furnaces, which have been developed for the high temperature melting of metal ores, for which purpose they have the advantage of introducing no impurities in the process, also have large concentrating collectors.

Some of these applications of solar energy, while certainly feasible technically, must still be regarded as in the stage of development from the point of view of cost. There is little doubt about the economy of solar water heating: the introduction of new materials for collectors and covers will doubtless reduce construction costs further but already costs of the order of £1 to £2 per square foot of collecting surface have been realised and, with an output of 1 gallon of water, at 135° F, per sq. ft. per day, the heating cost may be taken as between 0.1 and 0.16 penny per gallon.

Solar stills of a simple pattern, giving one gallon of distilled water per day, may cost between £1 and £2 and this does not appear excessive. The economy of more elaborate pieces of equipment, as for space heating and air-conditioning, depends upon the design of the house and of the installation itself: it is perhaps too early to express any general opinion on costs for this application. A solar water-pumping engine, using a flat plate collector containing liquid sulphur dioxide, was developed in Italy some years ago. The vaporised sulphur dioxide – the working fluid of the engine – was condensed in a condenser over which flowed the water pumped from below ground. The engine was to be produced in capacities from ½ to 3 h.p. but does not yet seem to have been adopted in practice. At the 1961 U.N. Conference on New Sources of Energy another form of solar engine (from Israel) which might well prove to be economic when produced in sufficient quantities, was demonstrated. There is no doubt that, if a solar water-pumping equipment could be produced at a reasonably low price, it would be of great benefit to many dry areas of the world.

Solar cookers, which employ concentrating collectors, have been put on the market in India, U.S.A., Japan and some other countries. Their output is usually between 300 and 600 watts and the heat energy produced by them is not likely to cost more than the equivalent of one penny per kWh. The difficulty is that a capital cost of around £5 for the cooker is too great for the villagers for whom it is intended. With the cooker, or with a steam-raiser using a concentrated collector, the need for continuous bright sunshine is an added disincentive towards their use.

(d) *Organic wastes*. In rural areas, wherever there are inhabitants cultivating the soil, or following some form of industrial activity, organic wastes, of one kind or another, are almost certain to be found. Even in deserted areas there is often much material which is not commercially valuable but which undoubtedly has an energy content that might be put to use. Examples are animal manure, sugar cane waste, sisal waste, coconut shells, straw rice husks and, in uninhabited areas, brushwood and many kinds of green vegetation (depending upon the climate of the area).

These materials have, in general, about half the gross heating value of coal or perhaps one third that of fuel oils. As an example, bagasse (sugar cane waste) has an average calorific value of some 8,500 British Thermal Units per pound as compared with 20,500 B.Th.U. per pound for petrol. Expressed in another way, the gross energy content of these materials (before conversion into a usable form of energy) is equivalent to about 4,500 kWh per ton. There may therefore be a valuable store of energy in an unconsidered pile of waste matter: the difficulty lies in converting it for power uses efficiently. Nevertheless, even if the efficiency of conversion is only, say, 3 per cent one ton of material represents a net output of 135 kWh which is almost equal to the work output of a man for a year.

In comparison with the other local sources of energy already discussed, this waste matter has the advantage that it is a form of stored energy which can be drawn upon, as required, to produce power. It is not a random source of energy – in the time sense. Its distribution is not, however, so widespread as wind or solar energy and, even when it occurs in adequate quantity for exploitation, it may have to be collected and this may involve some cost.

Such materials are already commonly used, in many countries, as fuels for heating and cooking and, sometimes, for steam raising in steam-driven power plants though most of these are large-scale plants associated with factories at which supplies of wastes are correspondingly large.

For small-scale plants three methods of use are possible:

(i) By burning dry material to produce steam for a small steam engine;

(ii) By feeding the material into a 'producer' to make 'producer gas' which can be used as a supplementary fuel in a dual-fuel engine;

(iii) By fermentation to produce methane gas which may be used as a simple fuel for domestic use or to drive an engine.

Let us consider these in order. The British National Research Development Corporation was responsible, some years ago, for the development of a 2½ h.p. steam engine with a specially-designed furnace and boiler. This was portable – it could be carried by two men – and could be driven by many different fuels with a fuel consumption of about 30 pounds per hour. For reasons which are not very clear, it does not seem to have been adopted in the areas for which it was intended. Perhaps maintenance proved a difficulty. Large, steam-driven plants, of more conventional designs, are operating in different parts of the world but, of course, need a skilled or at least semi-skilled, attendant.

As an alternative to burning combustible matter in a furnace, it can be used in a producer to make producer gas. Research work in East Africa has shown that wood can be so used successfully and that the gas, with a calorific value of between 100 and 160 B.Th.U. per cubic foot, is suitable as fuel for a modified diesel engine. It is suggested that maize cobs, coconut shells, groundnut or rice husks, cotton seed husks and bagasse could also be satisfactory in this process. When they are of large capacity, these producers may have an efficiency between 60 and 80 per cent but more research and development work is needed to evolve satisfactory, and sufficiently cheap, producers for small-scale plants.

Although, for many years, large sewage-disposal plants have used the methane resulting from fermentation of organic wastes as fuel for power production, attention has been paid only fairly recently to the possibilities of methane produced from farm and other agricultural process wastes. In France and Germany considerable numbers of small plants, using farmyard manure as their raw material, have been used and research work on the potentialities of sisal and other wastes has been done both in Germany and in East Africa.

The material used is put into a fermentation tank from which the gas is collected in either a low-pressure gas holder or compressed to a high pressure in portable cylinders which could be used, for example, to drive argicultural tractors. When farmyard manure is used, removal of the gas from it (over a period of a few weeks) does not destroy its manurial properties.

The fermentation process gives a mixture of gases – about 60 per cent methane and about 40 per cent of carbon dioxide with traces of other gases. The gross calorific value of the mixture is around 660 B.Th.U. per cubic foot and it is valuable as a fuel for internal combustion engines. When the carbon dioxide is washed out, the resulting gas has a calorific value of about 1,000 B.Th.U./cu. ft.

Research work in India has shown that many different kinds of waste material might be used successfully to produce methane but there are both technical and economic problems to be faced before this method of power production can be generally adopted.

It is difficult, with so many unknowns, to give any precise costs for energy production from organic wastes but it is probable that the cost would work out rather less than that for diesel generation and perhaps 4 pence per kilowatt-hour would be of the right order.

5. Planning and Utilisation of Power

Need for planning

In an industrialised country, with widespread electrical networks and perhaps also abundant supplies of oil and other fuels, planning the utilisation of power takes a minor rôle. Maintenance of the power supplies must, of course, be assured and provision of an electricity supply for the remoter districts may present some economic problems. But the latter are not really very serious: although electrical engineers naturally wish to extend their networks to cover all areas, alternative sources of power – oil, calor gas or even local sources such as peat or wood – are often available and can provide reasonably satisfactory alternatives.

Again, in all but the very remote areas of the industrialised countries, it is expected that an electricity supply, once having been provided, will have one-hundred-per-cent reliability – or availability. If the supply fails for even a very short time the consumers complain to their nearest electricity supply office.

Here, however, we are concerned more particularly with the question of providing power in areas where, at the moment, there are no adequate supplies, and where the economic outlook for the more conventional methods of providing them is poor.

It is unnecessary to repeat the arguments for or against small diesel-electric sets in comparison with power plant driven by local sources of energy. The costs of generating power by the former, in any given circumstances with known fuel costs, are easily determined. The interesting question is how, and to what degree, these costs – which are usually regarded as high – can be reduced through the use of complementary power plants of the kinds discussed in Chapter IV. But this is not simply a question of arithmetic for the calculation of alternative costs: other aspects of the matter, both social and economic, must be considered and some planning, either on a national or local scale may be needed.

National planning

Consider national planning first. Clearly governmental assistance will, in most cases, be needed for the initiation of local power-generating schemes, for their initial financing and for the guidance which is essential when something so entirely novel is being introduced to remotely-located populations. Field Surveys, based on long-term records of wind speeds, and the duration of bright sunshine, obtained by meteorological services, constitute the first step in any concerted effort to develop these two sources of power. The authority responsible for development must have reliable information on the quantities of energy to be expected annually from them, on the distribution of their occurrence during the year, on the maximum duration of periods when they are completely lacking and on the variations in their intensity.

Basic information of this kind enables those responsible for consideration of the potentialities of local energy sources to decide in relation to other known factors such as transport facilities, e.g. for oil fuel, and the availability of skilled or semi-skilled labour, in what parts of the country power installations using these sources would stand the best chance of success. The methods to be followed in undertaking energy surveys to obtain these essential data are now fairly well established and, indeed, in Great Britain and some other countries using British methods, the costs of making them, even in extensive areas, have been reduced to quite low figures. If necessary, technical assistance in work of this kind, can be organised through the United Nations Organisations and its specialised agencies.

At a number of international conferences, during the last few years, dealing with various aspects of the utilisation of unconventional sources of energy, much information on survey methods, on available equipment for different local purposes, and on methods of operation has been given so that there should be little difficulty, for a development organiser, in obtaining guidance on these questions.

It is to be assumed that no development authority would take the trouble to investigate the potentialities of local sources of energy unless financial provisions could be made for installations at places which the results of the investigations indicate as likely to be favourable. Any detailed discussion of such financing would be rather pointless because conditions differ so very widely in different countries. The most general method followed in parallel lines of development is perhaps through the establishment of some form of co-operative association or community which can take joint responsibility for repayment of loans and the payment of interest on them. Installations are made with the advice of the development authority and with continuing guidance until this becomes no longer necessary. The terms of repayment and rate of interest are usually made easy, as an encouragement.

As an example of this kind of development, the progress being made in northern Egypt can be quoted. Small groups of peasant farmers are allowed to form themselves into co-operatives which are registered and which become entitled to financial support, from the Government, in improving their agriculture through the installation of wind-driven water pumps. The pumps are installed by a government department and are paid for over a long period of years. Provision is also made for the purchase of fertilisers on easy terms. At an experimental farm in the western desert, at Ras el Hekma, dozens of such wind pumps have been installed as part of a large scheme to improve the agriculture of the area which is largely inhabited by Bedouin who roam over long distances to find the scanty and sporadic pastures upon which their flocks must depend. Provision of reliable supplies of water and the introduction of new grasses and other palatable plants which can withstand desert conditions may eventually revolutionise the area and the way of life of its inhabitants.

In Israel, also, the kibbutzim and other forms of agricultural settlements established in the dry, and previously-uninhabited, areas of the Negev, are provided with small power plants – mainly diesel-driven. The Israeli scientists have investigated the possibilities of wind power and, more especially, solar radiation for the production of small-scale power for these communities.

In Far Eastern countries, e.g. Malaya, the planning of new villages in hitherto-useless jungle is very active. Power must be given to these villages and, where they are distant from the main networks, diesel-electric sets are installed to cover the period which must elapse before these networks can be sufficiently extended to reach them.

When new villages are established the planning of power supplies is perhaps somewhat eased because, to some degree, they can be sited in such a way that a rationally-designed network can eventually pick up a number of them. And, also, the layout of the houses in the village can be planned so that the distances over which power has to be distributed from a central power station are minimised. In an old village, in which each peasant farmer has his house on his own plot of land scattering, with its disadvantage from the point of view of power distribution, is inevitable. Again, with development schemes of this kind there is some possibility of including the establishment of rural industries to accompany the agriculture and so to diversify the work of the people as well as to improve the characteristics of the electrical load. As already emphasised, the very essential task of building up the load, for income-increasing purposes, must follow the provision of a power supply if this is ever to achieve economy.

Perhaps the most important point to be appreciated is that the provision of power for a remote community is not to be regarded as a minor incident but as an event which had potentialities for changing radically the way of life of the inhabitants. Indeed, if it does not do this, it is doomed to economic failure although, of course, the amenities which it brings with it may greatly improve social conditions.

Local planning and utilisation

The points made in the foregoing remarks, on national planning or, at least, regional planning by some authority responsible for power supplies, will already be more or less familiar to anyone who has considered the question. The need for local planning is perhaps less obvious. Yet it would seem to be a very real need.

The reason is that, in the absence of a main network giving continuous (24 hours a day) service, the power supply will be, to a greater or less degree, restricted. To reduce operating costs by using only a limited amount of skilled labour, the daily running period of a small diesel station may be cut down to only 12 hours a day, or even less. Again, if power plants driven by locally-available energy sources such as wind or solar radiation are to be used to reduce the fuel consumption of the diesel plant – or, possibly, even run without the support of diesel plant – these will operate at random times. If the costs for such 'local energy' plants, estimated in Chapter 4, can be substantiated in practice, the fullest possible use should be made of them. This is not only to save fuel but to take advantage of the 'free' energy to be produced by plant with fixed standing charges. The low cost estimates for the energy from wind power or solar plants are made on the positive assumption that all the energy available from them is fully used.

We arrive, therefore, at a different conception of a power supply as something which, at least in part, dictates its own utilisation. Instead of there being continuously available power to be used as and when the consumer wishes, we have a supply which the consumer must make use of when it is available: otherwise it will run to waste. This state of affairs inevitably calls for planning – local planning – and willingness on the part of the consumers to accept the power régime which is thus imposed on them. It would be too much to expect that any community should be completely at the mercy of fickle wind or sunshine: some energy, though only a small part of the total produced, must be stored to meet first-priority demands, but the rest must be used as it becomes available. This requirement may not, in practice, turn out to be very troublesome. If one considers – as one must – the purposes for which the power may be needed, it becomes clear that by no means all of its applications have any precise time-dependance.

The possible power demands can, in fact, be subdivided according to their characteristics in this respect. Thus, power for water pumping, water heating, steam raising, water distillation, and perhaps even space heating and refrigeration, need not be supplied at any particular time of the day or night, assuming that the equipment employed has inherent storage. The water pumped can be stored in a tank or allowed to run for irrigation at any time. Heat can be stored in the water or steam and so on. It is, however, essential that there shall be some regularity in the power supply on a daily basis: whole days without power might be troublesome.

Certain other demands, e.g. those for agricultural purposes such as grinding, crushing, or winnowing, can be met at almost any time during the hours of daylight but the users must then be prepared to employ the power when it is available and not whenever they feel inclined to do the work in which the power assists. Other power demands certainly have precise timing requirements, e.g. meals must be cooked at certain hours of the day: one cannot refrain from eating until there is enough wind or sun to operate a windmill or a solar cooker. For these purposes an intimate knowledge of the usual diurnal variations in these sources of energy is a great advantage because, in some areas, their occurrence is not entirely random: some reliance can be placed upon their availability at certain hours of the day in different seasons of the year.

Power plants of different kinds can be operated, in combination, in two ways. They can feed their energy output into a common, local, power network which can absorb random power to save fuel whenever it occurs, a 'firm power' unit, e.g. a diesel engine, being one of the plants, or they can be used as disconnected units each fulfilling a particular purpose. The first method may need some skilled attention to ensure that the parallel operation continues smoothly without technical difficulties, while the second must be dependent upon either automatic operation or operation by the consumers who must then be responsible for adequate utilisation. Experimental work, in Britain, by the Electrical Research Association, has proved the value, in practical operation at a house in the Scottish Highlands, of an automatic load distributor. This is a device which automatically passes the power, as it becomes available, to loads which can use it. As the wind speed rises (the device was used with a wind-electric generator) and more power is generated, more loads are switched in, to be switched out again as the wind falls. This system has worked very successfully and it has demonstrated the practical possibility of making full use of random power without relying on the consumer in any way to manipulate the controls. The loads themselves must, of course, be judiciously chosen in the first place and the consumer can, by means of movable electric plugs, predetermine the order of priority for the loads. After the initial setting these loads are supplied in strict accordance with power availability.

Some power plants, e.g. water-pumping windmills and solar water-heaters, operate automatically without the need for any such control but they are single-purpose plants and their satisfactory operation depends upon adequate storage facilities – for the pumped water or the heated water – being provided.

Another form of power plant which has not previously been discussed is the mobile form – the tractor. These can be placed in in the category of individual plants operated by their owners without much regard to other supplies of power. They call for little comment here. Their capabilities and costs are, of course, well known and their use, which undoubtedly can have a great effect upon the agriculture of a developing area, is merely a matter of the availability of capital accompanied by provision for maintenance and repair.

In so far as planning is needed this will be mainly in the direction of supplying the necessary capital to enable groups of peasant farmers to make use of tractors. Governmental schemes for this can be introduced, on a co-operative basis, along with projects for land development.

6. Conclusions

The broad conclusion which can be drawn is that an adequate supply of power is one of the first essentials for a developing country. Without it both agriculture and industries are limited to such operating methods as will afford little more than a bare level of existence for those engaged in them. Setting aside the use of oil-driven tractors which, although highly important for agriculture, do not provide a general power supply, the obvious requirement is a widespread electrical network fed by power stations of ample capacity. The term 'ample capacity' needs some definition. The present world average for installed capacity of electrical generating plant is about one-fifth of a kilowatt per head of population. For Asia and Africa (excluding Japan and South Africa) it is less than one-tenth of this average. At an arbitrarily-chosen figure of £50 per kilowatt, the attainment, by the peoples in the under-developed countries, of the level at present enjoyed by the industrialised countries of Europe and North America implies an expenditure of between twenty and thirty million pounds sterling for each million of the population. And this must be matched by an approximately equal expenditure for transmission and distribution of the power to the scattered consumers.

Making all allowance for unlimited goodwill on the part of the industrialised countries, and for all possible support from international monetary agencies, it is clear that decades must elapse before this degree of electrification can be generally achieved. With the present knowledge of electrical engineering it is reasonable to assume that many of the mistakes of the past will be avoided in new schemes, and that their planning and execution will be much faster than that in the already-developed countries in which such electrification has been a slow process. Even so, large power schemes take a number of years to complete and, for the present, something less ambitious is needed to fill the inevitable time-gap. It is for this reason that so much attention is now being paid – as in the preceding chapters – to the potentialities of small-scale locally-installed power plants.

The second conclusion to be reached is that the electrification of under-developed areas cannot be done haphazardly: it must be very carefully planned. In the first place, the form of electrification – by general network or by small local schemes according to the distances from main power supplies – must be decided on. The economy of the scheme must be greatly influenced by the use which can be made of the power supply and the load-building process assumes a very important rôle calling for the collaboration of a number of different authorities as well as of the consumers themselves. Industrial and rural development authorities must plan activities which absorb surplus labour brought about by the increased productivity due to the use of electric power. Only by increased incomes of the population can the electrical energy be paid for: amenities such as electric light and radio improve the standard of living, and retard desertion of the rural areas, but they do not directly affect income. Agricultural advisory services can do much to help by studying the possibilities of improving the agriculture of their areas through the adaptation of electrical methods to the particular forms of agriculture being practiced there.

Education, both to demonstrate the advantages of electric power and to inform the population on its possible dangers, is a vital necessity.

The engineers responsible for the electricity supply in rural areas have, of course, a major part to play in discovering – perhaps even developing – electrically-operated equipment best suited to the needs of the farming population and in guiding them in its proper use. Various devices – demonstrations, talks, films and other forms of publicity – are very necessary and these can best be organised by rural development engineers who can speak to the population in their own language and with an understanding of their day-to-day problems.

If the electrification is to be done by means of a number of small local diesel stations, a repair and maintenance service will be needed and standardisation of equipment will be a great help in facilitating replacement of plant without carrying an excessive stock in the central stores.

Enough has perhaps been said about the unconventional small power plants making use of local energy resources – wind, solar radiation and organic wastes – to show that, while they offer good prospects of economy and have the great advantage of demanding no transport for their energy supplies, they need careful study before they can be installed in considerable numbers. Authorities considering such installations would therefore be well advised to establish a research or development department to survey their areas from the point of view of the energy available, to decide upon the most suitable forms of power plant for different circumstances and to test some of these under practical operating conditions. It would appear that these plants have good economic prospects if they are wisely installed and used, but if they are to be supplied as a proved piece of equipment which can be installed anywhere, and operated in the same way as a more conventional plant, economic failure is probable.

These remarks do not, however, apply to the simple water-pumping windmills, to the small direct-current electricity-producing windmills with battery storage, nor to solar water-heaters, all of which are sufficiently proved, and sufficiently simple in construction and operation, for them to be used by unskilled people. But these do not, of course, constitute a general power service: they are individual machines for specific purposes at particular sites.

To summarise the position, unless the thinly populated and un-electrified up-country areas are to wait for a considerable number of years for an electricity supply from a main network, the alternatives are small-scale power generation from fuels rendered expensive by heavy transport costs or from freely-available local energy resources which may result in much cheaper power. But the latter call for some care to be exercised in the choice of their design, and in their installation and operation.

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