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Prospects for Greater Efficiency in the Use of Different Energy Sources

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Prospects for greater efficiency in the use of different energy sources

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The United Kingdom grows a little more than one half of its food and it is shown that agriculture uses 4 % of national energy to make this unprocessed food available at the farm gate. Small though this may be, it is absolutely vital to British agriculture, for present levels of productivity are highly dependent on its use, principally through the media of mechanization and fertilizers. The prospects for the United Kingdom's indigenous energy supplies are examined and it is shown that while self-sufficiency seems assured in the 1980s, before the turn of the century we may once again be competing in world markets for scarce and expensive fossil fuels.

The prospects for making better use of existing and alternative energy sources in agriculture are discussed. It is shown that conservation measures may be practised in relation to existing energy sources in respect of powered machines, cultivations, drying of crops and glasshouse heating and that there are also possibilities in respect of fertilizers. New and under-used sources considered include solar energy by direct and photosynthetic means (energy crops), crop residues, animal wastes, wind power, industrial waste heat, and geothermal energy, and some examples are given of their application to agricultural systems. Some of these new and under-used sources of energy appear to offer some prospects of supplementing present sources but their future will be critically dependent on the availability and cost of energy from these more conventional sources.

1. Introduction

To feed the population of the U.K. involves an expenditure of about 16% of the nation's total energy use to cover the many activities that take place before food is available for consumption on the plate (see table 1 and White 1976*a*). (An appendix to the paper explains the units used in the tables and text and gives some useful conversion factors.)

The U.K. grows a little more than one half of its food, and agriculture uses only 4 % of national energy, or one quarter of the total involved in food supply, to make this unprocessed food available at the farm gate. Small though this may be, it is absolutely vital to U.K. agriculture, because present levels of productivity are highly dependent on its use, principally through the media of mechanization and fertilizers (see table 2 and White 1975, 1976*b*, *c*). The use of energy has brought great benefits to the whole food production cycle in that it has enabled us to maximize production in relation to land area and men employed and has given man varied foods to satisfy his needs in the form of hygienic, convenient and attractive packages. The benefits to agriculture may be illustrated by the fact that as recently as the two decades from 1950 to 1970, energy use in the form of direct fuels and electricity increased by a factor of 1.7 while the labour force was reduced to one half. During the same period, increased energy inputs in the form of fertilizers produced increased yields of arable crops and, in general, greater returns in output of metabolizable energy, in some cases by factors of 4 or 5 (White 1976*b*, *c*).

The substitution of energy for manpower and land has released resources for other purposes at the expense of increasing demand on our resources of energy. This would not matter if energy were both abundant and readily usable but our present state is one of overwhelming dependence on fossil fuels. In 1973 (see table 3), 97 % of the U.K.'s energy was provided by coal, petroleum and natural gas and only 3 % by nuclear and hydro-electricity (White 1975, 1976*b*). Fossil fuels will ultimately prove to be finite and although sources of abundant energy do exist, harnessing them has so far proved elusive. Thus, in considering the management of inputs for yet greater agricultural yield and efficiency, this paper discusses:

(i) the prospects for the continued availability of energy from present sources,
(ii) energy conservation in relation to existing sources,
(iii) the possibility of using alternative sources that are at present little used or not at all.

Table 1. Primary energy involved in food production, U.K. 1973

	primary energy PJ	percentage of national consumption (9260 PJ)
agriculture (to the farm gate)	361	3.9
processing, packaging, distribution	648	7.0
food storage and preparation	449	4.9
total	**1458**	**15.8**

Table 2. Primary energy consumed in U.K. agriculture, 1973

item	PJ	percentage of total
solid fuel	4.1	1.1
petroleum	85.0	23.6
electricity	33.1	9.2
fertilizer	83.5	23.1
machinery	52.0	14.4
feedstuff processing (off-farm)	51.3	14.2
chemicals	8.5	2.4
buildings	22.8	6.3
transport, services	16.3	4.5
miscellaneous	4.3	1.2
total	**360.9**	**100.0**

Table 3. National energy consumption in the U.K. 1973

source	consumption	energy equivalent PJ	percentage of total energy
coal	134 Mt	3500	37.8
petroleum	95 Mt	4300	46.5
natural gas	28.3 km^3	1170	12.6
nuclear electricity	—	240	2.6
hydro-electricity	—	50	0.5
		9260	**100.0**

2. Present energy sources

The situation in relation to the U.K.'s indigenous sources is illustrated in table 4 with data on reserves from *Energy R & D in the United Kingdom* (Department of Energy 1976*a*) and the life of each resource was calculated by using 1973 rates of consumption (*Digest of United Kingdom energy statistics* 1974). In fact, over the 20 years to the energy crisis of 1973, primary energy consumption in the U.K. grew at an average rate of nearly 2 %. Were the U.K. to return to this energy growth rate for the long term, energy consumption would double by the year 2010.

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The U.K. has no indigenous uranium resources but the amount of this material already in the U.K. could be equivalent to some 20 Gt of coal if the plutonium formed as a by-product in thermal reactors using uranium is recycled through fast breeder reactors.

In the early 1980s, the U.K. will have sufficient indigenous resources to balance its total energy needs, but production of North Sea oil and gas is likely to peak before the end of the decade and not long after that a gap will develop. The U.K. could again become dependent on imported fossil fuels, and scarcity will undoubtedly justify a premium price as world oil resources become depleted after world production peaks about the year 2000. The use of these natural hydrocarbons may become restricted to premium applications such as chemical feed-stocks and motor fuels, and as they decline coal will assume great importance as a supplementary source of these premium hydrocarbons.

Table 4. Estimates of the U.K.'s indigenous energy resources

resource	estimated recoverable reserves: unit given	estimated recoverable reserves: coal equivalent (Gt)	consumption per annum in 1973	estimated life (a)
coal	45 Gt	45	134 Mt	336
oil	3–4.5 Gt	4.5–6.7	95 Mt	32–47
natural gas	$(1.6–1.8) \times 10^3$ km^3	2.2–2.6	39.7 km^3†	39–46
uranium	—	20	—	100–200

† Given by Gray (1976) as 'current consumption'.

Although coal and nuclear fission could undoubtedly meet an increasing proportion of world and U.K. energy needs in the future, the precise extent to which the latter will do so may prove to be dependent on its social acceptability. Controlled thermonuclear fusion could remove the hazards of radioactive waste fission products, plutonium proliferation and the possibility of an explosive energy release in a reactor accident, but the scientific and technological problems of fusion are severe and feasibility has not yet been demonstrated (Roberts 1976). Thus, in the long term, we may be increasingly dependent on renewable natural sources such as solar energy, wind power, wave power and geothermal heat.

The question is, of course, what does this mean for agriculture? At least until 1990 and possibly beyond 2000, it appears that petroleum fuels for machines and natural gas for the manufacture of fertilizers will continue to be available but that after this there may be steep price increases as we turn to alternative sources through imports or by synthesis of hydrocarbons from coal. Thus the picture for the twenty-first century is uncertain but there is reason for the U.K. to make sensible use of its indigenous resources and to prepare for the future in every field of activity, including agriculture, by becoming a more efficient user of energy and by developing additional sources of energy. Successive sections of this paper attempt to develop these somewhat interrelated themes of conservation and new sources of energy in relation to agriculture and to assess the possibilities.

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3. Energy conservation

3.1. *Introduction*

We have seen from table 2 that petroleum fuels (23.6 %) and fertilizers (23.1 %) are the largest users of energy in agriculture. Table 5 gives a further breakdown of petroleum fuel use in various sectors (White 1976*b*). In the following, brief consideration will be given to conservation measures that are or may become possible in relation to tractor operations, cultivations, drying of crops, glasshouse heating and use of fertilizers. While improved use of animal wastes and crop residues may both be regarded as conservation measures, they will, in this paper, be treated as providing the basis of alternative sources of energy.

Table 5. Use of petroleum fuels in agriculture, U.K. 1972/73†

sector	consumption kt	energy equivalent PJ	percentage of total energy
tractors and self-powered machines	925	42.1	48.5
vehicles, lorries, vans, cars	293	13.7	15.8
glasshouse heating	496	21.8	25.2
heating, drying, lighting	198	9.1	10.5
total	**1912**	**86.7**	**100.0**

† May to June.

3.2. *Operation and maintenance of tractors and machines*

Tractors and other self-powered machines are the largest users of petroleum fuels (see table 5). Efficient use of energy in them depends on maintenance of the machines, the knowledge and skill to drive them most economically, and the setting and maintenance of implements. Good maintenance can reduce direct fuel consumption by avoiding leaks, while regular servicing of injectors and air cleaners can improve engine efficiency by as much as 10 % if they have been neglected for some time (Matthews 1975). It may also provide an indirect saving of energy by reducing the demand for spares and new machinery (see table 2).

It is worthwhile using the smallest tractor available which is capable of doing the job required. In this way, rolling resistance of the wheels is minimized and the engine may operate at optimum efficiency if a gear is selected which will allow the engine to operate near to its maximum torque. The tractor should be ballasted and loaded so that wheel slip does not exceed 15–20 %, at which point traction efficiency is normally a maximum. Attention to implement maintenance is important because worn shares, tines, knives and other cutting elements can increase the energy needed to carry out the work as, of course, can poor lubrication and adjustment.

3.3. *Cultivations*

In recent years, there has been a move towards minimizing cultivation operations with the object of decreasing manpower requirements and reducing the damage done to soil structure by compaction and smearing due to the repeated passage over the soil of heavy machines. Fuel may also be saved due to the reduced amount of work done on the soil. Where soil conditions allow it, seed may be directly drilled into the ground without prior cultivation. Experiments showed that this required only one ninth of the fuel used by a conventional cultivation system involving ploughing followed by a spring tine cultivator (Patterson 1976). However, in

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cereals production, fertilizers account for as much as one half of the primary energy used and substantial contributions are made by the energy to manufacture machines (19 %) and to dry the grain (15 %). The overall effect is that the direct drilling system uses about 11 % less energy than the conventional one (White 1976*a*). In addition, it offers worthwhile monetary savings (Patterson 1976).

3.4. *Drying of crops*

Artificial drying of crops, where practised, can be a considerable user of energy in relation to the field operations that the crops require (*Report of the energy working party* 1974). In the U.K. climate, cereals are frequently harvested at a moisture content in the range of 18–22 % and this must be reduced to nearer 15 % for storage. Bailey (1975) shows that the all electric in-store type of drier may use twice as much primary energy to dry a given quantity of grain as do the electrically fanned oil fired driers of the continuous or in-store types. In grass conservation, minimum energy is used if natural drying methods are employed to make hay or if the grass is made into silage.

The fuel consumed in high temperature drying of forage crops may be reduced by mechanically squeezing out some of the water before drying (Shepperson & Bennett 1975). The extracted juice brings with it some of the crop protein and is a suitable feed for non-ruminant animals such as pigs. The fibrous residue can be fed directly to cattle, made into silage or dried and made into pellets, cobs or wafers. A further development is a method for recovery of heat in grass drying plant from the exhaust air and steam from the drier (Kunz 1975).

3.5. *Glasshouse heating*

Glasshouse heating accounts for 25 % of the petroleum fuel used in agriculture (see table 5) and is undoubtedly the sector which has been hardest hit by rising fuel prices, simply because heating forms such a large proportion of the cost of producing protected crops. For example, for early tomatoes, fuel and power accounted for 40 % of the production costs in 1975 (Sheard 1976).

In many houses, there is scope for energy economies through improved installation, operation and control of heating equipment. To minimize spatial temperature gradients, steel heating pipes should be installed at low level around the perimeter walls, while with warm air systems, air should be distributed through perforated film plastic ducting near to the ground. Control sensors need to be carefully positioned since they can be subject to errors from radiation and draughts unless they are correctly screened and aspirated. The highest rates of heat loss occur in strong wind, and shelter belts, consisting of trees, hedges or woven or extruded plastic netting can reduce heat losses. Glasshouses orientated east to west transmit more radiation in winter than houses orientated north to south.

It has been shown that the heat loss from a glasshouse can be reduced by placing a canopy between the crop and the glass. This reduces the heat transferred by water vapour condensing on the inner surface of the glass and it also reduces radiation loss from the crop. Measurements on a commercial nursery showed that night use only of the canopy throughout the year would result in an annual fuel saving of about 20 % (Dawson & Winspear 1976).

Another development is an inflated-roof greenhouse which has interesting heat and light saving features. This design reduces the supporting framework to stanchions and gutters only and uses an air supported roof consisting of a double layer of plastic film secured to the edges of adjacent gutters, the two layers being held apart by a low inflation pressure. Through

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eliminating the opaque supporting structure, light transmission is comparable with that of commercial glasshouses and a heat saving of up to 45 % is possible (Bailey, Bowman & Cox 1976). This design is now being developed commercially.

3.6. *Fertilizers*

Manufactured fertilizers are a major user of energy in agriculture at 23.1 % of the whole (table 2) so there is an incentive to seek plant nutrients that consume less energy. There may well be reason to grow more leguminous crops, to choose rotations which decrease the need for artificial fertilizers and to ensure that effective use is made of animal manures as a source of plant nutrients. More effective systems for predicting fertilizer requirements in relation to such things as soil type, previous weather, cropping sequence and crop needs should lead to their more effective use (Cooke 1977). Several recent research findings have opened up exciting possibilities for the development of new chemical nitrogen fixation processes (Chatt 1977) which could perhaps lead to less energy intensive processes for producing nitrogen fertilizer commercially and for enhancing biological nitrogen fixation (Postgate 1977) which could reduce the fertilizer needs of plants.

4. Alternative energy sources

4.1. *Solar energy*

The total input of solar energy to the U.K. is impressive, some 80 times the present total primary energy demand. On entry to the atmosphere, the energy flux of the solar radiation is about 1.35 kW/m^2 but a variety of scattering and absorbing processes in the atmosphere reduce the maximum flux to about 1 kW/m^2 at the surface (Brinkworth 1976). However, the mean horizontal surface irradiance for the U.K. is much lower than this, at about 0.1 kW/m^2 (U.K.–I.S.E.S. 1976). In the U.K., less than half of the radiation reaching the surface is in the direct mode and this is important, because the larger part, in the diffuse mode, cannot be brought to a focus by a reflector. There are wide seasonal variations in the monthly mean energy flux with average daily totals of about 16 MJ/m^2 in summer and 2 MJ/m^2 in winter for the southern U.K. The total energy received by a horizontal surface in a year is about 3500 MJ/m^2, while countries which enjoy sunnier climates such as Australia have about 6500 MJ/m^2 (Brinkworth 1976).

The simplest direct solar energy collector is the flat plate type in which radiation passes through a transparent cover plate and is absorbed on the collector panel. Heat is transmitted to a fluid, usually water, flowing in passages in the panel or over the surface of the panel. The cover plate reduces convection losses and also acts as a radiation rectifer, as it is transparent to incoming radiation but opaque to the infrared radiation emitted by the collector. Typically, 50 % of the incident energy may be collected at 55 °C for British summer conditions (Brinkworth 1976).

The use of solar energy for heating purposes is already well established. A traditional dwelling house in temperate latitudes requires in midwinter about 350 MJ per day for space heating and about 50 MJ per day for domestic water heating. Assuming a usable roof area of 50 m^2, and using the previously quoted values of 16 MJ/m^2 in summer and 2 MJ/m^2 in winter, it is clear that even with high collection efficiency, the space heating demand cannot be met in winter though it may be in autumn and spring. Domestic hot water could not be obtained

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at the required temperature in winter. Thus, for both uses, solar heating must be seen as a means of fuel saving rather than a complete replacement for traditional heating methods. In Virginia, U.S.A., solar water heaters are being used in conjunction with a heat pump in a scheme to provide environmental control in a piggery nursery building (Vaughan, Bell & Hughes 1976).

4.2. *Application of solar heating of water to glasshouse heating*

One of the most likely applications for solar heating of water could be in protected cropping but it would be necessary to store the energy surpluses of the day against the energy shortages of the night. One possible way of doing this is by use of a solar pond. The incident radiation penetrates the liquid in the pond and falls on the blackened base which is thereby heated. Convection is prevented by dissolving suitable salts in the lower layers of water to increase their density while leaving the fluid still transparent. A build up of temperature then takes place at the bottom of the pond (Tabor 1963). In Ohio, U.S.A., such a pond $8.5 \times 18.3 \times 3.6$ m deep has been constructed to collect and store all the winter heat for a greenhouse 100 m^2 in area (Short, Roller & Badger 1976). The planned maximum temperature in the lower layers is 82 °C and heat will be extracted by pumping warm brine out of the bottom of the pond and through a brine-to-air heat exchanger. The first test is planned for the winter of 1976/7. It is estimated that a solar pond operated in the U.K. might yield about 10% of the incident energy at temperatures varying during the year between about 15 °C and 35 °C (U.K.–I.S.E.S. 1976).

A system for heating polythene greenhouses is being investigated in New Jersey, U.S.A. and has several novel features, comprising low cost solar collectors, storage and heat exchangers (Roberts, Simpkins & Kendall 1976). The solar collector consists of a rectangular frame 7.3 m long and 3 m wide which may be inclined at an adjustable angle. The frame supports a layer of black plastic sandwiched between two air inflated sections of clear film. Water flows by gravity between the inner layer of the front inflated section and the black layer and is returned to a store situated under the floor of a 5.2×7.3 m double film plastic greenhouse. The floor consists of a 9 cm thick layer of porous concrete with a rock aggregate underneath of 18 cm thickness which offers a solid surface but also provides storage space for the warmed water. The floor gives up its heat to the air inside the greenhouse but additional heat exchangers are incorporated for use at night. These consist of a single sheet of plastic film draped over a supporting member to which a trickle irrigation device is attached under the film. Warm water pumped from the floor storage flows by gravity between and down the inside surfaces of the plastic sheet and through the porous concrete floor back into storage. The plastic heat exchangers are easily dropped during the day to avoid shading the crops. The authors suggest that these elements can be put together to form an economical system for a commercial greenhouse operation.

4.3. *Application of solar heating to crop drying*

Solar energy is extensively used in crop drying and experiments are in progress which seek to enhance solar energy capture to reduce the supplementary fossil fuel inputs that are so often necessary. Crop drying systems invariably use air as the heat and mass transfer medium and most of these experiments employ solar air heaters. The basic design of these is similar to the flat plate water collector except that larger ducts are needed, within the collector and between it and the point of use, because of the necessity of using large volumes of air of low volumetric specific heat with low heat transfer coefficients compared with water.

One of the simplest systems, in Wisconsin, U.S.A., uses as a bare plate solar heat collector the galvanized roof of a metal building adjacent to a low temperature drying bin (Bauman, Finner & Shove 1975). A false ceiling was installed under the roof over one third of the building to give a solar collector of 140 m^2. Air was drawn between the false ceiling and roof before passing to the drying fan and hence to the grain bin of 8.2 m diameter by 5.5 m high. During 1974, about 50 % of the required supplementary heat was obtained from the metal building in the form of solar heat and the remainder was provided by electric heaters. In 1975, the solar contribution was increased to 93 % due principally to the effects of weathering of the galvanized roof and to improved management of the system. After 2 years of use, 58 % of the cost of the materials for collecting solar heat had been recovered in the form of savings in fuel costs.

Bare plate solar collectors have also been constructed as an integral part of the grain drying bin itself and take the form of a secondary wall which encircles the bin with an air space between it and the bin wall. In the bin constructed by Morrison & Shove (1975), in Illinois, U.S.A., the secondary metal wall extended around two thirds of the circumference of the 5.5 m diameter bin and the air space was approximately 8 cm. The drying fan was encased within the absorbing wall and all the drying air was pulled through the space created between the two walls. When the outside of the collector surface was painted black, it was found that the collector efficiency was approximately 30 % and it was found possible to dry grain of 24 % initial moisture content to 16.5 % without supplementary heat other than that gained through the solar energy collector and the fan itself. The authors suggested that the investment in the solar energy collector could be recovered in 3–6 years from the savings made in fuel costs for drying.

A similar arrangement to that already described was investigated by Peterson & Hellickson (1975), in South Dakota, U.S.A., except that the solar collector was of the covered suspended sheet type, with air flowing on both sides of a black painted solar absorber surface. The cover was a flat, translucent, fibreglass reinforced plastic material, sold for greenhouse use and the air space on each side of the absorber sheet was 8 cm. Grain with an average moisture content of about 18 % was dried to about 13 % with an apparent saving by use of the solar collector of 26 %. It was suggested that this would have been larger with grain of higher initial moisture content.

4.4. *Energy crops*

The photosynthetic process converts solar energy into fixed energy in the form of carbohydrates and the cellulosic material may be converted into hydrocarbon fuels by fermentation, pyrolysis or hydrogenation. Graham (1975) estimates that 1 t of dry organic material can be converted into 2 barrels of oil (275 kg) with an energy equivalent of 12.4 GJ. However, a lower conversion factor of 8 GJ/t of dry matter has also been suggested (Department of Energy 1976*b*). The present oil consumption of the U.K. is 95 Mt per annum with an energy equivalent of 4.3 EJ (see table 3) and using 8 GJ/t, the amount of dry matter equivalent is thus $(4.3 \times 10^{18}\ J)/(8 \times 10^{9}\ J/t) = 538$ Mt. Table 6 shows the average to good dry matter yields that may be expected from some high yielding crops in various parts of the world (U.K.–I.S.E.S. 1976). The best yields obtainable in the U.K. are about 20 t/ha and to produce the energy equivalent of our present oil consumption would require an area of (538 Mt)/(20 t/ha)

= 27 Mha. This is greater than the area of the U.K. (19 Mha). To produce even 10% of our present oil consumption would require a cropping area equivalent to one seventh of the U.K.

The importance of food is such that it seems unlikely that land could be released to raise fuel crops in the U.K. It has been argued (Department of Energy 1976*b*) that there is much marginal land not suitable for agriculture that could be so used, particularly by means of afforestation, and it will be noted that table 6 suggests that yields of dry matter from trees can approach those of the arable crops. If the use of land to raise crops for energy is practicable anywhere, it is most likely to be in the tropics where yields of napier grass can reach 85 t/ha (see table 6). Even here, however, the pressures of food demand are likely to prevent any such exploitation and these calculations do not take into account the inputs in the form of fertilizers that may be needed to sustain yields over a long period of time or the machines and fuels needed to harvest, transport and process the crops.

Table 6. Dry matter yields of some high yield crops in various countries

crop	country	yield of dry matter ($t\ ha^{-1}\ a^{-1}$)	photosynthetic efficiency (%)
temperate			
rye grass	U.K.	23	1.3
sugar beet	U.K.	23	1.1
evergreen forest	Europe	22	0.8
sub-tropical			
sorghum	U.S.A., California	47	1.2
alfalfa	U.S.A., California	33	1.0
tropical			
napier grass	El Salvador	85	2.4
sugar cane	Hawaii	64	1.8

4.5. *Energy from crop residues*

Conflict with the requirements of food and fibre production is less likely to arise if the residues of food crops are used for energy purposes instead of growing special crops. The largest residue available in the U.K. is cereals straw, and while published work (Smith, Rutherford & Radley 1975; Morris, Radley, Smith & Plom 1976) shows wide variations according to variety and soil type, it may be assumed that an average hectare in the U.K. yields roughly 3.5 t of straw. About 3.8 million ha of cereals are grown annually (*Annual review of agriculture* 1974) and assuming a moisture content in the field of 30%, this gives a total dry matter yield of 3.8 Mha × 3.5 t/ha × 0.7 = 9.3 Mt. The corresponding energy in the hydrocarbons that may be produced would be 9.3 Mt × 8 GJ/t = 74 PJ or rather less than 2% of the U.K.'s petroleum usage. However, a few years ago only about 38% of the straw produced was surplus to requirements (A.C.A.H. 1973) and it seems likely that even less would be available now. Apart from its traditional uses in managing animals and their wastes, in horticulture, and in making strawboard, it is increasingly being regarded as a useful raw material for processing into animal feed by means of delignification (Wilson 1974; Wilson, Sangster & Walker 1976), as a substitute for hardwood pulp in paper making (Truman 1974) and for furfural chemicals (Young 1976).

Rather than manufacture hydrocarbon fuel, it would be much more practical to burn and use the energy in straw on the farm. If directly burnt, straw of calorific value 18.4 GJ/t and

30 % moisture content, would have a gross energy value of approximately 3.8 Mha × 3.5 t/ha × 0.7 × 18.4 GJ/t = 170 PJ, that is, about 4 % of the U.K.'s petroleum usage. However, as was mentioned previously it should not be assumed that more than 38 % of this would actually be available. There is at least one case where a farm is using straw in addition to other materials such as logs and paper in a slow burning furnace which is draught controlled by the temperature of the water being heated. The water is used for central heating and domestic purposes, but such a system also has possibilities for agricultural purposes such as grain drying in bins and to provide heating for controlled environment houses. The heat of combustion of straw is being used to dry both grain and straw in an investigation (Wilton 1974) of whole crop cereals harvesting. The whole crop is harvested by means of a precision chop forage harvester, is dried in a rotary drier and then passes to a separator where the grain is removed and the straw is fed to a straw burning furnace which supplies heat to the drier. Surplus straw could be used to dry forage crops.

4.6. *Energy from animal wastes*

Animal wastes may undergo anaerobic fermentation to produce methane gas which can be used as a direct fuel. Up to 1950, a number of gas generators were in operation in the U.K. and many in France but they are now common only in developing countries such as India. Anaerobic digestion also provides a method of treating farm wastes to reduce pollution hazards. Plant nutrients are conserved in the material left over after gas production and the carbon/nitrogen ratio is reduced to a balance suitable for manurial purposes.

Production of methane in the U.K. has been a feature of municipal sewage works for many years, but what is feasible on a large scale is less attractive on a small scale, and there are many drawbacks to farm operation. The first is capital cost of the plant. The digestion process must be carried out in an airtight vessel, a digester in which raw wastes are added daily and sludge is withdrawn simultaneously. The second drawback is that optimum digestion is obtained at about 35 °C and this means that a proportion of the gas, which varies according to season, must be used to heat the raw wastes and maintain the plant temperature. Typically, the heating requirement as a percentage of the total gas produced is nearly 50 % for poultry manure and 40 % for pig manure (Jones & Brown 1974). While the gas can be used in suitably modified gas burning appliances, its use in engines requires plant for the removal of carbon dioxide and hydrogen sulphide and the gas must be compressed into cylinders. This requires special compression equipment, the use of power of a substantial order, and presents safety hazards.

Bousfield, Hobson, Summers & Robertson (1973) and Bousfield, Hobson, Mills & Summers (1976) have experience of constructing and operating plant including a 13000 l (approximately 13 t) capacity plant for methane production using piggery wastes. They suggest that a plant of 70000 litre capacity might be viable from an energy point of view alone with a continuous output of 25 kW for a capital cost of £15000–£20000. This implies an input of about 7000 l of waste per day which is equivalent to the output from a piggery holding about 1500 fattening pigs. The importance of the size of the unit is demonstrated clearly from the work of Oppenlander, Cassell & Downer (1975) who performed economic analyses of energy production by the anaerobic digestion of dairy cow manure from herds varying in size from 20 to 200 cows on farms in Vermont, U.S.A. Winters are severe in Vermont and only the dairy farm of 200 cows provided the necessary economies of scale for generating methane at a unit cost that approached the present charge for electrical energy there.

Holdom (1976) reports that a commercial digester is now in operation on a Perthshire farm and was designed to process up to 500 t of beef cattle wastes and straw each year, generate methane, and leave a slurry that could be used as a fertilizer and soil conditioner. No mention was made of the use envisaged for the gas. To use it on any substantial scale would require compatible enterprises in close proximity. For example, to supply the heating requirements all the year round, for a glasshouse of 1 ha, would require all the slurry from 22000 pigs. Considerable gas storage facilities would be required since the heat demand is a fluctuating one and 16 % would be required in February.

4.7. *Wind power*

The British Isles are set in one of the windiest regions on Earth. The winds are strongest around the west coast of Ireland, Scotland and Wales with an average wind speed of 7.6 m/s, fairly strong around the other coasts at 5.6–6.7 m/s and rather lighter over most inland regions at around 4.4 m/s (Swift-Hook 1976). Except in small sizes and specialized locations the use of wind as a source of energy has not been a viable proposition except perhaps where none other is available and power is required in small amounts discontinuously.

One company with a history of helicopter rotor design (Wind Energy Supply Company 1975) believes it can apply this experience to the design of cheaper and more efficient power producing rotors than hitherto. They envisage a twin bladed rotor of 18 m diameter which would generate a maximum power of 150 kW. The essence of the design is a simple built-in blade pitch control, which enables the rotor to start up in a light breeze, increase its speed proportionally up to a predetermined wind speed and then limits it to a constant speed and power for any higher wind speed. This company has a number of proposals for making use of the power generated but in its simplest form, the rotational energy of the rotor would be converted into hydraulic power and thence into heat energy which could, for example, be used to heat a glasshouse. Because of the uncertainty of availability of wind power it would clearly be sensible to retain the existing heating installation and only replace part of the demand by wind power. The viability of such a system hinges critically on the capital cost involved and in order to make a rational assessment of such schemes a 150 kW windmill is now being erected to provide part of the heat for a glasshouse of 400 m^2 at Efford Horticultural Station in Hampshire.

4.8. *Waste heat utilization*

The possibility of utilizing waste heat from power stations and industrial operations is one that is frequently raised in relation to agriculture and aquaculture. A coal fired power station with an electrical output of 2000 MW consumes the heat equivalent of 5500 MW of energy and disperses 3000 MW in the condenser cooling water and 440 MW in the flue gases (Owens 1976). The temperature of the cooling water at outlet from the condenser is usually within the range 15–35 °C, that is only 15–20 °C above the ambient air temperature. The possibility that the heat in this cooling water could be used to heat glasshouses within close proximity to power stations is currently being examined by the Central Electricity Generating Board in experiments at Eggborough Power Station in Yorkshire (Statham 1975; Masterson 1976; Owens 1976). Glasshouse complexes already exist in association with power stations in Russia and France and at least two industrial undertakings in the U.K. are building greenhouses to use their waste heat. Applications to aquaculture of both fresh and marine species of fish is under investigation at Ratcliffe-on-Soar Power Station, Nottingham, using eels and carp

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(Aston, Brown & Milner 1976) and at Hunterston Nuclear Power Station, Ayrshire, on plaice, sole and turbot (Kerr 1976). Commercial exploitation using eels and carp is taking place at Drax Power Station in Yorkshire.

In the experiment located at Eggborough Power Station, a 2000 MW coal fired station, there are three polyethylene tunnel greenhouses of semicircular cross-section, each with a growing area of 200 m^2 (36.5 m long by 5 m wide), two with evaporative heating units and the other with a fan assisted convector unit. In the evaporative heating units, air picks up heat by direct contact with the condenser cooling water and becomes saturated. In the convector unit, air and water are separated by finned tubes. The first evaporative heating system is housed in a double skinned structure formed by two concentric polyethylene tunnels of different widths, 6 m and 5 m respectively. Air flows from the direct contact heat exchanger through the growing area and the return air flow passes between the two skins back to the heat exchanger. This type of structure provides additional insulation, it should give a smaller temperature drop in the growing area and may reduce humidity and condensation. Disadvantages are increased cost and reduced light transmission. The second evaporative-pad heat exchanger and the finned tube convector are installed in single skin structures of 5 m width and warm air is distributed by means of flexible plastic ducts lying on the ground along the long sides of the houses. Conventional ventilation and irrigation systems and CO_2 systems are installed in each house. There is a proposal to build a fourth house which would be heated by circulating the condenser cooling water through lay-flat polyethylene tubes laid on the ground as in the French project at St Laurent des Eaux (Winspear 1975).

A more fundamental modification to power stations has been proposed to make use of waste heat by replacing the conventional cooling tower and condenser arrangement by a system of pipes buried in the topsoil of the ground area surrounding the station. It is assumed that the crop growing potential of the warmed area would be raised. Sanders & Skaggs (1975) showed that soil, air and plant temperatures could be increased in this way and conducted crop experiments in North Carolina, U.S.A., using cucumber, cabbage, snap beans, strawberries, sweet corn and sweet potato. It was found that crop emergence, growth and yield were generally increased, earliness enhanced and length of cropping season extended but there could also be a decrease depending upon the natural conditions of the crops' production.

Some ambitious schemes exist for integrated systems consisting of a power station and a series of agricultural enterprises such as greenhouses, soil warming for crop production, pond warming for aquaculture, warm water irrigation, heating of animal houses, and a pond for waste treatment (Bakker-Arkema *et al.* 1975). These studies appear to have the backing of some of the power companies in the U.S.A. (Rochow & Hall 1975) but since much of the basic information on crop yields, constructional and running costs are speculative, it is difficult to draw generalized conclusions except perhaps to say that there is a need for practical experiments.

4.9. *Geothermal energy*

Geothermal exploration of the U.K. so far indicates that the only resources available are likely to be low temperature (less than 80 °C) relatively pure water which may locally offer the possibility of inexpensive agricultural and domestic heating (Oxburgh 1976*a*). France already has several district heating schemes operating competitively on low grade geothermal energy in situations which can be matched geologically in the U.K. (Oxburgh 1976*b*).

5. Conclusions

This paper has considered some of the attempts that are being made to make better use of existing energy sources in agriculture and to harness the use of others which are new or under-used. If the prospects for some of these seem to be far from immediate, it should be appreciated that the balance could change if the price of fossil fuels should outpace general price levels. This imponderable renders projection into the future somewhat hazardous but it would seem right that research and development to examine technical feasibility and to establish realistic costings should be encouraged. Energy conservation measures and new energy sources must be economic in monetary terms; otherwise they are unlikely to be adopted.

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Appendix. Definitions and conversion factors

Primary energy

Every commodity, fuel and non-fuel, uses energy in manufacture and transport and all the other processes to make it available for use. For fuels, this energy is an 'overhead' and is added to the calorific value to give primary energy while for non-fuels it gives the primary energy directly.

Energy conversion factors

Throughout the tables and text, energy is given in terms of multiples of the joule (J). Some conversion factors to other commonly used units are given in the table below.

	J	kW h	cal_{IT}	Btu	therm
1 J =	1	2.778×10^{-7}	2.389×10^{-1}	9.481×10^{-4}	9.481×10^{-9}
1 kW h =	3.600×10^{6}	1	8.598×10^{5}	3412	3.412×10^{-2}
1 cal_{IT} =	4.187	1.163×10^{-6}	1	3.968×10^{-3}	3.968×10^{-8}
1 Btu =	1.055×10^{3}	2.930×10^{-4}	252	1	10^{5}
1 therm =	1.055×10^{8}	29.30	2.520×10^{7}	10^{-5}	1

General conversion factors

1 t (tonne) = 1000 kg = 2205 lb = 0.984 ton
1 ha (hectare) = 10000 m^2 = 2.471 acre
1 t/ha = 0.398 ton/acre; 1 ton/acre = 2.51 t/ha

Definitions of prefixes

prefix	kilo	mega	giga	tera	peta	exa
symbol	k	M	G	T	P	E
factor	10^{3}	10^{6}	10^{9}	10^{12}	10^{15}	10^{18}

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