FEASIBILITY STUDY: HIGHWAYS AS RENEWABLE ENERGY SOURCES

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SCOPE OF THE PROJECT

In response to the sustainable development agenda there has recently been an increasing emphasis placed on the generation of “green” electricity, from renewable resources. The UK government’s target is to exceed 5% and 10% energy production from renewable sources by 2003 and 2010 respectively and public consultations are currently underway seeking views on the kind of support mechanism which might be used to promote the development of renewables.

The importance of developing these resources has been recognised by the Highways Agency who commissioned this feasibility study to explore and assess the possibility of harvesting renewable energy from within the motorway and trunk road network. Initially energy obtained from the pavement structure was the focus of the study although, as other potential opportunities on the network became apparent, the scope of the project was accordingly widened to include the following.

(i) The use of photovoltaic panels on highway furniture and structures.
(ii) Use of wind turbines.
(iii) Generation of energy from watercourses which pass beneath highways or from water run-off.
(iv) Recovery of energy from pavement deflection under the action of vehicles.
(v) Heat exchangers in pavements.
(vi) The recovery of geothermal energy from the ground and deep founded structures.

This feasibility study has briefly reviewed these different forms of renewable energy and provided a preliminary assessment of the prospects of procuring energy from within the highway network.

SUMMARY

Renewable energy technologies are likely to become more important as other energy sources become depleted and the cost of power generation rises. These sources of energy have considerable potential for increasing security of supply and are environmentally friendly although, in most cases, they require significant initial investment. It is only in remote rural locations and new build situations where high installation costs can be offset against the provision of cable connection to the grid and renewable energy may be immediately cost effective.

Techniques for recovery of electricity from solar, wind and hydro power have potential for implementation at small scale and are appropriate for further investigation.

IMPLEMENTATION

This initial feasibility study recommends various options for full scale trials of which one would be a major trial focused on the use of photovoltaic panels mounted on a length of motorway noise barrier. The results from trials such as this should enable an informed decision to be made about implementation.
ABSTRACT

Renewable energy technologies are likely to become more important as other energy sources become depleted and the cost of power generation rises. These sources of energy have considerable potential for increasing security of supply although, in most cases, they require significant initial investment. Currently the Highways Agency is an energy user and has no significant energy generation capability. This report surveys the different forms of renewable energy and provides a preliminary assessment of the prospects for procuring renewable energy from within the highway network.

1. INTRODUCTION

In response to the sustainable development agenda there has recently been an increasing emphasis placed on the generation of “green” electricity, from renewable resources. The UK Government and the devolved administrations recognise the importance of developing renewable sources of energy as part of the drive for sustainable development and the long term response to climate change (DETR, 2000). For these reasons the Highways Agency commissioned TRL Limited to undertake a feasibility study to explore and assess the possibility of harvesting renewable energy from within the motorway and trunk road network. Initially energy obtained from the pavement structure was the focus of the study although, as other potential opportunities on the network became apparent, the scope of the project was accordingly widened.

Currently the Highways Agency is an energy user and has no significant energy generation capability. As a first step the likely capacity for energy production within the network needs to be assessed with the aim of making the Agency at least partly self-sufficient in terms of its energy usage for lighting, road signing, tunnel ventilation systems, pumping and drainage systems, etc. The brief for this project is such that only energy generation from renewable sources is being investigated: the separate issue of conservation and efficiency in energy usage needs to be separately addressed.

Renewable energy sources currently account for almost 6% of Europe’s supply, including 2% just for hydroelectricity (European Commission Green Paper, 2000). Their more widespread introduction could make a significant impact on reducing resource consumption and greenhouse gas emissions in support of sustainable development strategy and the commitments made by the UK in response to the Rio Earth Summit (1992) and the Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997). The UK government’s target is to exceed 5% and 10% energy production from renewable sources by 2003 and 2010 respectively. In 1999 the government published a consultation paper seeking views on the kind of support mechanism which might be used to promote the development of renewables, the conclusions from this public consultation are reported by the Department of Trade and Industry (2001). These sources of energy have considerable potential for increasing security of supply although, in most cases, they require significant initial investment. Some renewable sources are still far from being economically competitive although in the longer term this is likely to change as other energy sources become depleted and the cost of power generation rises.

A number of forms of renewable energy generation are technically possible and these are now outlined.
2. FORMS OF RENEWABLE ENERGY

Different forms of renewable energy generation methods which exist in a highway situation have been identified, they are as follows.

(i) The use of photovoltaic panels on structures, acoustic barriers and sign gantries, etc.
(ii) Use of wind turbines on pavement/structures.
(iii) Generation of energy from watercourses which pass beneath highways or from water run-off in site specific situations.
(iv) Recovery of energy from pavement deflection under the action of vehicles, including the use of piezoelectric devices.
(v) Heat exchangers in pavements.
(vi) The recovery of geothermal energy from the ground and deep founded structures.
(vii) Biomass and bio-energy techniques involving the recovery of energy from tree and grass crops.

Biomass and bio-energy techniques (vii) are recognised energy generation techniques at large scale in, for example, an agricultural or forestry situation, but are not considered so appropriate in reclaiming energy from within the highway network. These techniques would be labour intensive in requiring the recovery of tree and grass crops from situations with poor access, eg. verges, embankment and cutting slopes. The necessity for traffic management in harvesting energy of this type would also reduce its cost effectiveness. For these reasons, biomass and bio-energy techniques are not investigated in detail in this initial feasibility study although they are mentioned for completeness in this introduction.

The different forms of renewable energy that have been identified are now described in turn.
3. PHOTOVOLTAIC PANELS ON STRUCTURES AND STREET FURNITURE

3.1 Introduction

The Earth receives an incredible supply of solar energy with enough energy being received in one minute to supply the world's energy needs for one year. However man's ability to harness this power is very limited although a considerable amount of research and development is currently under way. The amount of solar energy received in southern Britain in a year is around 1000kWh/m$^2$ this can be compared with the 1500 and 2200kWh/m$^2$ received in sunny locations in southern Spain and the Sahara desert respectively (McNelis, 2000). On a clear day in June solar energy may be received at about 6kWh/m$^2$ in Britain, although in December it might be only 0.5kWh/m$^2$. Because there is considerable daily and seasonal variation in the UK, the use of photovoltaics must be adapted to this intermittent supply and suitable energy storage must be incorporated.

The process of converting sunlight into electricity involves using a photovoltaic cell. These cells are solid-state devices composed of thin layers of semiconductor materials that produce an electric current when exposed to light. Most commercially available solar cells are manufactured from silicon (amorphous, single crystal, or polycrystalline) although other materials such as copper indium diselenide and cadmium telluride can be used. Crystalline types are currently preferred because they have an electrical efficiency about 50% better than solar cells constructed from amorphous materials. However, in the long term, amorphous materials may offer good potential as cell cost is likely to reduce by mass production and they respond to a broader range of frequencies than the crystalline type making them possibly more suitable for use in the UK.

Cells are typically combined into modules that hold about 40 cells. Arrays of modules are connected together to form a flat plate: typically a plate with a surface area of a few square metres may contain about 10 modules. About 10 to 20 arrays are normally required to make a worthwhile contribution to the domestic power for one household. Demonstration houses (Figure 3.1) powered by photovoltaics have been constructed in the UK although, because of high installation costs, the techniques have yet to be widely adopted. The number of photovoltaic arrays required for industrial applications or significant generation is many orders of magnitude higher. The voltage and the current output can be engineered by configuring the array to match the proposed requirement.

In addition to flat panels, many other configurations are available with considerable research and development having gone into systems that concentrate the sun's energy by using a lens or a parabolic, dish or trough shape. Receivers of this type often require solar tracking systems to maximise output and the collected energy normally heats a fluid from which the energy is then recovered.

Photovoltaic cells produce direct current (DC) electricity although, by adding an inverter to the system, alternating current (AC) can be produced. When an inverter is added to the photovoltaic system, a loss of power output of 5-15 percent occurs. Most electrical appliances and plant, however, are designed to use alternating current (AC) electricity, and an inverter is therefore necessary. Systems may be either "stand-alone" with backup from either battery or alternative power source, or connected to an electric utility.
Figure 3.1. Flat solar panels on the 2001 Big Brother house on Channel Four
(from www.solarcentury.co.uk, by courtesy of Solarcentury)

Figure 3.2. Solar powered high pressure sodium street lighting
(from www.geosolar.com, by courtesy of GeoSolar)
The primary disadvantages of using solar power are the capital cost of the equipment and the variable amount of sunlight in the UK. In installing solar panels, their security against theft may also need to be considered in locations where they are accessible to the general public. Once installed they provide a source of renewable energy that is relatively maintenance free although cleaning may be advisable annually. Where systems employ batteries, these need to be maintained.

3.2 Examples of current and potential usage

3.2.1 General

Electricity generated from photovoltaic cells has many current applications at small scale and, less commonly, at large scale. It has already become adopted in the consumer products market by providing energy for products with small power requirements, such as solar calculators, watches, computers and radios. Other applications include water pumping, navigational systems and signals, lighting, electric fence charging, vehicle battery charging, radio relay stations, and utility scale electricity generation. The latter, while feasible, is not normally cost effective because of the currently low costs of producing electricity from other sources such as coal or nuclear energy.

Solar power is particularly important in remote or rural locations where power from grid-connected systems may not be available. In these locations, photovoltaics can be used to provide essential services such as lighting, communications, refrigeration, etc. A system of this nature in many instances proves more cost effective than running a utility line even a short distance.

Household energy supply is also a use of solar power that is receiving much research and development attention. Show-houses powered by photovoltaics have been constructed in most countries in the world, and a choice of domestic systems is commercially available. In many cases, solar thermal energy also forms a valuable contribution in heating domestic water supplies. In this application, heat exchangers are often conveniently used to directly heat the hot water supply rather using a photovoltaic system with an inverter. The use of heat exchangers is discussed in Section 7.

3.2.2 Highway situation

Highway safety equipment that relies on solar power for dependable, constant power in situations remote from any power lines is already being used in many countries. Roadside call boxes and lighted highway signs are typical of current usage. Interactive road warning signs powered entirely by solar energy with a wind energy system as back-up have been installed in Cheshire (Surveyor, 2001). Solar powered pay and display terminals for car parking are also becoming increasingly used by Local Authorities (Highways, 2001). An example of solar powered street lighting columns is shown in Figure 3.2. These columns have been installed in Florida, South Africa, and other countries.

In terms of more significant power generation, the Dutch government is one of those making a significant financial contribution to researching and implementing renewable energy systems. Potential large scale demonstration projects in a highway situation include the installation of solar panels on noise barriers (Figure 3.3). Near Ouderkerk aan de Amstel (A9 motorway in the Netherlands) 2,200 solar panels have been mounted on a 1.5km long noise barrier to...
Figure 3.3. Solar panels fitted onto noise barriers
(from www.caddet-re.org, by courtesy of CADDET Dutch National Team)
investigate their suitability (Rijkswaterstaat, 1999). Similar demonstration projects have been undertaken in Switzerland, Austria, France, Germany and other countries. In the UK there are 41 km of noise barriers on the M25 alone so the infrastructure exists for mounting solar panels.

Other assets owned by the Highways Agency include buildings (e.g. roofs of maintenance depots, pumping stations, control rooms, etc) and structures (e.g. bridges, sign gantries, lighting columns, etc). All of these provide opportune locations at which solar panels can be installed. In addition to these locations, the land adjoining the highway network and owned by the Agency could also be used for mounting photovoltaic panels. Potentially this land will include embankment and cutting slopes together with verge areas wherever they are significant. It must be noted that there may be policy issues involved in some of these installations, in terms of distraction and possible reflections affecting highway users, which would need careful consideration.

The University of Utrecht has identified land with potential for the placement of solar panels this includes, for example, old farmland that will no longer be used for agriculture, fallow land, industrial and harbour areas, and land adjacent to airports, sound screens next to highways and railway lines. The use of these locations for solar energy instead of other forms of sustainable energy is generally efficient, for example photovoltaic solar energy provides almost 20 times more energy per hectare than biomass (Greenpeace Nederland, 1999). However, it should be noted that placing solar panels at locations where they are not at the ‘point of use’ of electricity means that they are effectively acting as a power station supplying the grid. This means that these systems have to compete economically with other primary generators.

3.3 Cost issues

The current output from a flat solar panel with a surface area of 100cm$^2$ is approximately 1watt peak (Wp). The cost of installing a solar panel with a capacity of 100Wp is currently about £4 per Wp; this is equivalent to a cost of about £400 for a 1m$^2$ panel. Of this cost, approximately 60% is the cost of the solar panel and 40% are the installation costs, which include the provision of cabling and an inverter. Example annual outputs of 800Wh from 1Wp have been obtained in the Netherlands and those in the UK are expected to approach this figure.

Electricity generated with the help of solar panels is, for the end user, approximately 5 to 10 times more expensive than electricity from conventional sources and is currently therefore not competitive in terms of the capital and installation costs. However, solar energy systems could reasonably be expected to have a service life of at least 20 years and, because of the likely world energy shortage in the coming decades, may in the longer term prove a worthwhile investment.

The late Professor Bob Hill at the University of Northumbria carried out aerial photography to identify suitable south facing surfaces around the UK and in London. He pointed out that a similar study of Berlin estimated that the city could generate 2.5 GW of photovoltaic power which is equivalent to the output from two nuclear power plants. London is likely to have a similar potential to that of Berlin.

Cost issues associated with the use of stand-alone panels or connection to a utility power grid, are discussed in Section 9.3.
4. WIND TURBINES ON PAVEMENT/STRUCTURES

4.1 Introduction

Wind is the response of the atmosphere to uneven temperatures and pressures and wind flow at any particular location is enhanced or reduced by the topography of the surrounding area. The main drawback of wind power as a source of renewable energy is its erratic nature. It is therefore important that the energy produced can be stored in some way or that a hybrid system, incorporating perhaps solar energy capture, is employed.

The power obtainable from wind varies as the cube of the airspeed, thus 27 times more power is theoretically available from air moving at 9m/s than at 3m/s. For average atmospheric conditions of density and moisture content the power obtainable is $0.0006v^3$ per square metre of swept area, where $v$ is the wind velocity in metres/sec and power is in kilowatts.

Another factor to consider is the efficiency of the windmill/turbine. A traditional four arm Dutch windmill (not ideal for mounting on a gantry) has a theoretical efficiency of 16%, whilst a modern rotary multiblade reaches about 30%. A high speed propeller type can be up to 42% efficient.

As Highways Agency does not generally have large tracts of land (with suitable elevation and wind exposure) on which wind farms could be constructed to provide large scale power generation, it is envisaged that wind power will be mainly used on a small scale. There may be some exceptions to this in areas such as the Pennines.

The values given in Table 4.1 illustrate the potential output in kWh/year for a small windmill with a rotor diameter of 2m.

<table>
<thead>
<tr>
<th>Wind speed (mph)</th>
<th>Percentage of year wind blows at stated speed</th>
<th>Output (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (-9m/s)</td>
<td>10</td>
<td>2500</td>
</tr>
<tr>
<td>40 (-18m/s)</td>
<td>10</td>
<td>20000</td>
</tr>
<tr>
<td>20 (-9m/s)</td>
<td>50</td>
<td>12500</td>
</tr>
</tbody>
</table>
If a suitable site is available for wind turbines, there are many advantages as it is clean, inexpensive, safe and reliable, and uses land resources sparingly. Wind power can be harvested at different scales (Figure 4.1) and current research by manufacturers and others ensures that it is an advancing technology.

Although in some circumstances the flow of traffic could artificially generate wind and air turbulence, the magnitude of this effect is not likely to be sufficient to reliably drive wind turbines. For example, measurements of traffic induced wind speeds in Fore Street tunnel (Figure 4.2) gave speeds varying between about 3 and 5m/s on a day when natural wind speed outside of the tunnel was about 1.6m/s. Generally wind speeds consistently exceeding 6.5m/s are considered advisable for economic energy production in the UK (ETSU, 2001) and for this reason traffic induced wind is not currently considered to be a cost effective energy source for consideration.

4.2 Use in small scale energy generation

Wind is widely used as a source of energy on a small scale for a range of applications including supplies to buildings, offshore platforms, lighthouses, as well as for the low power requirements of battery charging for boats and caravans, etc. Wind power has also been used in the UK as an energy source for remote installations such as monitoring stations and telecommunications facilities. An example of such a use was a 600watt generator installed to power a remote British Telecom microwave station (Proven Engineering Products, 2001). The turbine had a rotor diameter of 2.55m and the wind speed required for the rated output was 10m/s.

A cost comparison also carried out by Proven for an approximate 4400kWh annual output showed solar power to cost over five times as much as wind power. It showed that during winter wind power output was twice that of solar power, but during summer this was reversed, further strengthening the case for combined wind and solar generation at a particular site.

The range of sizes and outputs of wind turbines is enormous varying from a few watts to many kilowatts depending on the required application. For example, Alternative Power Systems (2001) claim that they can supply turbines to provide power anything from a single camping trailer to a ranch home or commercial building. Anglesey Wind and Energy (2001) suggest that wind power can be used for remote homes, battery charging, water pumping, remote street lighting, communications, recreational vehicles or monitoring instruments. Many further examples can be found in current literature.

Of particular relevance is potential usage on highway networks. There are wind turbines available that could conceivably be mounted on signal gantries to power traffic signs, or mounted on masts to power the street lighting in remote areas where the provision of mains electricity would be prohibitively expensive. However, if such turbines were mounted close to the road or on existing overhead gantries such possible draw backs as additional wind loading on the structure, noise, and visual distraction of drivers would need to be carefully considered. Energy storage provision would also be needed and in most situations on the highway network, hybrid systems would seem preferable.

A recent development for generating small amounts of power is the ducted wind turbine. This type of turbine is still at the experimental stage and there are papers by various authors discussing their development, typical of these is one by Grant et al (1994). With these devices, the turbine is fitted inside an enclosure so that the wind enters and is deflected upwards.
Figure 4.1. Wind turbine of 5.5m diameter
(from www.provenenergy.com, by courtesy of Proven Engineering Products Ltd)

Figure 4.2. Measured and calculated wind speeds in Fore Street tunnel
through the turbine, exiting from the top of the enclosure. Unlike conventional wind turbines that turn to face the wind, the ducted types require the wind to come from a fixed direction (±15 degrees). An advantage of their being enclosed is that they may be more acceptable close to a road than a conventional series of windmills, although further research and development is required before they become more commercially available.

4.3 Cost issues

Advantages claimed for wind generation are relatively low capital costs and very low operating costs. The data in Table 4.2 indicate the capital cost for three sizes of wind turbine as supplied by one manufacturer. The costs only include for supply of the turbine and not for any controllers, masts or fittings.

<table>
<thead>
<tr>
<th>Power output (watts)</th>
<th>Rotor diameter (m)</th>
<th>Output voltages available</th>
<th>Cost (£k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>2.55</td>
<td>12,24,48</td>
<td>1.7</td>
</tr>
<tr>
<td>2500</td>
<td>3.5</td>
<td>24,48,120</td>
<td>3.4</td>
</tr>
<tr>
<td>6000</td>
<td>5.5</td>
<td>48,120,240</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Note: Cut-in wind speed is 2.5m/s in all cases

Generally manufacturers of wind turbines are in agreement in recommending that they need very little maintenance, although a maintenance check every 6 months is advisable. As turbines have moving mechanical parts, that is blades and bearings, some wear is inevitable particularly in a road situation where grime can accumulate. For this reason, maintenance costs are likely to be higher than with, for example, solar panels.

4.4 Assessment of site suitability

Prior to the installation of wind turbines, the viability of generating energy from the wind at the particular site location needs to be assessed. Factors which are important include the peak and average wind speeds, the percentage of time during which the wind blows at a rate sufficient to generate the required output, and the predominant wind direction. Monitoring systems, some of which are wind and/or solar powered, are commercially available to collect the required data. Other site specific considerations may also affect the suitability of a particular site. Calculating the annual energy production from a wind turbine is quite a complex task and expert advice is needed.
Environmental issues are also important considerations in the choice of locations. With large scale wind farms there have been problems with both noise and visual impact. The swish of a turbine can be obtrusive although well-designed wind turbines are barely audible at 400m away. Once built, a wind turbine can soon become an accepted feature. As previously mentioned, driver distraction is an issue in use on the highway network and current industry guidelines for large wind turbine installations recommend that they should be at least 200m from highways. For this reason, small scale energy generation using ducted turbines may be more acceptable in this situation, if such devices become more commercially available.
5. HYDROELECTRIC POWER FROM WATERCOURSES OR HIGHWAY DRAINAGE

5.1 Introduction

Traditionally, large scale hydroelectric power generation involves the use of high head power plant with generally a dam to store water at an increased elevation. Recent developments and innovative turbine design means that low head hydroelectric plant can now be effectively used for small scale power generation. For this reason low pressure turbines may be viable when located either in or adjacent to culverts beneath the carriageway or in the highway drainage system where a reasonable velocity of flow and head of water can be generated. The water does not need to flow vertically and there are commercially available low pressure turbines.

Power generation is a function of the head, the difference in water level upstream to downstream of the turbine and the flow rate. Power output can be approximately estimated from the following equation:

\[
\text{Electrical power (kW)} = 9.81 \times \text{efficiency} \times \text{flow} \times \text{head}
\]

where the flow is measured in \(\text{m}^3/\text{sec}\) and the head is measured in metres. Efficiency is generally in the range 50 to 70%. Table 5.1 gives some idea of the power outputs calculated using this equation, although it must be noted that outputs will vary according to the efficiency of the particular turbine system and a number of other factors.

Table 5.1 Approximate power outputs for particular heads and flow rates

<table>
<thead>
<tr>
<th>Head (m)</th>
<th>Flow rate (litres/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1  1.5 2  2.5 3  5  7  10 20 50 100</td>
</tr>
<tr>
<td>1</td>
<td>9  12 15 18 30 41 59</td>
</tr>
<tr>
<td>2</td>
<td>12 18 24 30 35 59 83 118 236 590</td>
</tr>
<tr>
<td>3</td>
<td>9 18 27 35 44 53 89 124 177 354 885 1770</td>
</tr>
<tr>
<td>4</td>
<td>12 24 35 47 59 71 118 165 236 472 1180 2360</td>
</tr>
<tr>
<td>5</td>
<td>15 30 44 59 74 89 148 207 295 590 1475 2950</td>
</tr>
</tbody>
</table>
“Low head” hydroelectric power plants generally utilise heads of only a few metres or less. Using a low dam, or a weir, to generate the required head can run power plants of this type (Figure 5.1).

Various other types of turbine are being developed which require strong flow but little head and these are known as river current or free stream turbines. Some of these systems include submersible generators that comprise a high output alternator driven by a propeller. Many innovative designs for hydraulic generators have been proposed. For example, a “hydromotor” comprising twin interlocked rotors revolving in a closely fitting casing has been proposed by Brinkworth et al (1998) and this is but one of the various suggestions by many authors. Generally the market for river current and free stream turbines is low and they tend to be designed as “specials” rather than being readily commercially available. For this reason, low head turbines rather than this latter category of turbine are likely to be more appropriate for use within the highway infrastructure.

5.2 Examples of low head turbines

Commercially available turbines will operate at a minimum of 1m head and flows as little as 6 litres/sec. These are referred to as micro-hydro turbines and normally use a propeller driven by the water flow in order to generate electricity.

Many designs of micro turbines are commercially available and these can generate electricity from heads as low as 1m with a feed from a small stream or pond (Figure 5.2). In highway applications this could be a stream flowing through a culvert or the outlet from a balancing or detention pond. Some turbines are mounted horizontally with a scroll type chamber that eliminates guide vanes and hence reduces the risk of blockage. Example power outputs from this type of generator are 500 watts from a flow of 85 litres/sec and a 1m head, to 3.5kW where the available head is 3m. In micro-hydro applications cost usually dictates that a fixed geometry turbine is used: a single regulated propeller turbine and a full Kaplan turbine are two and three times more expensive respectively and are generally more appropriate for major installations with a power output of 50 to 100kW.

5.3 Scope for use on the highway network

The effectiveness of any micro-hydro installation on the highway network depends on many site specific factors which need to be investigated in a feasibility study.

Watercourse sites

Environment Agency consent may be required for works within a watercourse. Watercourse sites need to be identified where there is a constant flow of relatively fast moving water and an acceptable head of at least a few metres. There are a significant number of HA owned bridges and culverts to rivers and watercourses that may provide viable sites and these are listed on the structures database. For example the database shows that, for culverts in excess of 900mm diameter, there are about 1300 corrugated steel buried structures and about 1750 concrete box structures on the trunk road and motorway network. The majority of these, but by no means all, carry a watercourse.
Figure 5.1  Connecting the turbine to the water supply
(after www.waterturbine.com, by courtesy of Nautilus Water Turbine)

Figure 5.2  Typical 3kW micro-turbine
(after www.provenenergy.com, by courtesy of Proven Engineering Products Ltd)
Highway drainage systems

Utilising the flows from highway drainage systems may be feasible although it must be viewed as speculative at the current time. Significant flows in surface water drainage systems will normally only occur during precipitation: systems designed to control ground water are generally unlikely to provide sufficient flow. Highway drains are designed not to surcharge during a 1 in 1 year storm event, however they will run more that half full at least once per month. Some locations can be readily identified where the gradient will give a suitable head, eg. at the base of inclines such those on the M40 at Stokenchurch or M3 at Tywford Down. Ideal areas are those where the drainage system is relatively steep and can generate pipe full velocities in excess of 1 m/s. Even allowing for drag at the pipe wall, this should not be too onerous as the ideal full bore velocity is 1 m/s. In addition to pipe drainage systems, channel systems may also be suitable and the possibility of installing micro-turbines within catchpits may be worthy of further investigation. Generally, however, the long periods where there is no water flow means that efficiency of recouping power from highway drainage systems must be considered limited.

5.4 Cost Issues

From Table 5.1, it can be seen that only a modest amount of power is going to be generated by these types of micro-turbines. Generally the turbines have been developed to provide electricity to a group of remote properties that are adjacent to a constant flow of water. Hence this proposal is an adaptation of the devices from their original purpose.

The cost of small turbines can be relatively cheap, from around £750, however the greater cost will be in the temporary and permanent construction works necessary to install the turbine. It has been estimated that the cost of supplying and installing micro-turbines may be up to £3000 per kW capacity depending on location (National Energy Foundation, 2001).

Although constructing a low dam, weir or flume within a watercourse could involve costly temporary works such as coffer-dams and pumping, a more constant supply and cost effective source of energy is likely to be obtained than from installing turbines in highway drainage systems. It must nevertheless be borne in mind that the cost of insertion into a catchpit, at the downstream end of a steep pipe run, could be minimal.

In general, the likely maintenance costs and also the implications of water borne debris and its screening and removal need to be assessed on a site specific basis.
6. RECOVERY OF ENERGY FROM VEHICULAR LOADING OF PAVEMENTS

6.1 Introduction

A possible source of energy may be envisaged from vehicle loading of the pavement structure. Techniques for conversion of mechanical energy induced by this type of loading into electrical energy are, however, in need of further development. One potential technique involves using piezoelectricity. Piezoelectricity is the characteristic of a small class of materials, generally ceramic in nature, which have the capability to directly convert mechanical energy that distorts the material into electrical energy and vice versa. Commonly used piezoelectric materials include quartz, lithium niobate, and lead zirconate titanates.

The major applications of the piezoelectric effect have however been in the development of transducers, sensors, actuators and other devices mainly for the measurement of acceleration, pressure or load. Signals generated by piezoelectric sensors can be readily amplified for monitoring purposes. Piezoelectric transformers have also recently been researched because they have the ability to create high voltage step-up ratios.

6.2 Potential use in a highway situation

At first sight the goal of obtaining parasitic power from vehicle loading on highways is attractive, however technology is not yet sufficiently advanced for this to be a practical option. The nearest example of this type of application that could be found in the literature is that of shoe mounted devices (Kendall, 1998) with energy normally dissipated as heat being collected by means of a piezoelectric device inserted into the shoe of pedestrians. Different devices were investigated which utilised either the heel striking or the sole bending action. In both cases the power output was limited by the displacement or flexure which could be tolerated by a pedestrian using the shoes and prototypes gave outputs of no more than 5mW of power. Whilst this might be adequate to trickle charge the battery of, for example, a mobile phone or a calculator, the power generated is low.

If a calculation is carried out assuming a contact area of the shoe mounted device of 80cm$^2$, a pedestrian weight of 68kg (ie. contact pressure of 0.08N/mm$^2$) and an output of 5mW, the equivalent power generated by the 11.5 tonne axle of a lorry can be crudely estimated. For this purpose a tyre inflation pressure of 0.8N/mm$^2$ was used which gives a total contact area of 1410cm$^2$ for the tyres on that axle. As the contact pressure for the axle is ten times higher and the contact area is eighteen times higher, the piezoelectric power might be expected to be of the order of 1W. This however is likely to be a very optimistic figure as pedestrian loading occurs at a regular and higher frequency than axle loading, furthermore displacement to distort and load a piezoelectric device may be more readily tolerated by a pedestrian than a vehicle.

In the recovery of energy in this way, other fundamental issues would need to be considered before implementation was feasible; these include the following.

- Installations in concrete pavements are less likely to be suitable because load-spreading effects would reduce the piezoelectric effect.
- Devices are better installed at shallow depths as the loading will be higher, their inclusion may affect the integrity of the structure and lead to crack development in bituminous pavements.

- Mechanical energy is converted into electrical energy by piezoelectric devices and whether the pavement deflection for their operation has any measurable detrimental effect on vehicle fuel consumption is unknown.

Although in principle this innovative recovery of energy from vehicle loading appears possible, considerable further research and development is necessary to establish whether efficiency of energy recovery can be improved and implementation can be viewed as even a possibility.

6.3 Cost issues

It has not been possible to provide guidance on costs involved if this technique were to be implemented on the highway network because a viable form of the system has not been identified during this scoping study.
7. HEAT EXCHANGERS IN PAVEMENTS

7.1 Introduction

The innovative use of geothermal energy and solar heat to melt snow and ice on pavement surfaces has been successfully employed at a few locations, particularly in the USA and Japan. Generally fluid (usually an anti-freeze solution) is pumped from the heat reservoir around pipes embedded in the pavement so that heat transfer to the pavement surface occurs. In theory, the same system could be used to retrieve heat from a hot pavement and in this way generate energy.

TRL has, over the years, collected much data on the temperatures within pavements in the UK. Wilson (1976) looked at the temperature distribution in a fully flexible construction in the summer of 1967 when the temperature at 10mm depth reached a peak of 52°C. At this time the temperatures at 40mm, 100mm and 250mm depth were 46°C, 39°C and 27°C respectively. This data demonstrates that if collecting solar heat energy from pavements, the pipes/coils are better installed at shallow depths to maximise the energy recovery. Thermal absorptivities of 0.9 and 0.65 are typical for bituminous and concrete surfaces and for this reason the former will be a better source of energy.

Because of the high heat retaining capacity of asphaltic surfaces, trials of heat exchange systems are taking place in the Netherlands. This system involves the use of plastic tubes that can be installed during asphalting. These trials are described in more detail in Section 7.2.

The recovery of solar heat from pavement structures is likely to be used in conjunction with heat storage systems in the ground. The information given in Section 8 on geothermal energy and the use of ground source heat pumps is therefore also relevant to this application.

7.2 Examples of pavement heat transfer systems

A schematic drawing of a typical pavement heat transfer system is given by Chiasson (1999) and reproduced in Figure 7.1. Generally the fluid is carried by a series of embedded pipes positioned in parallel circuits. Experience has shown that to maximise heat transfer to the surface of the pavement slab, the piping needs to be typically at a depth of less than 100mm beneath the surface. If extracting energy from solar heating of the pavement surface, the same caveat would be expected to apply.

Generally either hydronic or geothermal systems (or combinations of the two) have been employed for de-icing or snow melting systems. With the former, a buried water tank is coupled to the heat exchanger pipes. In the summer, heat is transferred to the tank which heats the surrounding ground. The flow is then reversed in the winter and heat passed to the road surface so providing an effective winter maintenance technique. An example of such a reservoir heat collection system was built on the campus of Fukui University in 1975 (Fukuhara et al, 2000).

Snow melting systems whose main heat source is geothermal energy have also been constructed in Japan. The National Institute for Resources and Environment of Japan has been involved in the development of the Gaia system which uses downhole coaxial heat exchangers (Morita and Tago, 2000). After several years of operation of a system at Ninohe City, it was
Figure 7.1. Schematic drawing of pavement heat transfer system  
(from Chiasson, 1999; by courtesy of Oklahoma State University)
found to be both effective and economical to run. An analysis of costs showed that the power consumption of the Gaia system were approaching 20% less than those of an electric heating cable system.

In 1998 heat exchange systems were installed in the asphaltic surface of various trial sections of a road subject to heavy traffic loads (Ooms Avenhorn Holding bv, 2001). The main feature of the system was that plastic tubes for the heat exchanger were installed during asphalting in a single operation. Heat storage took place in water-carrying strata and this heat (or cold) could be used to control the temperature of nearby buildings and the road surface. In the latter case, the system enabled snow and ice to be melted in the winter. It was also found that in the summer, cooling of the surface prevented wheel rut formation and crack formation due to temperature stressing and provided a more durable surface.

7.3 Potential scope for use on the highway network

The principal uses of pavement heat exchangers have currently been for de-icing or snow melting systems. Although the use of geothermal energy (see Section 8 also) and solar heat has been innovative in this application and resulted in a reduced electricity consumption compared with electric heating cable systems, the heat exchanger systems in many cases have still been net energy users rather than energy generators. This is primarily because of the seasonal usage and the intermittent need for pumps to circulate the fluid.

Further experience with this type of system would be advantageous before its use for the recovery of renewable heat energy from within the highway network could be implemented. Generally this type of renewable energy system is better for heating applications rather than power generation, primarily because conversion of heat to electricity is conventionally carried out using steam turbines and energy losses of up to 75% may occur during this process. Particular aspects, which would need careful consideration are as follows.

- The piping system needs to be near surface to benefit from the maximum temperature rise caused by solar heating and any heating effects due to the passage of vehicles. The presence of the piping may have implications both on the structural performance and on maintenance procedures when resurfacing is needed.

- Installation of systems is likely to be less viable in concrete pavements than in bituminous surfaces as larger temperature changes due to solar heating occur with the latter.

- Energy is used to drive the pumps circulating the fluid, this may seriously affect the cost effectiveness of the generation of heat energy.

- The recovery of energy is likely to be intermittent with a high seasonal dependence, the thermodynamics of pavement heat exchangers needs a more in depth investigation.
7.4 Cost issues

Although the use of solar thermal energy captured by using heat exchange systems installed in pavement structures may prove valuable for de-icing and snow melting, the technology does not currently exist to efficiently convert heat energy into electricity. Because this form of energy is therefore more appropriate to heating applications, an assessment of costs in terms of electricity generation could not be realistically attempted.
8. GEOTHERMAL ENERGY FROM THE GROUND AND DEEP FOUNDED STRUCTURES

8.1 Introduction

Geothermal energy is heat energy which originates from within the earth’s molten interior, where temperatures can be as high as 7000°C at the earth’s core. The heat is brought near to the surface of the earth by means of thermal conduction and by intrusion into the earth’s crust of molten magma. The hot molten rock surrounds the groundwater and forces it to the surface in certain areas in the form of hot steam or water, such as in geysers and hot springs. This heat energy that is close to, or at, the earth’s surface can subsequently be utilised as a source of energy. It has generally been established that for every 100m you go below ground, the temperature of the rock increases by about 3°C.

When the ground water is heated, a hydrothermal resource is created. Hydrothermal resources arise when hot water and/or steam is formed in fractured or porous rock at shallow (100m) to moderate (4500m) depths. High temperature hydrothermal resources, with temperatures from 180°C to over 350°C are usually heated by hot molten rock. While low temperature resources, with temperatures from 100°C to 180°C, can be produced by either process.

Various technologies exist which permit the extraction of heat energy from within the earth ranging from dry steam to binary cycle technologies. Dry steam technology involves drilling down to the aquifer and bringing the superheated steam to the surface and passing it through a turbine to generate electricity. Whereas with binary cycle technology the geothermal fluid is passed through a heat exchanger, where a secondary fluid (with a boiling point lower than water), is vaporised and passed through a turbine to generate electricity.

As the UK is located in a tectonically stable area, geothermal resource is generally restricted to deep aquifers and, since permeability is rarely adequate at depths greater than 3km, to temperatures well below 100°C (Garnish, 1985). Resource assessments have been summarised by Gale et al (1984) on behalf of the British Geological Survey. Generally geothermal source temperatures high enough for electricity generation could be obtained only if heat extraction from granites or other basement rocks is feasible. It is not proposed that this type of energy recovery from deep boreholes is within the remit of the Highways Agency as detailed geological assessments are required and it is unlikely that the optimum borehole locations in the UK are within Highways Agency property.

However, the use of lower grade thermal resource which includes recovery from deep foundations and in some cases from shallower systems, can be achieved using ground source heat pumps. It must be noted that these techniques are more appropriate to direct heating applications, but this may be of benefit for example in the heating of control buildings for tunnels and maintenance depots. For this reason, these techniques are now dealt with in more detail.
8.2 Methods of recovering geothermal energy

Different types of system using ground source heat pumps can be employed to recover geothermal energy and generally more energy is generated the deeper the installation. As previously mentioned low grade resources are often used in direct heating applications for buildings.

A variety of loop configurations can be used in the ground or structure depending upon the particular application. Closed loops may be installed vertically or horizontally in the ground/structure, or in a body of water. The fluid that circulates through the pumped system is normally a mixture of water and anti-freeze solution. Other systems, such as those in water wells, may employ open loop systems. Types of system include the following.

- **Vertical loop systems** where the set of pipes are installed and grouted into vertical bore holes 50 to 150m deep depending on the design considerations. The number of loops required primarily depends on ground conditions and the depth of each hole. This design is appropriate for applications where minimal space is available and minimum soil disruption is desired.

- **Horizontal loop systems** are utilised when more space is available and trenching can be easily accomplished (ie. new construction). Typically a series of parallel pipes are installed in 1 to 2m deep trenches which are then backfilled. A “slinky” coil configuration can maximise the amount of coil in each trench.

- **Lake / pond loop systems** are cost effective because of the good heat transfer properties of water. The heat exchanger is then submerged in a series of coils beneath the water surface rather than buried in the ground or structure. This system offers minimum excavation and great efficiency.

- **Open loop systems** may be used with geothermal heat pumps where ground water is plentiful. Ground water is either pumped directly through the condenser water piping or alternatively an intermediate plate frame heat exchanger can be used to isolate the condenser water from the raw well water. This system usually has supply and return wells for the water system, but usually requires more maintenance.

8.3 Examples of applications relevant to highways

Utilisation of geothermal energy for heating and cooling of buildings has been reported by Brandl (1998) and also in the prestigious Rankine Lecture (Brandl, 2001). Deep foundations, incorporating concrete piles, diaphragm walls or raft foundations were equipped with coils of polyethylene pipes carrying a heat transfer medium (brine or water). The pipes were mounted along the reinforcement cages as shown in Figure 8.1 for a bored pile system. A reversible heat pump installed in the distribution system enables cold energy to be extracted from the ground for cooling in the summer, and the converse in the winter. Broadly speaking some electricity is used to drive the pumping system, but approximately two-thirds of the conventional heating costs of a building are saved.

A study in Japan to derive energy for snow melting purposes includes the recovery of (i) hot water from springs (geothermal) and (ii) hot water from hot pavements during the summer and
Figure 8.1. Loops of polyethylene pipe attached to the reinforcement cage of 1200mm diameter bored pile

(after Brandl, 1988; by courtesy of A A Balkema, Rotterdam)
stored below ground. Hot water systems, which are being installed at key points such as tunnel portals, include a system on a large 2.7km long scheme in the Japanese Alps.

Research into a geothermal smart bridge is ongoing at Oklahoma State University (Spitler, 2001). The project is aimed at the development of a bridge deck heating system to eliminate icing. The system uses a ground source heat pump system to recover energy stored in the earth which heats the fluid circulated through tubes embedded in the bridge deck. Automatic control is linked to local and remote weather stations to forecast potential icing conditions. In addition to improved safety, the system obviates the need for deicing salt which can cause long term damage and durability problems if it penetrates the deck and substructure.

Ground source heat pumps have also been proposed as a means of cooling underground railway tunnels in London. In summer the tunnels become hot and uncomfortable for passengers, cooling of the tunnels using heat exchange systems has the added advantage of the recovery of heat energy. The idea has not yet been implemented but is probably less applicable to the shallower bored tunnels constructed for road schemes.

The use of heat exchangers in pavement structures for the recovery of solar energy has been dealt with in Section 7 and the techniques employed are similar to those used for geothermal energy recovery.

8.4 Potential scope for use on the highway network

The recovery of geothermal energy from within the boundaries of HA property is likely to require a major investment even at small scale. Furthermore, insufficient new build of deep foundations for retaining walls and bridge abutments on the highway network is planned for geothermal energy recovery to make a significant contribution. Recovery of energy from low grade geothermal resource such as trenches and balancing ponds is more suited to direct heating applications. Serious development of deep geothermal resource for generating electricity may be better left to the relevant utilities.

8.5 Cost issues

Although the technology for harvesting geothermal energy is established, it is not possible to give guidance on the costs of installing such systems because they are very dependent on site specific factors. Generally the technology is more efficient if the heat gained is used directly for the purpose of heating buildings or perhaps for deicing and snow melting on pavement surfaces (see Section 7). The conversion of heat energy into electricity involves losses which mean that small scale power generation is not normally viable.
9. DISCUSSION

9.1 Power consumption on the highway network

Currently, figures obtained from the Highways Agency indicate the following un-metered energy requirements:

- annual consumption of 183,484MWh for street lighting and lit signs on motorways and trunk roads
- annual consumption of 8,988MWh for motorway communications equipment.

Ten percent of this electricity supply obtained from the utility companies is from “green tariff” sources according to the UK government’s directive. The total annual cost for these two items is approximately £7.4million.

It is worth noting that the current trend during maintenance operations and new installations is to improve the luminance of the road lighting, this generally means that high pressure sodium lanterns are becoming the preferred lighting source rather than low pressure sodium lanterns. High pressure sodium lanterns have a larger power requirement of typically 22kW/km of motorway and an approximate annual consumption of 89000kWh/km. The corresponding figures for low pressure sodium are 15kW/km of motorway and about 60400kWh/km respectively.

There is also an increasing demand for traffic monitoring and better driver information systems, which in turn require more communication systems and gantry gantries. Typical power ratings of individual items of equipment are as follows.

- gantry sign lighting typically between 1.2kW and 2.2kW (based on four lantern units with two lamps of either 125W or 250W depending on the complexity of the gantry and with some allowance for power loss)
- matrix indicators are typically between 120W to 400W
- enhanced message signs are typically between 625W to 900W
- outstations are typically between 30W to 330W
- cabinet heaters are typically 180W.

It should be noted that the above information may not be representative of the latest technology equipment.

Clearly there is a conflict in terms of trying to improve driving conditions and safety whilst being more energy efficient to conserve the energy resources of the UK. Considerable effort has been made to conserve energy by some Local Authorities; for example Lancashire County Council has implemented an energy management approach to street lighting since 1978. Some of the measures that have been introduced over this period include replacing mercury lamps.
with more energy efficient sodium lamps, improved photocell control with ability to switch to dimmed mode after midnight or when traffic flows reduce, installing lanterns which restrict the upward fill of light from the lamp, and reducing wastage by installing electronic control gear.

9.2 Relative costs of the different forms of renewable energy

A comparison of power generation costs for heavy electricity intensive industrial plant was reported in the European Commission Green Paper (2000). This included some forms of renewable energy, notably wind and solar energy. The base year for the analysis was 2000 and production costs were considered at a power plant utilisation of 7000 hours. Table 9.1 summarises the production costs if the impact of excise duty in the various countries is ignored.

Table 9.1 shows that at this level of utilisation and ignoring excise duty that production costs are broadly similar throughout Europe and that the most economic options are combined cycle gas turbines and imported coal. Of the renewable forms of energy included in this survey, thermal plant using biomass or waste as a fuel was the most competitive. Large on-shore wind farms showed potential for use, whilst solar photovoltaic production was relatively expensive because of high capital costs.

The above discussion relates to large scale energy generation, whereas generation from resources within the highway network is expected to be at a much smaller but nevertheless significant scale. For this reason the capital cost and potential power generation capacity have been separately summarised in Table 9.2. No costs are included in Table 9.2 for techniques recovering energy from vehicular loading and heat exchangers in pavements as serious production of electrical power is not deemed viable at the present time. Installation costs for geothermal energy systems are likely to be high and will be site specific and for this reason are also not included. Techniques using biomass which Table 9.1 identified as efficient at large scale were not evaluated in this current study.

Table 9.2 serves to illustrate the high initial investment required for the installation of small scale renewable energy technologies. Assuming a typical supply and installation cost of £3000/kW, that the installation functions at full capacity, and the current cost of £0.04/kWh of power from the grid, a period of 8.5 years would elapse before break even on installation costs was reached. However this calculation takes no account of annual rises in the cost of electricity from the grid which may be significant in view of the depletion of conventional energy resources, the environmental benefits of using “green” energy, and the reduced installation costs which may arise from mass production of small scale systems.
Table 9.1. Production costs of power generation technologies at 7000 hours (European Commission, 2000)

<table>
<thead>
<tr>
<th>Country</th>
<th>Imported coal</th>
<th>Monovalent fuel oil</th>
<th>Combined cycle gas turbine</th>
<th>Monovalent biomass-waste</th>
<th>Wind turbines*</th>
<th>Solar photovoltaic*</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>0.036</td>
<td>0.049</td>
<td>0.034</td>
<td>0.036</td>
<td>0.072</td>
<td>0.640</td>
<td>0.059</td>
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<td>Belgium</td>
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<td>0.049</td>
<td>0.028</td>
<td>0.037</td>
<td>0.072</td>
<td>0.640</td>
<td>0.040</td>
</tr>
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<td>0.029</td>
<td>0.039</td>
<td>0.067</td>
<td>0.853</td>
<td>0.059</td>
</tr>
<tr>
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<td>0.049</td>
<td>0.026</td>
<td>0.039</td>
<td>0.072</td>
<td>0.853</td>
<td>0.038</td>
</tr>
<tr>
<td>France</td>
<td>0.032</td>
<td>0.049</td>
<td>0.032</td>
<td>0.040</td>
<td>0.072</td>
<td>0.512</td>
<td>0.034</td>
</tr>
<tr>
<td>Germany</td>
<td>0.032</td>
<td>0.049</td>
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<td>0.043</td>
<td>0.068</td>
<td>0.640</td>
<td>0.051</td>
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<td>Greece</td>
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<td>0.049</td>
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<td>0.047</td>
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<tr>
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<td>0.072</td>
<td>0.640</td>
<td>0.051</td>
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<tr>
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</tr>
<tr>
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<td>0.072</td>
<td>0.853</td>
<td>0.047</td>
</tr>
<tr>
<td>UK</td>
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<td>0.049</td>
<td>0.026</td>
<td>0.038</td>
<td>0.072</td>
<td>0.640</td>
<td>0.043</td>
</tr>
</tbody>
</table>

Note: * For intermittent generating options the 7000 hours refer to availability of equipment and not overall availability which is clearly much lower.
Table 9.2. Outline supply and installation costs at small scale

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Supply and installation cost per kW capacity</th>
<th>Time at or near output capacity</th>
<th>Other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaic</td>
<td>£3000 to £5000</td>
<td>Daylight hours only</td>
<td>Large surface area required for mounting panels</td>
</tr>
<tr>
<td>Small wind turbines</td>
<td>£2000 to £3000</td>
<td>Dependent on wind speed and elevation</td>
<td>Installation on sign gantries or lighting columns provides better elevation</td>
</tr>
<tr>
<td>Micro-hydro</td>
<td>Up to £3000</td>
<td>Output is good in watercourse; rainfall dependent in highway drainage</td>
<td>Installation may require significant temporary and permanent works</td>
</tr>
</tbody>
</table>

**Note:** These costs have been based on systems with inverters that are grid connected. Installations using battery-based systems may be up to twice the cost.

### 9.3 Grid connection issues

In Table 2 it is evident that small scale methods of renewable energy generation cannot be relied on for constancy of supply. For example photovoltaic arrays tend to produce their maximum output at midday, whereas the energy demands to drive motorway lighting peak overnight. Power from small wind turbines is also erratic according to the weather and the prevailing wind speed. It is only output from micro-turbines in watercourses that may be able to supply a steady source of energy.

A decision on approach generally needs to be made according to the method of renewable energy generation and the location of the proposed installation. The main approaches are as follows.

#### 9.3.1 Stand-alone systems

Where there is a network power requirement at a location remote from an electricity grid system, installation of a lengthy cable run is likely to prove very expensive. A stand-alone system, which is battery backed, generating energy from small scale renewable sources may then prove a very cost effective solution for relatively low power applications. This type of system is ideally suited for providing emergency services communications, driver information, and other low power requirements. In terms of providing street lighting where the power requirement is higher and if occasional failures cannot be tolerated, a grid-supported system (see Section 9.3.3) or a hybrid system may need to be employed. For example, a combined solar and wind powered system may ensure continuity of supply. With stand-alone systems some provision also needs to be made for battery maintenance costs.
9.3.2 Grid connected systems

There is a significant advantage with a grid connected system in so far as no battery back-up system is required. This reduces not only the installation costs (provided that easy access is available to the electricity grid) but also eliminates battery maintenance costs. However electricity generated from renewable sources must then either be immediately used or fed back into the grid. As previously discussed the peak use of electricity on the highway network generally occurs for lighting purposes overnight when output from renewable sources such as solar is at a minimum. The possible exception to this is the specific application of tunnel lighting and ventilation where there is also heavy daytime electricity demand.

As Highways Agency has its own private network connected to the national grid at intervals, power from any of its own renewable energy sources would probably be immediately consumed. It is only if considerable power generation from renewable sources is achieved that electricity would need to be sold to the grid with repurchase some hours later. In this eventuality, the economic viability of grid connected systems (with no battery back-up) would therefore ultimately depend on the relative costs of selling and buying power from the electricity utilities. This is a matter for negotiation and the comparison is considered outside of the scope of this report.

9.3.3 Grid supported systems

A stand-alone system with battery back-up and grid support, which operates only in the event of unavailability of renewable energy, may be attractive in many instances. This means that all the available renewable energy is either used or stored for reuse near its source and, in the event of loss of supply, electricity is drawn from the grid with there being no impact on the operation of the highway equipment or furniture. An installation of this type is the most expensive to install and battery maintenance is required periodically, however continuity of supply is assured.

9.4 Potential for development on the highway network

Most forms of renewable energy, which have potential for recovery from within the highway network, are more suited to low power applications. For this reason their installation cannot be viewed in isolation from measures to improve the energy efficiency of the network. For example, some relaxation in the luminance requirements of motorway and trunk road lighting may be possible which combined with an increasing use of LED rather than high pressure sodium lanterns would make renewable energy recovery more viable.

The high capital cost of most renewable energy sources means that it is often only in new build situations where this cost can be offset against the cost of connection to the national grid. This is also the case in remote and rural situations where long landlines would otherwise be required.

A preliminary assessment of the potential for the development of the different forms of renewable energy available within the highway network and considered in this report are prioritised in Table 9.3.

In Table 9.3 it is important to note that the potential for electricity generation has been separated from that for use as a source of direct heat. Although in principle electricity can be
Table 9.3. Potential for development as small scale renewable energy source

<table>
<thead>
<tr>
<th></th>
<th>ELECTRICITY</th>
<th>DIRECT HEATING</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Photo-voltaic panels</td>
<td>Wind turbines</td>
<td>Hydro-electric power</td>
<td>Energy from vehicle loading</td>
<td>Heat exchangers in pavements</td>
<td>Geothermal energy (ground and deep foundations)</td>
</tr>
<tr>
<td>Bridges</td>
<td>M/L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Retaining structures</td>
<td>M</td>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td>M/L</td>
</tr>
<tr>
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<td>L</td>
<td></td>
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<td>M/L</td>
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<tr>
<td>Noise barriers</td>
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<td>L</td>
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<tr>
<td>Sign gantries</td>
<td>H</td>
<td>M</td>
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<tr>
<td>Lighting columns</td>
<td>H</td>
<td>M</td>
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<tr>
<td>Slopes and verges</td>
<td>L</td>
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<td>Watercourses</td>
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<tr>
<td>Drainage</td>
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<td>M/L</td>
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<td>Balancing ponds</td>
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<td>L</td>
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<td>Concrete pavements</td>
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<tr>
<td>Asphalt pavements</td>
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<td></td>
<td>L</td>
<td>M</td>
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<tr>
<td>Buildings (eg.depot)</td>
<td>H</td>
<td>L</td>
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Notes: (1) H = high, M=medium, L=low. (2) Biomass and bio-energy sources not considered. (3) Passive solar sources for direct heating not included.
reclaimed from direct heat, the process is generally relatively inefficient and for this reason these sources are considered separately in the table.

In terms of the recovery of solar power it is primarily the highway furniture and the exposed faces of noise barriers, structures and buildings which are likely to provide suitable mounting for photovoltaic panels. The necessary elevation for wind exposure to efficiently operate small scale wind turbines is also more available on sign gantries and lighting columns. It is assumed that Highways Agency does not have sufficient land resources to permit the construction of more large scale wind farms. One of the other promising areas is the small scale recovery of hydroelectric power from watercourses where they pass below highways: liaison with the Environment Agency may be necessary on these issues.

It must be emphasised that significant research into the recovery of energy from renewable sources is underway in the UK and elsewhere in the world and the assessments of potential given in Table 9.3 need to be kept under review.

9.5 Recommendations for site trials

Increasing use of renewable energy resource is likely in the next decade as other energy sources become depleted and renewable energy becomes more economically viable. Full scale trials are therefore strongly recommended so that Highways Agency is better placed to implement their installation as and when it is appropriate. The following particular trials are considered to be currently of value.

(i) There is an increasing need for driver information systems on motorway, trunk and local roads. These transport telematic systems are generally mounted on gantries and incorporate LED’s which are ideal for powering by photovoltaic cells fixed to the backface of the gantry. Eliminating the requirement for cabling and grid connection, which is particularly expensive in remote locations, offsets the capital cost of a photovoltaic system with battery backup. A trial is proposed of the performance over a minimum period of one year of a prototype gantry using photovoltaic power as its sole electricity supply.

(ii) Large scale demonstration projects where solar panels have been installed on noise barriers have been undertaken in many European countries including the Netherlands, Switzerland, Austria, France and Germany. In the UK there are 41 km of noise barriers on the M25 alone so the infrastructure exists for mounting solar panels. A trial is therefore proposed on the motorway network with photovoltaic panels mounted on a significant length of barrier. These trials should be fully instrumented to monitor the influence of weather and location on power generation.

(iii) In remote locations, where grid connection would be expensive, there is often a limited power requirement whether it is for traffic signals, emergency telephones, minimal lighting, or other use. There would be merit in carrying out a trial to investigate the performance of a hybrid solar and wind power system capable of driving, for example, a single lighting column.

(iv) Watercourses that pass beneath highways may provide a constant source of power. A trial of a micro-turbine system at a bridge or culvert location would be of value in
assessing the ease with which output can be fed into the HA electricity network. Liaison with Environment Agency would probably be necessary on this issue.
10. CONCLUSIONS

This feasibility study has reviewed the different forms of renewable energy and provided a preliminary assessment of the prospects of procuring energy from within the highway network. The main conclusions were as follows.

(i) Renewable energy technologies are likely to become more important as other energy sources become depleted and the cost of power generation rises. These sources of energy have considerable potential for increasing security of supply and are environmentally friendly although, in most cases, they require significant initial investment and no economic benefit should therefore be anticipated over their first decade in service. It is only in remote rural locations and new build situations where high installation costs can be offset against the provision of cable connection to the grid and renewable energy may be immediately cost effective.

(ii) Most forms of renewable energy, which have potential for recovery at small scale from within the highway network, are more suited to low power applications. For this reason their installation cannot be viewed in isolation from measures to improve the energy efficiency of the network.

(iii) Techniques for recovery of electricity from solar, wind and hydro power have potential for implementation at small scale. The use of heat exchangers and ground source heat pumps in recovering energy from solar thermal heating of pavements and geothermal resources is more suited to direct heating applications rather than electrical power generation. Recovery of energy from pavement deflection under vehicle loading is currently not technically viable. The use of biomass and bio-energy techniques was not within the scope of this study.

(iv) In terms of the recovery of solar power it is primarily the highway furniture and the exposed faces of noise barriers, structures and buildings which are likely to provide suitable mounting for photovoltaic panels. The necessary elevation for wind exposure to efficiently operate small scale wind turbines is more available on sign gantries and lighting columns. Highways Agency generally does not have sufficient land resources to permit the construction of more large scale wind farms. One of the other promising areas is recovery of hydroelectric power by installation of micro-turbines in watercourses where they pass below highways: liaison with the Environment Agency may be necessary on these issues.

(v) The report discusses grid connection issues. Small scale methods of renewable energy generation cannot be relied on for constancy of supply and therefore need to be used as stand-alone systems with battery back-up, grid connected systems, or grid supported systems.

(vi) Highways Agency will accrue positive publicity by implementing trials at full scale and showing an active response to the UK government’s commitment to the Kyoto Protocol and “green” energy production as well as to the current public consultations organised by the Department of Trade and Industry. The report recommends various options for full scale trials of which one would be a major trial focused on the use of photovoltaic panels mounted on a length of motorway noise barrier.
11. ACKNOWLEDGEMENTS

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12. REFERENCES


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