A practical trial to investigate the feasibility of wide-scale collection of cuttings from roadside verges in Powys, for use in biogas and compost production

Living Highways Project

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Summary

The collection of cuttings is an important consideration when managing grassland areas for the benefit of biodiversity. However, despite the ecological benefits, there are considerable practical and economic implications associated with applying this practice as part of wide-scale road verge management. It has previously been difficult to address these constraining factors due to a lack of quantitative information on which to base discussions and decisions.

A trial was carried out in Powys, Wales, UK, during four weeks spread between May and August 2005. A specialised harvesting machine was used to cut and collect vegetation from a variety of road verges (on different grades of road and in different locations) and the efficiency of the operation was monitored. The feasibility of using the collected vegetation for compost and biogas production was investigated by laboratory analysis and commercial-scale processes. The quality, quantity and potential economic value of the end products were estimated. This will inform a future assessment as to whether any income from these products could help to counteract the initial costs of the harvesting and transportation operations.

The quality and quantity of harvested material varied depending on the location, but the overall mean values recorded during the trial are summarised as follows. Compost and biogas values are based on a conservative vegetation yield estimate of 0.3 tonnes dry mass/km/yr* and on economic values at the time of writing.

Vegetation yield	Minimum 0.08 tonnes dry mass/km/yr*
	Maximum 0.6 tonnes dry mass/km/yr*
	Typically 0.3-0.4 tonnes dry mass/km/yr*
Estimated potential compost production	0.6 tonnes/km*
Estimated market value of potential compost production	£1.24 - £12.40/km*
Biochemical methane potential of road verge vegetation	0.27 m^3_{CH4}/kg volatile solids
Estimated methane production	73 m^3_{CH4}/km/yr*
Estimated market value of anaerobic digestion products	£22/km/yr*

* these values are per km of road verge cut with a 1.2m flail, cutting a single swath.

Concerns remain as to the overall feasibility of such management. The trial has highlighted particular areas in which further development and evaluation will be required before wide-scale harvesting is likely to be considered as part of general road verge management. The reliability and efficiency of the harvesting and transportation operations need to be improved and optimised before the economic feasibility can be realistically assessed. The relevance of any potential economic gains from the end products will depend on the costs associated with these operations, as well as on the nature of any future economic relationship between the harvesting business, and the business producing the end products.

However, the trial demonstrated that it is physically possible to collect cuttings from Powys road verges on a relatively large scale and that the material is suitable for compost and biogas production. The potential economic value of these products has also been estimated. In addition to the environmental benefits associated with diverting the material from landfill, biogas production would also have the potential to provide a source of sustainable energy, with obvious advantages in terms of minimising global warming.

The feasibility of future scenarios, in terms of economic and environmental sustainability, will need to be evaluated on a case-by-case basis, taking into account the particular circumstances involved. The trial has been successful in providing the necessary preliminary data to enable such evaluations to be carried out, used in combination with other freely available data on costs and efficiencies. This issue can now be considered further in Powys with an improved understanding of the economic and practical limitations, weighed against the potential economic and environmental gains.

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1. Introduction

1.1 The Living Highways Project

The Living Highways Project is an established partnership, started in 2001, between the Montgomeryshire, Radnorshire and Brecknock Wildlife Trusts, Powys County Council, the Countryside Council for Wales and the Powys Verges and Hedgerows Concern Group. The project aims to safeguard and encourage valuable wildlife habitats and species associated with road verge areas in Powys, Mid Wales. The project is working on a number of different initiatives to achieve this, including setting up systems to protect known sites of high ecological value and improving verge management practices. This report relates to one area being pursued by the project, which is the principle of removing cuttings as part of the management regime on grassland areas, as a means of encouraging and maintaining plant species diversity.

1.2 Aims and Objectives of the Trial

This trial did not aim to investigate the ecological benefits of removing cuttings from road verges. The relationship between the removal of cuttings from grassland areas and increased plant species richness is already well understood, and has been demonstrated in a number of published studies (see Section 2.1). The removal of cuttings is now widely accepted as an important part of grassland management and restoration for wildlife, and is already practiced on road verges in some other European countries for this reason

Although the ecological benefits of removing cuttings from road verges are well known, it is not currently part of standard road verge management procedures in the UK, perhaps due in part to a lack of awareness, but certainly also due to the considerable economic and practical implications. The purpose of this trial was, therefore, to establish a better understanding of these economic and practical considerations, including the harvesting operation itself and the subsequent transportation of the collected material. The trial also investigated the potential benefits of using the material to produce useful end products, such as biogas and compost. Ultimately, it is hoped that the trial will provide a first step towards devising a practical and affordable system for harvesting vegetation from road verges on a wide scale in the future.

The objectives of the trial were:

- To test the suitability of specialised large-scale harvesting machinery for use on Powys road verges
- To assess the likely resource inputs required to collect cuttings from Powys road verges on a wide scale.
- To determine the suitability of road verge cuttings for utilisation in compost and biogas production
- To determine the potential economic benefits of utilising the collected vegetation to produce useful end products (including compost and biogas)
- To draw initial conclusions as to the future potential for collecting cuttings from Powys road verges

1.3 Project Development

The Living Highways Project has acknowledged the importance of removing cuttings from road verges, as a means of improving the biodiversity value of grassland areas on the Powys road network. Ideally, cuttings should be removed from all road verges, especially those that have become dominated by rank vegetation. In 2003, the practice began to be incorporated into the management regimes for a number of locally designated ‘Road Verge Nature Reserves’ in Powys, using small-scale machinery and hand rakes. However, it was clear from an early stage that it would not be feasible to collect cuttings on a wide scale as part of general verge management, within current financial constraints and with existing equipment. There were also concerns about the best way to utilise or dispose of the material collected. As a first step towards addressing these obstacles, it was decided that there was a need to establish a much better understanding of the resources and practical issues that would be involved. This would be achieved by carrying out a practical trial during spring and summer 2005.

As can be seen from the objectives listed in Section 1.2, the trial was not designed as a scientific study to produce comparative data. It was intended to be a field trial, to evaluate the principle of collecting vegetation from Powys road verges.

The trial took approximately two and a half years to come to fruition from the initial idea, although within that time there were periods where the proposal was ‘shelved’ due to other work priorities. The early stages involved a gradual development of the idea, reviewing the literature and making contact with people working on relevant projects, both within and outside the UK. The Living Highways Project already involved a number of organisations working closely together on road verge wildlife issues in Powys, and this group formed the starting point for a partnership to carry out the trial.

In May 2004, Glasu funded a preliminary investigation to gather and review available information and to devise a preliminary plan for the trial, including identifying a suitable machinery supplier, locations for the trial, and estimating the appropriate extent of the pilot area based on the capacity of disposal sites, quantities, time and costs involved.

The project relied on funding secured from a variety of sources and on the participation of a wide range of different organisations. In this regard, the risks associated with the project were considerable. If any part of the funding requirements or specialist services were not successful, this had the potential to affect the success of the project as a whole. For this reason, a comprehensive risk assessment and management exercise was carried out at the start of the project, to anticipate and plan for potential problems as far as possible.

Communication and coordination activities were very important throughout the project, especially in view of the number of different groups involved. However, this factor also allowed the project to benefit from an input of ideas and advice from a wide range of subject areas. Synergies were actively sought between the verge management/ecological objectives and issues being addressed in other fields, including waste management and sustainable energy.

1.4 Funding and Project Management

The Living Highways Project partners came together with Transport Wales (TW, Welsh Assembly Government) and the Mid Wales Trunk Road Agency (MWTRA) to plan and carry out the trial. All these organisations shared a common interest in enhancing roadside areas for the benefit of wildlife, within their respective areas of responsibility. TW is responsible for managing the motorways and trunk roads that provide the primary transport links across Wales. MWTRA acts as the Agency for these roads in the Mid Wales area. Management of all other classes of road in Powys is the responsibility of the Local Authority, Powys County Council.

Funding and resources were provided by Transport Wales, Montgomeryshire Wildlife Trust, Powys County Council, Mid Wales Trunk Road Agency and the Powys Leader Plus programme, Glasu. Glasu funded the biogas and compost production, as well as the laboratory testing associated with these processes, under their Energy and Waste funding programme.

Collaborative project management was carried out by Transport Wales and Montgomeryshire Wildlife Trust, in consultation with Powys County Council and the Mid Wales Trunk Road Agency. The project was coordinated by the Living Highways Project Officer, employed by Montgomeryshire Wildlife Trust.

The practical/field aspects of the project were carried out by Powys County Council and Montgomeryshire Wildlife Trust.

Further services involving equipment supply, laboratory analyses and waste management were contracted to third parties (see later sections).

1.5 Links to Policies and Strategies

The proposed harvesting of road verge vegetation, with subsequent utilisation of the material, has the potential to support a number of policies and strategies relating to ecology and biodiversity, waste minimisation and recycling, and sustainable energy production. Some examples of relevant policies and strategies are given in the following sections.

1.5.1 Biodiversity

There is a legal duty on the National Assembly for Wales, and therefore the Welsh Assembly Government, under Section 74 of the Countryside and Rights of Way (CROW) Act 2000 "in carrying out its functions, to have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biological diversity in accordance with the convention." Part of that duty relates to preparing a list of habitats and species that are of principle importance to Wales. Included in that list (Welsh Assembly Government, 2003) are a number of grassland habitats (lowland meadow, lowland and upland calcareous grassland, and lowland dry acid grassland), all of which are represented on roadside verges.

The Environment Strategy of the Welsh Assembly Government, published in May 2006 contains the commitment in relation to transport issues, to produce a new Transport Strategy that will deliver outcomes relating to "conserving and enhancing biodiversity, soils, landscape and heritage". Additionally, the outcomes of the Strategy include an outcome that "…..there is a definite recovery in the number, range and genetic diversity of species including those species that need very specific conditions to survive" and "that the wider environment is more favourable to biodiversity through appropriate management….."

The Trunk Road Estate Biodiversity Action Plan (2004-2014) (TREBAP), published by Transport Wales, Welsh Assembly Government, seeks to achieve the conservation and enhancement of biodiversity of its trunk road and motorway network. The TREBAP includes action plans for the maintenance or restoration of important grassland habitats (e.g. Calcareous Grassland, Lowland Acid Grassland and Lowland Meadows). The action plan for Calcareous Grassland includes the commitment to "Develop appropriate grass-cutting regimes to maintain species diversity in identified areas", while the other two plans referred to above include commitments to restore sites and apply appropriate management regimes.

Grassland also features prominently in the UK Biodiversity Action Plan (BAP), as well as in the local BAP's for Powys and the Brecon Beacons National Park. Grassland types designated as priority habitats in these Action Plans include

Lowland and Upland Calcareous Grassland, Acid Grassland and Lowland Meadows. The Powys BAP also includes specific actions and targets for linear habitats, including road verges, due to the particular value of these areas as ecological and genetic refuges, and as potential links between fragmented habitats.

1.5.2 Waste

The EU Landfill Directive has determined that member states reduce the amount of waste being sent to landfill, and legislation and statutory targets have been introduced nationally to ensure compliance.

The Assembly Government's Waste Strategy, "Wise About Waste: The National Waste Strategy for Wales" (June 2002) does not directly refer to road verge cuttings as a waste or a compostable material. However, the Strategy does set targets for the reduction of waste from industry, households and public/municipal bodies, by increasing the recycling, reuse and composting of waste, in addition to reducing the production of waste. The Strategy sets targets for all UK Local Authorities in terms of specific amounts of waste that must be diverted from landfill, through recycling and composting targets and Landfill Allowances, which limit the amount of biodegradable wastes going to landfill.

The Waste Strategy for Powys 2004/05 – 2013/14 echoes these objectives, including timescales for the achievement of targets for waste diverted from landfill through recycling and composting. The strategy also includes plans for waste segregation and appropriate waste treatment facilities, as well as fore-planning for the requirements of the draft European Bio-waste Directive. The Directive, when implemented, will force Local Authorities to adopt separate collection schemes for food waste, to be treated using methods that meet the Animal By-product Regulations 2003. These methods could include composting and biogas production, under specific conditions.

Road verge vegetation is not currently included in the figures for waste generation in Powys, because it has never been collected or disposed of on a significant scale. Hence, the utilisation of this material for compost and biogas production may not directly benefit the current Powys targets for waste diversion from landfill. However, if road verge vegetation were to be collected and utilised in the future in sufficient quantities, it is possible that this could help to encourage the development of new compost and biogas facilities. This in turn could improve the viability of other green waste recycling streams.

1.5.3 Energy

The Kyoto Protocol was agreed in December 1997, under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases. The UK Government agreed to a 12.5% reduction and set a domestic goal of reducing carbon dioxide emissions by 20% of 1990 levels by 2010. In an effort to deliver these targets, the Government and the devolved administrations in Scotland, Wales and Northern Ireland have produced a new UK Climate Change Programme, published in March 2006, entitled 'Climate Change – The UK Programme'. The programme includes, among other renewable energy options, the encouragement of small-scale generation from biomass and biofuels.

2. Background Information and Related Work

2.1 Ecological Benefits of Removing Cuttings

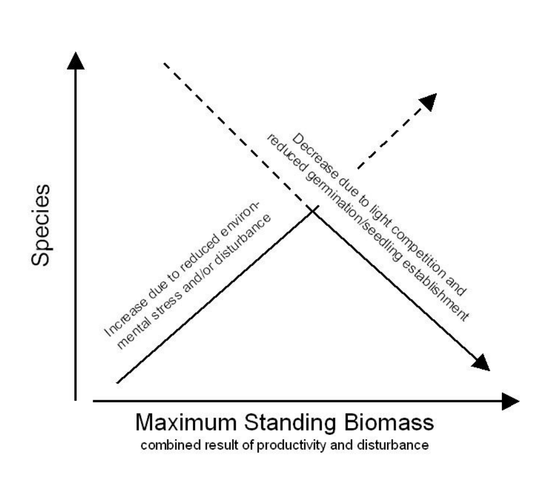
The ecological importance of road verges has become widely recognised and highways authorities have become increasingly interested in managing them with due regard to the conservation of biodiversity. In the UK, road verges contain some of the last remaining examples of species-rich habitats that were once common in the wider countryside and that have declined at an alarming rate over the past few decades. As such, it is considered that they may also help to provide physical links between otherwise isolated pockets of remaining habitats, assisting in the expansion and dispersal of less mobile species.

The removal of cuttings is an important management consideration when aiming to maintain or increase the biodiversity of grassland areas. This section aims to summarise and explain the evidence for the ecological benefits of such management, in terms of increasing and maintaining plant species richness.

2.1.1 Factors Affecting Species Richness

Figure 1 (Schaffers 2002) illustrates a conceptual model for the well known relationship between species richness and maximum standing biomass. (Standing biomass is the total weight of plant material in a given area at a given time, so it is closely related to the productivity/fertility of a site, along with its management regime). Schaffers (2002) explains that in this model, species richness (vertical axis) is presumed to be limited by two opposing sets of mechanisms: environmental stress and disturbance on the one hand and space/light competition on the other. Maximum standing biomass (horizontal axis) is linked to both. It is itself *determined* by environmental stress and disturbance, but in turn it *governs* space/light competition and germination/seedling establishment. Peak species richness is reached at intermediate values of maximum standing biomass, when both limiting processes balance.

Figure 1



The model applies mainly to vascular plants, as opposed to bryophytes and lichens. It reinforces the importance of management in enhancing species richness on productive (fertile) sites. The graph is explained further by Schaffers (2002) as follows:

"Environmental stress (productivity) and disturbance (management) have often been considered in relation to species richness (e.g., Grime 1973, Huston 1979, Fox 1979). However, both factors also regulate the maximum standing biomass. If productivity is low (or disturbance high), both standing biomass and species richness will be low. Many species will simply be unable to persist under these stress levels. When environmental stress levels (or disturbance rates) decrease, species richness will increase, but so will maximum standing biomass. Gradually, there will be a shift from belowground competition to aboveground competition for space and light. At a certain point, maximum standing biomass itself becomes the causal factor limiting species richness. It sets its own constraints as soon as space and light competition begin to outweigh the, now reduced, environmental stress and disturbance. Competitive exclusion will now cause species richness to decrease again, aggravated by the fact that many species will not be able to germinate and establish or re-establish. Highest species richness may thus be expected if there is a balance between environmental stress and disturbance on the one hand, and competition for light and space on the other."

This highlights the importance of inter-specific competition for space and light, in determining species richness. This is supported by other studies showing the relationship between light penetration and species richness (Abrams 1988, Newman 1973, Tilman 1993, Grace & Pugesek 1997, Grytnes 2000).

Schaffers explains that species richness, and the presence of rare species, are related to the actual quantity of standing biomass on a site, rather that to the site productivity as such. (The 'productivity' of a site is taken to mean the relative plant growth rates that it can achieve, or the quantity of plant matter that is produced during a given period of time). This supports the observation that species richness can be enhanced by management, even on sites with high productivity (fertility). Clearly, however, there is often a close relationship between productivity and standing biomass and many studies refer to productivity as a general descriptive term covering both.

2.1.2 How Removing Cuttings Affects Species Richness

As described above, with the exception of very nutrient-poor habitats, there is considerable evidence that the species-richness of grasslands is correlated with soil fertility and plant productivity (the effects of which can, however, be influenced by management). There is evidence that nutrient levels have been increasing in recent years in Wales and across the UK, leading to reduced species diversity on road verges and increasing domination by tall, competitive plants associated with increasing nutrient status (Haines-Young *et al* 2000, Ellis *et al* 2005).

Fertile, productive sites are able to support the growth of vigorous species, whose rapid growth rates and large stature can lead to competitive exclusion of many slower growing species, resulting in a plant community dominated by relatively few vigorous species. Hence the removal of nutrients by cropping is often suggested as a means of reducing soil fertility and increasing plant species richness (Fynn et al, Maron *et al*, Oomes 1990, Willems *et al* 1993). This has been widely demonstrated to be effective, although the rate of fertility reduction is very much dependent on the characteristics of individual sites and the extent of the simultaneous nutrient inputs from precipitation, weathering of the rock base, pollution or biological fixation. Furthermore, biodiversity benefits have been demonstrated even in cases where the effects on soil fertility have been minimal, so it is thought that the benefits of removing cuttings are also related to the physical effects of the cuttings and the removal process.

A further consideration, where nutrient depletion is aimed for, is the importance of removing cuttings as soon as possible after mowing. A study carried out in Holland (Schaffers *et al*, 1998) showed that unless cuttings are collected within one or two weeks, much of the nutrient content may be leached back into the soil.

A number of studies have demonstrated the benefits of removing cuttings. One study carried out on road verges in Cambridgeshire, UK, over a period of 18 years (Parr & Way, 1988) demonstrated significantly higher numbers of plant species in plots where cuttings were removed. The study was carried out in two different areas, one with chalk soils and one with a clay soil. Parr & Way suggest that, in addition to the effect on soil fertility, there are two other ways in which the removal of cuttings may increase species-richness. First, a large mass of cuttings left on the ground may smother the underlying vegetation, reducing photosynthesis, increasing susceptibility to disease and, particularly if wet, leading to plant deaths. The light, temperature and soil conditions under decaying vegetation are often unfavourable to germination and seedling establishment. Furthermore, cuttings are often left at times when vegetative growth is rapid and gaps are quickly filled by the spread of existing plants (i.e. those which can tolerate the conditions described above) rather than by new plants. It is interesting to note that traditional management methods for road verges, which involved grazing and/or hand cutting with removal of the sward for animal fodder, would have avoided these effects. In other studies referred to by Schaffers (2002), plant litter accumulation resulting from lack of management (Dickinson 1984) has also been shown to significantly affect seed germination, seedling establishment and the outcome of competition between existing species (Carson & Peterson 1990, Tilman 1993, Foster & Goss 1998, Berendse 1999).

Secondly, Parr & Way suggest that in some cases, the removal of cuttings may involve a disturbance of the grass turf, which favours the establishment of new plants from seed. This is particularly likely to occur when cuttings are raked off. The scarification caused by raking may be sufficient to create gaps in the surface layer of plants and thatch, exposing dormant seeds to the light and stimulating germination. Germination from seed is more likely to result in the introduction of a new species than is vegetative spread, so such disturbance may be sufficient to cause an increase in species richness.

A study by Schaffers (2002) also clearly demonstrated that the removal of cuttings increased general species richness, as well as increasing the occurrence of rare and endangered species. The only exceptions in this study were found in shaded plots, where environmental stress (lack of light) and hence low productivity would have reduced the significance of inter-specific competition.
Interestingly, a study carried out over 23 years on British chalk downland (Wells & Cox, 1993), failed to find any difference in species richness between plots where cuttings were removed and plots where cuttings were returned to the sward in a dried and powdered form. This supports the suggestion that the benefits of removing cuttings are not simply related to nutrient levels but are also related to the physical effects.

The findings presented above suggest that on road verge areas with sparse plant growth, and hence with small volumes of cut material, the effects of cuttings may be expected to be less significant, especially if a cutting machine is used that will shred and distribute the cut material in a fairly divided form. However, on productive verge areas, the removal of cuttings would be expected to bring about significant benefits in terms of species richness. It is therefore essential that it be incorporated into the management process, if biodiversity is to be maintained and/or increased.

2.2 Road Verge Vegetation – Waste or Resource?

The practice of removing cuttings from road verges generates significant quantities of ‘green waste’ that needs to be dealt with in a cost effective and sustainable manner. There are already a number of established technologies for converting green waste into valuable products, which provide the potential for such material to be seen as a resource, rather than a waste problem. One of the objectives of this trial was therefore to determine whether, given the right circumstances and facilities, the material could be used to produce useful end products and offer economic benefits that would help to cover the costs of the harvesting operation in the future.

This trial investigated the use of road verge vegetation for compost and biogas production. However, other potential uses for plant material include use as animal fodder (either directly or through silage production), as a fuel for biomass power stations and boiler systems, or as a substrate for worm culture, which can produce a range of composts and plant feeds.

2.2.1 Composting

Compost is a common name for humus, which is the result of the aerobic decomposition of biological material. During aerobic decomposition (in the presence of oxygen), there is no net production of greenhouse gases. Although carbon dioxide (CO_2), a greenhouse gas, is produced, the amount of CO_2 released only corresponds to the CO_2 that was fixed from the atmosphere into the plant material when it was alive. Hence, there is no net release of CO_2 and no net contribution to global warming.

Compost is used in gardening, landscaping and agriculture to improve soil structure, increase the amount of organic matter, and provide nutrients. During the composting process, decomposition is performed primarily by microbes, although larger invertebrates such as worms and ants contribute to the process. Decomposition occurs naturally in all but the most hostile environments. However, rather than allowing nature to take its slow course, commercial compost producers aim to provide an optimal environment in which decomposers can thrive. To encourage the most active microbes, the compost pile needs the proper mix of ingredients, especially Carbon, Nitrogen, Oxygen and water. Decomposition happens even in the absence of some of these ingredients, but is much slower.

All guidelines for building compost piles have the goal of creating and maintaining the proper environment for a decomposing ecosystem, especially the bacteria that work directly on the organic content of the pile. The most rapid composting occurs with the ideal ratio, by dry chemical weight, of carbon to nitrogen of around 20-30 to 1.

As the bacteria decompose the organic matter, they generate heat, and the inner part of a compost pile heats up the most. Compost producers usually turn the pile periodically to aid aeration and to mix the material before the nutrients become depleted in the hot centre of the pile. They also monitor moisture levels to ensure optimal conditions.

Managed compost production can take as little as three or four weeks, compared to around two years for unmanaged decomposition.

A Publicly Available Specification for composted materials, PAS 100, has been developed by the Composting Association, in collaboration with the Waste and Resources Action Programme (WRAP) and the British Standards Institution. The specification includes quality limits for the selection of input materials and the quality of composted materials, as well as for the marking and information labelling of the product. PAS 100 includes upper limits for human pathogen indicator species, potentially toxic elements, physical contaminants and weed propagules in the final compost product. It also specifies minimum performance in a plant germination and growth test.

2.2.2 Anaerobic Digestion (AD) / Biogas

Anaerobic digestion (AD) is a natural biological decomposition process that occurs in the absence of oxygen. The process produces a gas mixture principally composed of methane (CH4) and carbon dioxide (CO2), otherwise known as biogas.

Methane has a relatively high global warming potential if it is allowed to escape into the atmosphere, and this is one of the main concerns associated with the land-filling of biodegradable materials (Burial of the material creates anaerobic conditions and the biogas produced eventually escapes to the surface). In fact, the Intergovernmental Panel on Climate Change has estimated that methane has a relative global warming potential 21 times that of carbon dioxide (mass for mass). However, if the methane produced during anaerobic decomposition is captured and burned, the methane is converted to carbon dioxide. Although carbon dioxide (CO_2), a greenhouse gas, is produced, the amount of CO_2 released only corresponds to the amount of CO_2 that was fixed from the atmosphere into the plant material when it was alive. Hence, there is no net contribution to atmospheric CO_2 concentrations and hence no net contribution to global warming. Because of this, it is considered to be an environmentally friendly energy source and is receiving a lot of interest as a fuel for sustainable energy. (The obvious contrast to this scenario is the burning of the fossil fuels coal, oil and natural gas. Although these were derived originally from biological material, burning them releases into the atmosphere carbon that would otherwise remain locked up in these deposits as it has been for millions of years, i.e. there is a net release of CO_2 into the atmosphere.)

Biogas can be produced from a wide range of biological wastes, such as livestock manure, food processing waste, and other animal and plant material, including ryegrass and other vegetation (see Section 4.3.3). The methane produced can be burned as a fuel to generate electricity and heat, and it has already started to be used in some European countries as a fuel for trains and other vehicles. Excess electricity can be sold to electricity suppliers and heat can also be used for heating other buildings.

In addition to biogas, the anaerobic digestion process produces a nutrient-rich liquid that can be used as a fertiliser, and a solid residue similar to compost, which can be used as a soil dressing or for producing fibre products. The carbon-dioxide fraction of the biogas can also be isolated and used (eg. it can be piped into glasshouses to promote plant growth).

In commercial anaerobic digestion, biological waste is put into an airtight container or tank called a digester, where it is steadily digested by a range of naturally occurring anaerobic bacteria. Some systems utilise several successive tanks in order to provide optimum conditions for each stage of the process. Depending on the waste feedstock and the system design, the biogas produced is typically 55 to 75 percent methane.

Many anaerobic digestion technologies are commercially available and have been demonstrated for use with agricultural wastes and for treating municipal and industrial wastewater.

The ideal ratio, by dry chemical weight, of carbon to nitrogen for biogas production is 20-30 to1 (Marchaim 1992).

The process of anaerobic digestion consists of three steps. The first step is the decomposition (hydrolysis) of plant or animal matter. This step breaks down the complex organic material to usable-sized molecules such as sugars. The second step is the conversion of decomposed matter to simpler soluble organic molecules, including volatile fatty acids (VFA's). Other micro-organisms then finally convert the VFA's into methane. An AD reactor may consist of a single chamber, in which all three stages occur together, or it may comprise two or three consecutive chambers, which allows physical separation of the biochemical stages.

In a single stage reactor, the aim is to optimise conditions for both groups of micro-organisms, but the second group (those responsible for converting VFA's to methane) work more slowly than the first and are inhibited by low pH values. Hence, if for any reason they don't keep up with the first group, the pH falls due to excess VFA production, the rate of conversion to methane falls still further and the process can grind to a halt. A high level of VFA's in a single-stage reactor is therefore an indication of inefficiency (not all of the feedstock (raw material) is being converted) and also of impending operational problems. On the other hand, a feedstock that produces lots of VFA is a good one for biogas production if the conditions can be controlled. For these reasons, VFA's and pH are often monitored during the process.

Ensiling the feedstock material before it is digested, by storing it in watertight and airtight conditions as for silage production, has some benefits. It preserves the material so that it can be fed to the digester over a period of time, allowing biogas and energy to be produced continuously even when no fresh material is being cut. In addition, ensiling can potentially increase the overall methane yield. It is thought that the initial fermentation that takes place acts as a kick-start to the AD process, by providing a supply of simple soluble compounds. The ensiled material starts to decompose, but cannot decompose beyond a certain point because the microbes required for the later stages of anaerobic digestion are absent. Only when it is added to the AD reactor, where the necessary microbes are present, can the further biochemical stages of AD proceed.

2.3 Examples from Other Projects

The aim of this section is to summarise some examples of other projects that have demonstrated the potential for addressing similar issues with regard to environmental and financial conflicts, or that deal with issues relevant to this study.

2.3.1 Composting Bracken

Several projects in the UK are taking steps to turn the environmental problem of bracken infestation into a commercial product, bracken compost. These projects have all been successful in covering the costs of harvesting the material and achieving a profit from an environmental management activity.

Black Down, part of Burrington Commons, is an extensive area of lowland heath and one of the last large, open spaces within the Mendip Hills Area of Outstanding Natural Beauty (AONB). Over time, the site was becoming increasingly covered with dense bracken, which was detrimental to the overall wildlife value of the site, as well as limiting public access. Controlling the bracken by chemical or mechanical means would be a costly process. However, a feasibility trial was carried out in 2000, to determine whether the bracken could be harvested and used as a resource for compost production. The project involved a partnership of the AONB Service, Langford Court Estates, the landowners and Fountain Bark Products Ltd, a local wood-products and compost business. Over the following years, the partnership carried out further work to develop the harvesting methods and machinery, the composting methodology, and marketing. ‘Bracken Down’ soil conditioner is now a successful commercial product, sold under the slogan ‘Good for the environment as well as your garden’. The enterprise not only serves to cover the costs of the nature conservation management on Black Down, thereby adding to the biodiversity and landscape value of an important area, but is also now an independent profitable business, Bracken Down Composting Ltd. In addition to the Bracken Down product, the company has also become involved in the on-farm composting of green waste from the Local Authority community recycling centres.

Bracken is a dominant and invasive species that has been increasing in recent years. It is no longer used as livestock bedding. Sheep have replaced cattle in many upland areas, thus reducing the amount of trampling which helps to keep the bracken at bay. Cutting the bracken and creating grassy areas for sheep gives heather a chance to regenerate. Bracken also offers a viable alternative to the use of peat in compost production, which is leading to the loss of important peat bog habitats.

Similar projects that have been set up to produce bracken compost include the highly successful 'Lakeland Gold' brand, produced by Barker and Bland in Cumbria, and 'Green Frond', which is produced in Shropshire from bracken harvested from the Long Mynd near Church Stretton. The Green Frond project was developed by Shropshire Wildlife Trust, in collaboration with the National Trust and local landowners. An initial feasibility study investigated the quality of the compost process and product as well as the potential market. The product is now sold through the Wildlife Trust and the National Trust, priced at a premium as a peat-free conservation-friendly product. Transportation distances and production costs are relatively low and sales are sufficient to cover the cost of production and time inputs by the landowners.

2.3.2 Worm Composted Products

In Monmouthshire, the Local Authority is working in partnership with the green waste recycling company, Wormtech Ltd. The scheme demonstrates the potential for Local Authorities and communities to save money while improving the environmental sustainability of their operations, through mutually beneficial partnerships. Wormtech operates a kerbside collection service in Monmouthshire and converts green waste and cardboard into a range of commercial products, using conventional composting and worm-culture methods. Products include wormcast lawn re-vitaliser, liquid plant feeds and solid fertilisers. Although the company bears the costs of transportation and production, the Local Authority pays a fee for the service. However, the costs to the Local Authority are lower than if the material were taken to landfill, and they also take a share of any profits.

2.3.3 Heat and Power for Communities

In the Austrian town of Atzbach, both heat and power are generated and supplied to the town from a combined biogas and woodchip heat and power plant, which is fuelled entirely by biological materials, including waste woodchip, liquid manure and dung. During the summer months, the plant is fuelled mainly by vegetation cut from the surrounding farmland. Farming patterns in the region have changed in recent years as many are not farming livestock. Consequently, it is reported that this shift and the creation of the plant has resulted in local farmers 'farming grass'.

The scheme has been set up successfully with financial support from the government. The plant has a thermal capacity of 500kw. It supplies approximately 40% of the houses in the region and the facility could potentially supply around 400 households.

2.3.4 Creating Biogas from Agricultural Energy Crops

The Biogas company Greenfinch Ltd, have recently carried out a project in Shropshire to investigate the business feasibility of growing ryegrass as an energy crop for biogas production on British farms (Holliday *et al)*. The work was carried out as part of the Department of Trade and Industry's New and Renewable Energy Programme, which is managed by Future Energy Solutions. The study investigated different cutting regimes and biogas reaction methods, and presents business cases based on three different scenarios regarding sales of electricity, compost and heat. The data generated by the project are referred to in sections 4.1.2 and 4.4 of this report.

Reports indicate that in Germany, there is a rising demand for biogas substrates and therefore an increasing interest in using vegetation of various kinds (Prochnow *et al* 2005). This is reported to be driven largely by their Renewable Energy Sources Act, which forces power supply companies to take over electricity from renewable sources and to pay guaranteed minimum prices.

A German study (Prochnow *et al* 2005) has investigated the feasibility of using 'landscape management grass', from nature conservation areas, as a feedstock. The results are referred to in section 4.3.3. A further economic study is planned, to evaluate the economic feasibility of using such areas as a source of raw material for biogas production. When available, the results will be extremely relevant to the issue of collecting road verge vegetation.

2.3.5 Growing Vegetables from Garden Waste

In Newtown, Powys, the Cwm Harry Land Trust (CHLT) operates a kerbside collection scheme for garden waste, which they turn into compost. The compost is used to grow vegetables and fruit, which adds value to the product and helps to develop a local food economy, bringing together sustainable waste management and sustainable agriculture. Households buy into the scheme to receive back regular deliveries of the produce. The Local Authority has a contract with CHLT whereby it pays the Trust per tonne to receive green waste collected from Newtown residents. The County Council also provided some capital funding alongside Lottery funding under the Powys Cleanstream Project.

2.3.6 Wood Chips to Provide Animal Bedding

A partnership of ten farms in north Powys are using chipped waste wood as a winter bedding for livestock. Not only does this remove the necessity to buy in straw but also, the wood chip bedding is reported to outperform straw. At the end of the winter, used bedding is sieved to remove remaining large chips, which are used again the following year. The remaining material is composted and used as a soil dressing on the fields and as a growing medium for a native tree nursery.

3. Methods

The trial was carried out between May and August 2005. All harvesting work was carried out on roads within the county of Powys, Wales, United Kingdom (see Figure 5). Powys is a rural and mountainous area, and the roads generally include frequent bends and steep gradients, especially on the minor roads.

3.1 Overall Design of the Trial

The timetable for the trial was designed to represent the current normal verge management schedule in Powys and the typical variety of road types and vegetation types encountered. However, the trial was carried out just before the scheduled cutting dates (approx. 1 week ahead), to ensure that the scheduled cutting work would not interfere with the trial work.

Roads throughout the UK are classified and assigned code letters according to their strategic status. Motorways (prefixed M) are expressways, usually comprising two or three traffic lanes. There are no motorways in Powys. A-roads (prefixed A) are the other major routes. They vary from motorway-standard to single-carriageway local roads. B-roads are local routes (prefixed B). 'Trunk road' describes any road or section of road under the control of central government or one of its executive agencies. Trunk roads (suffixed (T)) are the major strategic routes across the UK, for long-distance and freight traffic. For smaller roads that carry less traffic, and which have less strategic importance, there is a further 'C' classification. Finally, the very smallest (in Powys, often single-track,) roads are generally 'unclassified' (prefixed U).

The work areas used in the trial included Trunk, A, B, and C classified roads, as well as unclassified (U) roads. The trial did not cover any dual carriageway roads (of which there are very few examples in Powys). Trunk roads in Powys, and across Wales, are managed under the authority of the Welsh Assembly government, while other roads in Powys are managed directly by Powys County Council. However, at the time of writing, Powys County Council are also contracted to manage the trunk roads in Powys. The main roads (and particularly trunk roads) generally receive more intensive maintenance than minor roads, including verge-cutting regimes, de-icing salt applications and structural work, and they of course have greater traffic levels. It was considered that these factors could affect the quality and quantity of vegetation harvested.

The trial was carried out over four separate working weeks during the normal cutting season, corresponding with the usual cutting dates for the areas in question. In Powys, as elsewhere, the timing and frequency of verge cutting is dictated by the road safety requirements balanced against time and budget constraints, while taking account of seasonal variations in growing conditions. Most of the major roads receive two cuts per year, with junctions and other sight lines typically cut three times per year. Minor roads are typically cut only once per year. ‘Urban’ verges (usually associated with 30 or 40 mph speed restrictions) may be cut up to five times per year.

In Powys, some road verges are subject to special management regimes. For example, trunk road operations are avoided during peak holiday periods. Through the Living Highways Project (see Section 1.1), a number of sites have also been identified as ‘Road Verge Nature Reserves’ and are subject to specific cutting regimes with the removal of cuttings (currently mostly by hand-raking).

During the first and third weeks of the trial, the vegetation collected was taken to an on-farm anaerobic digester at Bank Farm, near Churchstoke, for biogas production. Vegetation from weeks two and four was taken to a waste treatment facility, Bryn Posteg, near Llanidloes, for compost production. For each area, this represented the normal two cuts that would take place. The slightly different timings for each area are related to the way the cutting schedule is organised for the county as a whole, and to local growing conditions.

The harvesting locations are shown in Table 1 and Figures 6 and 7. For each trial week, the locations were chosen within a reasonable travelling distance of the relevant waste treatment facility, Bank Farm, Churchstoke or Bryn Posteg, Llanidloes. The locations of the waste treatment sites are also shown in Figures 6 and 7, along with the ‘bulking sites’ where the harvested vegetation was transferred from the Trilo harvester into a larger capacity vehicle, ready for transportation (see also Section 3.2).

Powys is a mountainous area and the vegetation growth observed on road verges at different locations reflects the local environmental conditions associated with different altitudes. In upland areas, where environmental conditions are generally harsher, plant growth tends to be relatively sparse, in contrast to the relatively lush growth observed on lowland sites.

The harvest dates and locations were chosen well in advance of the trial. The aim was to choose a range of road types, typical of those likely to be encountered in Powys, while minimising safety risks to operators and other road users by avoiding sections known to be particularly narrow or winding. Single-track and unclassified roads were also avoided. The original plan was to harvest from the same stretches of road on the first and second cuts. However, in practice, it became necessary to make a number of changes to the planned schedule as the harvesting operation proceeded (e.g. the programme was readjusted following machinery breakdowns).

Table 1 Harvest locations

	Date (2005)	Waste Treatment Site	Road number
Week 1	23 May	Bank Farm, Churchstoke (Biogas production)	A489
	24 May		No operations
	25 May		A489
	26 May		A489
	27 May		B4385
Week 2	6 June	Bryn Posteg, Llanidloes (Compost production)	B4518
	7 June		A470(T)
	8 June		A470(T)
	9 June		A470(T)
	10 June		No operations
Week 3	11 July	Bank Farm, Churchstoke (Biogas production)	A489
	12 July		No operations
	13 July		A483(T)
	14 July		A483(T)
	15 July		A490
Week 4	1 August	Bryn Posteg, Llanidloes (Compost production)	U2734
	2 August		B4518 & C2019
	3 August		C2019
	4 August		No operations
	5 August		No operations

Litter collection was carried out from road verges on the following dates:

A483, Welshpool to Llanymynech, 10 to 14 January 2005
A470 Llanidloes, 20 to 21 January 2005
A489 Snead Churchstoke, 15 to 18 March 2005

Further litter picking was carried out on all main roads following the May and June cuts. The frequency of litter picking during the trial was typical. However, on a couple of occasions, a litter pick was specifically carried out in advance of the trial cuts. It is more usual to collect litter after the mowing operation (when the litter is easier to see and pick up).

Various factors were recorded during the trial e.g. times and distances involved and mass of material collected (see Section 3.2.1). Samples were taken from the collected material for laboratory analysis (see following sections).

During the trial period, the weather conditions were predominantly fine and dry. However, some of the cuts were taken following and during moderate showers (see appendix 1).

3.2 Harvesting and Transportation

A search was carried out of mowing and harvesting machinery available on the UK market. The aim was to find machinery that would cut and collect simultaneously, had a large collection capacity, and which would cut to the side while being driven on the highway, without compromising road safety. Unfortunately, no UK suppliers were found, although such equipment was known to be used widely in some other European countries. Further investigation allowed us to identify a number of European suppliers, who were approached with a view to hiring machinery for use in the trial. Although several suppliers of suitable machinery were identified, the main challenge was to find a company interested in supplying equipment for a short-term hire period.

The eventual supplier of machinery for trial was MJT Contracts Ltd, which is the British supplier for equipment manufactured by the Dutch company, Trilo. Trilo are established suppliers of grass collection and other vacuum collection machinery in mainland Europe. Rather than import an existing machine from Holland, MJT Contracts formed a new collaboration in the UK with Bomfords and Massey, to put together a complete harvesting unit for use in the trial. The equipment (shown in Figure 2) comprised a Trilo SG1100 vacuum collection unit, and a 5.5 metre reach Bomford Falcon flail arm fitted with a specially adapted 1200 Protrim head, incorporating a double helix rotor shaft, an auger and extraction pipe. The Falcon Collector was specifically designed for the project and engineered to drive the existing Trilo unit. The Trilo-Bomford machinery was teamed with a Massey Fergusson 6470 Dynashift tractor.

The machinery cuts and collects the vegetation in a single operation. In addition to the standard double helix flail rotor shaft, the cutter head also incorporates an auger behind the rotor that moves cut material to the centre of the head, where it is sucked into the accompanying Trilo vacuum collector trailed behind the mowing unit. The vacuum unit is powered from the tractor power take-off (PTO). To provide PTO power to the Trilo, Bomford also had to redesign the gearbox on the Falcon so that it has a through drive-shaft. When full, the load is emptied from the rear of the trailer using a walking floor feature, operated from the tractor cab once the rear door has been opened manually.

The same Trilo machinery can also be used for other functions such as leaf and litter collection, and drain emptying. It is easily adapted by unhitching the collection hose from the cutter head and means that the same machinery could potentially be used for different operations throughout the year.

Figure 2 The specialised machinery used to harvest vegetation from Powys road verges

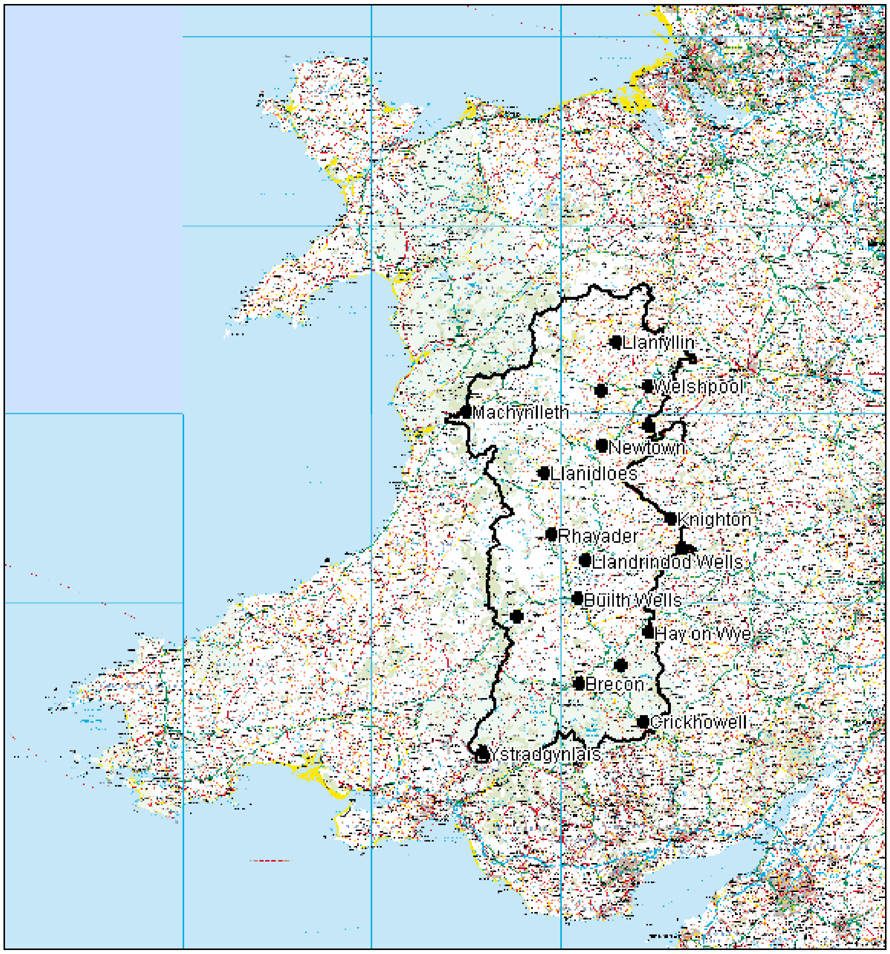
Vegetation was harvested from the verges on both sides of the road, in 1-mile sections (in accordance with current verge-cutting and traffic signing procedures). Sometimes a single swath was cut and sometimes two or more, depending on the road safety requirements, in keeping with normal practice at each location.

Each day during the trial, a site was chosen near to the harvesting operation for use as a 'bulking site'. The harvesting machine was driven back to the bulking site every time it was full, where the contents were emptied onto the ground. Further equipment was used at the bulking site to transfer the material from the ground into a large capacity vehicle for haulage to the relevant waste treatment facility. This allowed the harvester to continue working, and bulking up the material in this way reduced the number of journeys to the final site of utilisation. Bulking sites used included lay-bys, highways depots and wide verges, where it was possible to work a safe distance from the carriageway. The locations of bulking sites are shown in Figs. 6 and 7.

Figure 3 The Trilo-Bomfords harvesting machinery in operation

Figure 4 A full load being emptied from the harvesting machinery at one of the 'bulking sites'

Figure 5 Map showing the location of Powys (black border) in Wales, UK. Main County towns are also shown.



Key to maps in Figures 6 and 7.

Roads:

Green – Trunk Roads
Red – Other A roads
Brown – B roads
Yellow – C roads
Pink – Unclassified roads

Other:

Black stars – Bulking sites (locations close to where the harvester was working, where harvested material was loaded up into silage wagon or lorry for transportation to the AD site)

Blue stars – Compost & Biogas production sites (final destination for harvested material)

Black circles and diamonds – locations of towns and settlements

Figure 6 Map of sites used near Churchstoke (Biogas production)

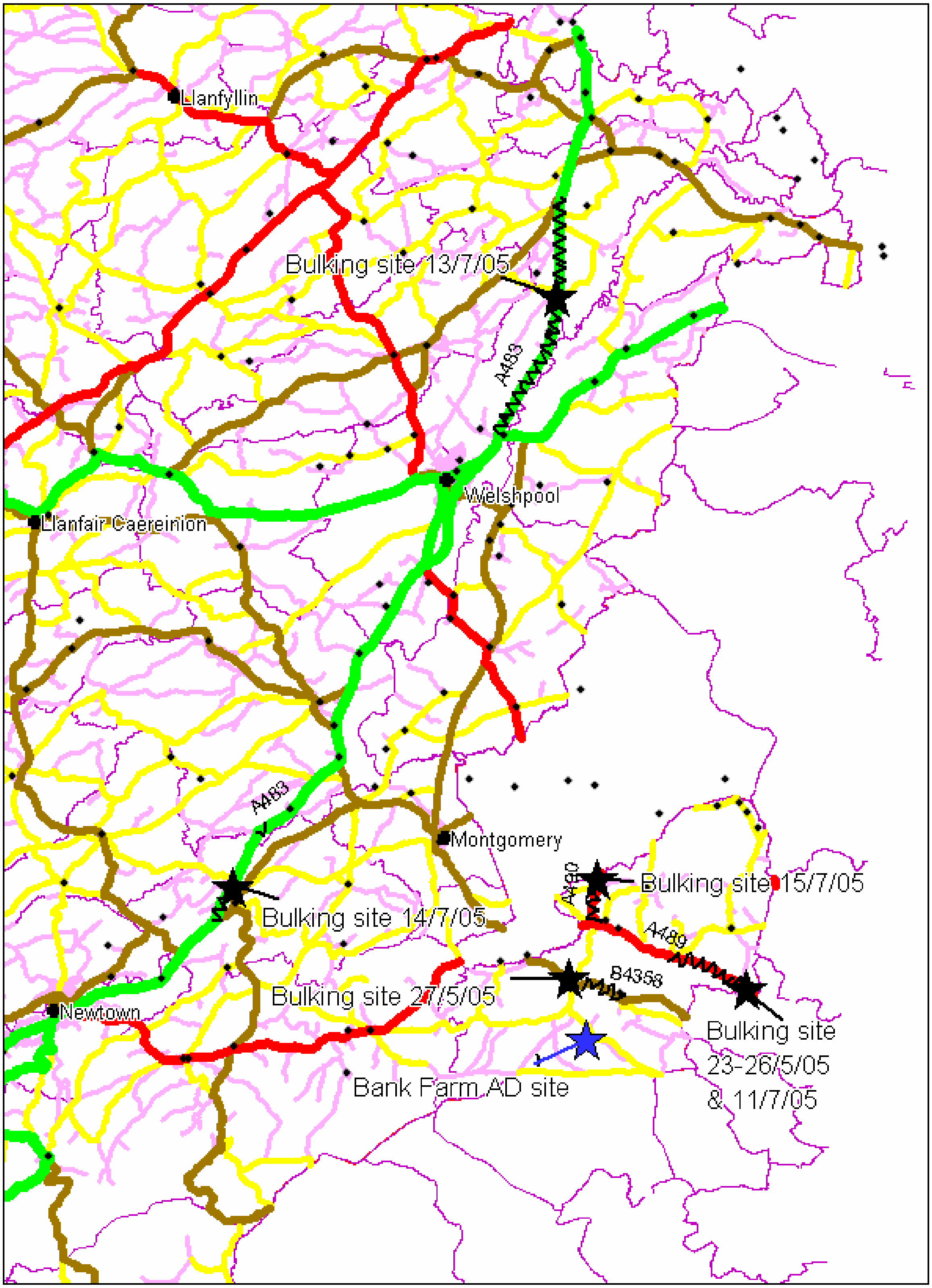
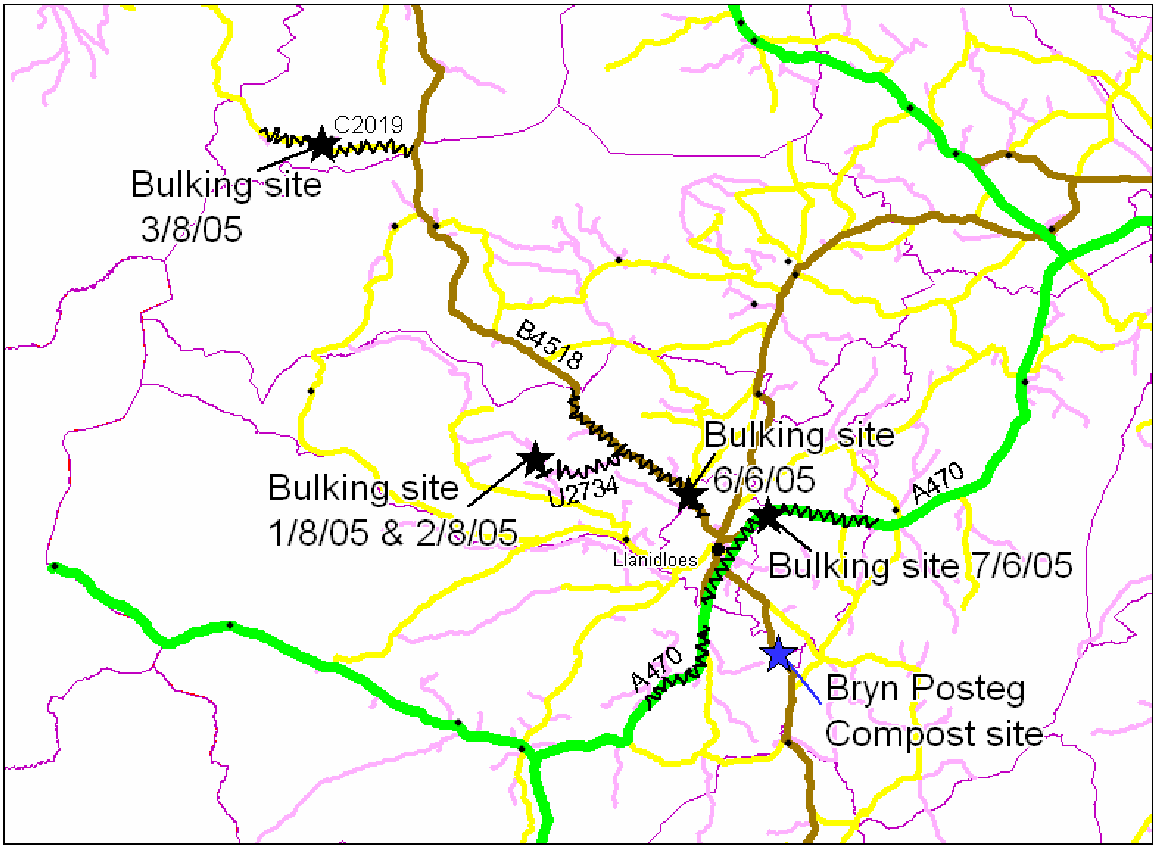


Figure 7 Map of sites used in trial near Llanidloes (compost production)



A range of different equipment was used to bulk up the collected material and transport it to the site of utilisation. This equipment was chosen on the basis of immediate cost and availability to serve the purposes of the trial. It was not necessarily intended to represent the most efficient system for the longer term. Some of the equipment was owned by Powys County Council and some was hired from an agricultural machinery supplier. During weeks one and two of the harvesting operation, the collected material was loaded into a silage trailer hauled by a tractor, but this combination was replaced with a lorry for weeks three and four. During weeks one, two and three, the material was loaded using a Merlo telescopic loader (with a weighing function for weeks one and two (see Section 3.2.1). In week four, a JCB loader was used.

Figures 8 to 10 show the different machinery used for handling and transporting the collected material.

Figure 8

Figure 9

Figure 10

Before harvesting work commenced each day, it was necessary to drive all the required machinery out to the bulking site and to return it again to the nearest Local Authority depot, or other suitable storage facility, at the end of the day. Sites used for storage included depots in Newtown and Llanidloes.

3.2.1 Record Keeping

Throughout the trial, records were kept of the locations harvested, time taken, distance travelled and fresh mass of material collected for each trailer load. Records were also kept of the number of staff involved, the locations of 'bulking sites' where the material was transferred into the haulage vehicle, the time taken to load the material, as well as the weather conditions and the type of vegetation being cut, including whether the vegetation had been cut previously in the season. Distances were recorded by marking the start and end points in the field on a large-scale map and measuring the distance along the road using a digital mapping computer programme on return to the office.

In weeks one and three, the collected material was weighed using the weighing function on the Merlo loader and during weeks two and four, using a weigh bridge at Bryn Posteg.

3.2.2 Waste Regulations

The Environment Agency (EA) was consulted to ensure that the proposed activities would comply with current legislation. Road verge vegetation is currently classed as a waste material, which is subject to the existing regulations relating to on the handling and transportation of green waste. The EA advised that, under the Environmental Protection Act 1990, the activities associated with handling the collected material should only currently be carried out if authorised by a Waste Management Licence. In particular, the fact that the material was off-loaded onto the ground before being transferred onto the haulage vehicle meant that the site at which this occurred (ie each 'bulking site') would be subject to the licensing requirements. However, as a risk-based regulator, the Environment Agency has established a mechanism whereby it may not pursue this requirement if it is decided nationally that it is not in the public interest to do so and it is considered that the waste activity is likely to pose little or no risk to the environment. With changes due to take place in the regulations, it is also possible that the activity may meet the proposed amendments to exemptions from the Waste Management Licensing Regulations, depending on how these are defined.

Hence, details of our proposed activities were presented to the EA to make a decision at a national level as to whether a Waste Management License would be required. The resulting decision was that the activity can be considered to be a 'paragraph 40' exemption under the Waste Management Licensing (Amendment etc.) Regulations 1995 (an exemption for the storage of non-liquid waste at any place other than the premises where it is produced, incidental to collection and transport). To obtain this, an exemption notification form was completed and submitted to the EA, to register the sites that would be used during the trial and the type and scale of activities that would be carried out. It should be emphasised that this permission related specifically to the trial period and locations. Further consultation with the EA will be required if activities progress in the future.

It is not clear at this stage whether road verge vegetation would continue to be classed as a waste material if it became widely used as a 'crop' for commercial processes and was consistently shown to be non hazardous.

3.2.3 Health & Safety

Road safety considerations were paramount throughout the trial. At the planning stage, the locations used in the trial were chosen with care, to avoid any sections of road that were considered too narrow or windy. As a result, it must be acknowledged that the trial did not completely reflect the likely practical and safety issues on all types of road.

Temporary warning signs were installed in accordance with Chapter 8 of the Traffic Signs Manual (DfT 2002) and harvesting work was carried out within a 1-mile length of road at a time.

To increase visibility, all staff involved with the trial wore high-visibility reflective clothing at all times while working on or near the road. The tractor and Trilo trailer both had an amber flashing light on the top, and the rear of the trailer displayed a 'keep right' sign along with reflective strips.

Safety measures were reviewed on a daily basis depending on the location and circumstances. In some cases, additional warning signs were put in place over and above the Chapter 8 requirements. This involved adding countdown markers to emphasise the warning to road users approaching the works area.

In some situations, a second vehicle was driven behind the harvesting machine to provide a buffer between the harvester and approaching traffic. In some cases, a sign board with flashing lights and a 'keep right' sign was trailed behind the second vehicle and in other cases, the sign-board was parked at the side of the road to provide a warning.

Figure 11 The second vehicle and safety sign board that accompanied the harvesting machinery in some areas.

Feedback on the effectiveness of the safety measures is provided in Section 4.1.1

3.3 Utilisation of the Harvested Vegetation

3.3.1 Anaerobic Digestion (AD)

Vegetation harvested in weeks 1 and 3 was delivered to Bank Farm, near Churchstoke, where it was fed into an anaerobic digester.

Figure 12 The Anaerobic Digester at Bank Farm.

The digester is a single-stage reactor (the whole process taking place within a single chamber), which is fed with feedstock semi-continuously (fresh material is fed into the reactor periodically, and a proportionate amount of solid end product is extracted from the reactor at similar intervals).

Prior to the trial period, the digester had been fed with chicken litter and small amounts of slurry. The road verge material was fed into the digester with very small amounts of slurry on a daily basis.

Soon after delivery and prior to being fed into the digester, the road verge material was chopped using an agricultural ‘diet feeder’, then compacted and ensiled. Ensiling the material helps to kick-start the anaerobic digestion process while preventing further degradation until such a time as it is convenient to feed the material into the digester (see Section 2.2.2).

The material was soaked in water immediately prior to being fed into the digester,

in order to dilute the consistency of the material and to aid the auger mechanism, through which the material is fed into the digester.

Any practical issues and observations were noted. It was not possible to reliably quantify the biogas or methane yields within the full-scale AD reactor, so this was investigated further by using laboratory tests (see section 3.4).

3.3.2 Compost Production

Vegetation harvested in weeks 2 and 4 was taken to a waste treatment facility at Bryn Posteg, Tylwch, near Llanidloes. The site is owned by Potters Waste Management Ltd and includes the main current landfill site for Powys domestic waste. However, the site also processes many segregated waste materials. The company is not a commercial producer of compost, but usually composts green waste for use in capping the landfill site, as well as composting mixed domestic waste, in order to minimise its volume and its methane production potential prior to landfilling. The fresh weight of harvested vegetation was recorded via a weighbridge upon delivery to the site. The road verge vegetation was composted along with other non-food green waste materials delivered to the site, such as garden waste. Unfortunately it was not possible to determine the final quantity of compost produced. However, general observations were made as to the quality of the raw material for compost production.

The compost facility at Bryn Posteg is organised into two areas, the first of which acts as a reception bay for the incoming material. Material in this bay is turned each week to let the oxygen penetrate the composting matter. Material is held there for between 4 and 8 weeks, depending on the rate of material input. The material is shredded in a large scale shredding plant and mixed in transition from the first to the second compost areas.

Within the second area, again the material is not covered. It is turned at least weekly and remains there for 3 to 6 weeks or longer, depending on the site's activities at the time. The finished compost was used on the site as a topsoil substitute on 'temporary restoration areas' within the landfill site. These are areas for which there is no need to engineer a permanent cap, but which will not have waste added again for a number of years.

Figure 13 The collected material combined with garden waste, ready for composting at Bryn Posteg

3.4 Sampling and Laboratory Testing

Samples of the collected vegetation were taken immediately upon harvest and/or upon delivery to the waste treatment sites. These were packaged in polythene bags and posted to the appropriate laboratory as shown in Table 2. Samples were taken in accordance with the method for sampling soil improvers and growing media provided in British Standard BS EN 12579:2000. Although the method is not specifically designed for fresh plant material, it was considered to be appropriate, because it provides a means of obtaining a representative sample, based on pooling an appropriate number, volume and distribution of sub-samples taken from a larger pile of material.

Sample codes were assigned to each sample (an explanation of the coding system accompanies the raw data tables in the appendices).

Moisture content was determined for all samples where a load fresh weight had been recorded, in order to calculate the corresponding load dry weight. Using dry weights enables more accurate comparative analysis of the data, to compensate for any variation in mass due to weather conditions and moisture.

A composition analysis was carried out by Direct Laboratories, Wolverhampton. The aim of the composition analysis was to indicate the potential nutritional and energy value of the material and the presence of any potentially toxic elements (PTE's) listed in the PAS 100 compost specifications. This would highlight any obvious issues relating to the suitability of the material for compost or biogas production.

Further laboratory work was also carried out by the School of Civil Engineering and the Environment at Southampton University, to determine the potential value of the material for biogas production (Zou 2005, He & Zhang 2005). Some of the work was carried out by MSc students. Upon arrival at the University, the material was frozen to preserve it until ready to be tested. A series of tests were carried out including a determination of carbon and nitrogen content, total solids and volatile solids, fibre analysis and calorific value. Also, laboratory-scale batch and semi-continuous digesters were run to determine the actual and potential biogas and methane yields for the material. In a batch system, the digester is filled once with fresh feedstock and allowed to go through all of the reaction steps sequentially, whereas in a semi-continuous system fresh feedstock is added at intervals and an equal amount of effluent is withdrawn. The tests were initially carried out using a pooled sample, created by combining equal quantities of all the samples collected during June. However, subsequent testing was carried out using a combined sample incorporating all the samples taken across the whole trial period. The anaerobic digestion process was also monitored by periodically measuring pH and volatile fatty acid (VFA) concentration. This was important because the laboratory scale reactions took place in a single chamber, a system that is especially vulnerable to inhibition by over-acidification (see Section 2.2.2).

Table 2 Schedule of Sampling and Laboratory Testing

TESTS	SAMPLES TAKEN	LABORATORY
Cd, Cr, Cu, Pb, Hg, Ni, Zn, Na, N, P, K, Mg, Ca, S, Fe, Mn, B, Cl, volatile solids, organic carbon, % dry matter.	One per day (1st load)	Direct Laboratories, Wolverhampton
% dry matter only	For each additional load weighed	Direct Laboratories, Wolverhampton
Small-scale Anaerobic Digestion Determination of potential biogas yields & relevant components	One per day (1st load)	School of Civil Engineering & the Environment, University of Southampton

4. Results & Discussion

4.1 Harvesting Operation

4.1.1 Performance, Safety and Practicality

When the harvesting machinery worked without interruption, it cut and collected the road verge vegetation effectively and to a high standard, leaving behind a good, clean and regular cut. While in use, the machinery attracted a number of compliments from the public about the quality of the cut provided.

Figure 14 An example of the road verge vegetation harvested during the trial and the quality of cut achieved.

The vegetation being cut was generally between 20cm and 60cm tall, although the quality of the vegetation varied considerably between sites. In some areas, species such as cow parsley grew to heights approaching 1m.

Feedback from the machinery operators who carried out the harvesting operation indicated there may be some aspects of the machinery design that could be improved upon. The machinery used in the trial was reported to be more tiring to operate than a standard tractor and flail, mainly due to the wider range of functions that need to be monitored. There was also limited visibility to the rear, especially where the suction hose obscured the drivers view in some circumstances (depending on the extension and position of the flail arm).

A further concern was that, in order to achieve the required extension of the collection hose, it was necessary to extend the flail arm a minimum distance from the vehicle when in operation. On some of the smallest roads used in the trial this presented a problem, because it forced the tractor and trailer out beyond the centreline of the road. However, it is suggested that the arrangement of the collection hose could be altered in the future to improve this aspect.

Table 3 gives an indication of the reliability of the experimental Trilo-Bomford harvesting equipment during the trial period. The time for which the machinery was fully operational is expressed as a percentage of the intended usage time. The intended usage time for the trial was five hours per day over a five day working week. The time taken to move the machinery to and from working locations was not counted. The delays experienced were due to a variety of blockages and breakdowns. The likelihood of blockages seemed to increase when weather conditions were wetter.

The harvesting machinery was used without the detachable solid roof on the trailer (but retaining a mesh ceiling) because this increased the efficiency of the collection process. However, some dust was generated that did not occur when the solid roof was fitted.

Table 3

Trial week	Reliability (% operational time)
1	-
2	47%
3	75%
4	54%

It is suggested that further development would be required prior to any future investment or commitment to harvesting equipment, to ensure that the equipment is reliable enough for use in local conditions and that the specifications are appropriate to local road safety issues. The reliability levels observed during the trial limited the amount of data that could be collected and would affect the practicality of this particular machine in long term use. However, the equipment was newly designed and assembled for the purposes of the trial and could benefit from further modification and improvements. In addition, other arrangements or sources of machinery could be considered.

Road safety issues were reviewed continuously throughout the trial (see Section 3.2.3). Additional signs were used in some situations to emphasise the hazard to other road users, over and above the legal requirements. There was considerable debate over the effectiveness of using a second vehicle to follow the harvesting machine, with or without a lighted sign board. The second vehicle provided additional signing to warn approaching motorists and also provided a buffer to provide more freedom for the harvester operator to concentrate on the job in hand and to reverse small distances if needed. However, the second vehicle also added length to the convoy, making it more difficult for other vehicles to overtake and hence increasing delays to the public. Sufficient space was allowed between the two vehicles to enable drivers to overtake one vehicle at a time. However, most drivers were observed to overtake the entire convoy in one step. The keep right sign may have contributed to this interpretation and it has been suggested that perhaps the sign is more suited to dual carriageway or motorway situations than two way traffic on a single carriageway.

4.1.2 Quantities of vegetation harvested

Table 4 summarises the yield of vegetation collected from road verges during the trial. The full data set is presented in Appendix 1.

The fresh weight of vegetation harvested per km was greater during the first cut (May/June) than during the second cut (July/August). However, this was linked to a higher moisture content earlier in the year and in fact there was very little difference between the dry weight yield during the first and second cuts. There is even some indication that the dry mass yields per km may be slightly higher in July/August than in May/June.

Annual yields have been estimated using the mean data from each cutting period. The mass yield of vegetation varied considerably between the different locations harvested during the trial. The minimum and maximum annual yields observed during the trial are considered to be a good representation of the likely range of road verge productivity that would be observed in Powys, because the harvest locations were deliberately chosen to represent a wide range of characteristics. The greatest potential annual yield indicated during the trial was 642 kg dry mass per km travelled with a flail cutting a single swath width of 1.2m. This value came from a locally designated ‘Roadside Verge Nature Reserve’ site in a lowland area on the A483(T), which received a single annual cut on 14th July. The data from the areas cut twice a year indicate a maximum potential annual yield of 565 kg dry mass/km travelled. The lowest yield recorded during the trial was 78 kg dry mass/km travelled. This came from a single annual cut on 3rd

August, on the C2019 (Staylittle to Dyliffe) road, an upland location with relatively harsh environmental conditions and consequently sparse vegetation growth. It is important to note that usually there would not be any requirement on nature conservation grounds to remove cuttings from sites such as this, where the vegetation growth is very sparse. Such vegetation growth barely needs to be cut for road safety purposes, and the effects of plant inter-specific competition in such an environment would be minimal (see Section 2.1).

Figure 15 An example of the sparse vegetation growth on the upland C2019 (Staylittle to Dyliffe) road

From the data collected, it is not possible to determine absolute yields from particular locations, or to extrapolate an absolute potential yield of vegetation from across the whole Powys road verge network. While the yield range across Powys is likely to be similar to that observed in the trial, the relative extent of different types of verge may be different. Hence, the trial data do not necessarily represent a quantitative sub-sample of Powys road verges. In any case, yields would be expected to vary from year to year and may be expected to decline over time in some cases, if harvesting were carried out regularly (in line with nature conservation objectives).

In spite of these limitations, the data do allow us to get an indication of the orders of magnitude that could be expected. The data suggest that in most cases, mean annual yields could be expected to fall within 300 to 400 kg dry mass for each km travelled with a 1.2m cutter swath. Of course, many road verges receive a cut of two or more swath widths, and each km of road includes 2km length of road verge (one on each side of the road). However, for the purposes of the further calculations in Section 4.4, a conservative estimate of 300 kg dry mass/km verge cut has been used as the expected annual yield.

There is no obvious indication of a relationship between the road classification type and the vegetation yield. This may be due to insufficient data, but may also indicate that other factors play a significant role in determining productivity on road verges. While highways maintenance conditions (such as salt applications and traffic volumes) vary between different classes of road, there are also many other factors affecting local growing conditions, including soil properties, drainage, altitude, aspect and various routes of nutrient enrichment.

The volume of collected material was not recorded. Clearly, this would vary considerably depending on the site and weather conditions, and the quality of the material. However, as a very rough guide, it was observed that a full Trilo trailer load of compact collected material, volume approximately 11m^3, typically weighed in the region of 4 tonnes.

Table 4 Yield of vegetation from Powys road verges.

Figures are expressed as kg dry mass collected per km travelled cutting a single 1.2m swath. Mean % dry mass figures for the relevant samples are shown in brackets.

		Minimum	Maximum	Mean
Verges cut twice a year	1st Cut	110 (18.6)	266 (25.8)	182 (21.85)
	2nd Cut	123 (26.1)	299 (38.9)	219 (32.6)
Verges cut once a year		78 (36.2)	*642 (42.9)	**296 (34.2)

* This value was recorded on a ‘Roadside Verge Nature Reserve’ on A483
**Only 3 values recorded

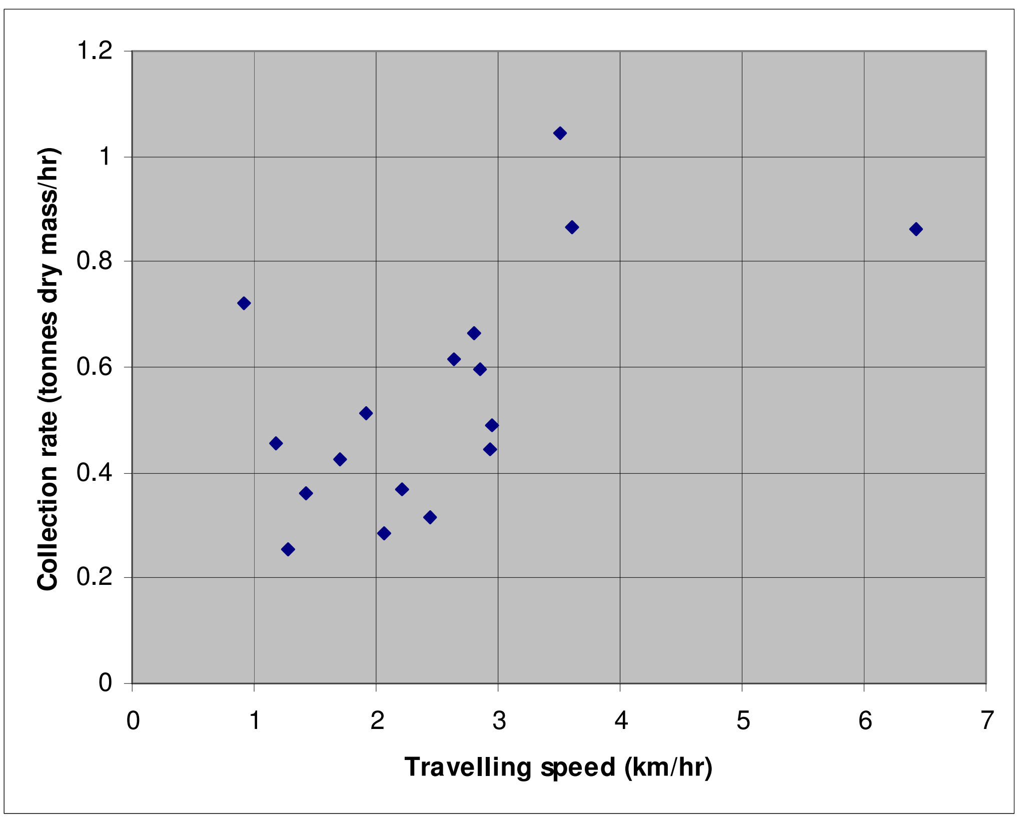
An annual yield of 300-400 kg dry mass/ km travelled is equivalent to 2.5-3.3 tonnes dry mass/ha/yr. When considering the potential value of material for biogas production, this yield is extremely low compared to yields of up to 12.7 tonnes/ha/yr recorded by Greenfinch Ltd, in their study on the feasibility of ryegrass energy crops on British farms (Holliday *et al*). In this study, Greenfinch propose a balanced business model for biogas production from agricultural ryegrass. However, the model includes consideration of a number of costs, such as fertiliser applications, designed to maximise yield, which would not apply to road verge management. The potential biogas yield and value of this material is covered further in Sections 4.5.3 and 4.4, along with a comparison with the yields reported from ‘conservation grassland’.

4.1.3 Efficiency

The graph in Figure 16 illustrates mean travelling speeds for the harvesting machinery while engaged in the harvesting operation, along with the corresponding collection rate of material for each. These were recorded at various times during the trial.

It was generally observed that the harvester needed to be driven at a slower speed where the vegetation was denser and taller, in order for the suction process to keep pace with the volume of material being cut, and could be driven more quickly in areas of sparse vegetation where the material was collected relatively easily. This could lead to the assumption that the collection rate over time might be relatively consistent. As can be seen in Figure 16, there is an indication that this is very broadly the case, although the relationship is somewhat variable. This may reflect the variation in travelling speeds that was required to perform the harvesting operation in different conditions and on different vegetation qualities.

Figure 16 Travelling speeds and corresponding collection rates recorded during the harvesting operation



The operators reported to be mowing at approximately half the normal travelling speed they would achieve with a conventional tractor and flail without collection. This clearly has considerable resource implications and would need to be addressed if the practice were carried out on a wide scale in the future.
On the whole, the travelling speeds of the harvesting machinery during the actual harvesting operation were in the region of 1 to 4 km/hr. The average of all the speeds recorded was 2.7 km/hr. The operators usually report travelling speeds between 8 and 16 km/hr for a conventional flail cutter without collection.

The collection rates recorded ranged from 0.3 to 1.0 tonnes dry mass/hr, averaging 0.55 tonnes dry mass/hr.

The harvesting operation itself involved one member of staff to drive and operate the harvester. However, a second member of staff was required to drive the following safety vehicle where this was used.

4.2 Handling and Transportation of Material

During the trial, a third member of staff was employed to load the collected material into the haulage vehicle and transport it to the final site of usage. The time taken to load the material from the ground into the haulage vehicle was in the region of 10 minutes each time.

No appraisal is presented in this report relating to the material handling and haulage operations. The methods used for the trial were based purely on what equipment could be obtained in the short term to carry out the trial, to ensure that the other key information could be collected. Since these methods were inevitably inefficient and would not be proposed as a viable method for the future, there is little value in examining them in detail. The efficiency of any future proposals for material handling and transportation should of course be considered carefully, according to the options available and the specific circumstances. It would be a relatively simple task to estimate travelling distances and costs associated with any future proposals.

Despite the lack of a detailed analysis, a number of general observations were made during the trial relating to the methods used that will be useful for future decision-making. The harvesting, handling and transportation equipment was stored each night in a secure depot. Therefore, before work could commence each morning, and at the end of each day, all the necessary equipment and staff had to be ferried out to the relevant site. This typically took in the region of 1 hour each time and clearly had a significant impact on the overall efficiency of the process. In addition, the amount of machinery, and number of staff, required to handle and transport the material during the trial is not considered to be viable for the future.

Any future system of collection and transportation should involve the lowest possible number of operational stages. One suggestion is that the harvesting machinery could be further developed to include a baling function, so that the harvester could be emptied wherever it became full and collected later as part of a separate collection round. This would eliminate downtime with the harvester and reduce mileage associated with collection and transportation, but would obviously need to be examined further with regard to feasibility and safety implications.

4.3 Utilisation of Collected Material

4.3.1 Composition Analysis

The results of the composition analysis have been presented in such a way as to indicate the mean values and the range obtained across all the samples taken throughout the trial. This is intended to provide an initial indication of the potential suitability of the material for producing useful end products, taken across a whole mowing season and from a variety of locations within Powys. The full data set is presented in Appendix 2.

In Table 5, the absolute dry matter figures indicate the proportion of the road verge vegetation that is not water. The volatile solids figures are equivalent to the organic matter content, which indicates the proportion of the (dry) material that would be available for decomposition by composting or anaerobic digestion.

The moisture content of the road verge vegetation tended to be lower later in the growing season. There were no obvious trends related to weather conditions (see Appendix 1), although there was very little rainfall during the harvest operation to allow comparison. The volatile solid content of the harvested material was relatively consistent across all the samples and the mean value of 88.3% is therefore considered to be reliable.

Table 5 Dry Mass and Organic Matter Content of Vegetation

	Minimum	Maximum	Mean
Dry Matter % mass/mass fresh matter	18.0	46.2	29.0
% Volatile Solids (loss on ignition) % mass/mass dry matter	82.8	91.7	88.3

Table 6 shows the concentrations of a range of plant macro- and micro- nutrients. There was considerable variation in the elemental composition of the collected plant material. This may be due to the diversity of locations (and hence diversity of soil types, altitudes, etc) from which the vegetation was collected. These factors also have an influence on the plant species composition of the vegetation, all of which results in a heterogenous material. This data may be relevant to composting activities in the future.

Table 6 Elemental Constituents

	Minimum	Maximum	Mean
Carbon % mass/mass dry matter	32.3	44.2	37.9
Nitrogen g/100g dry matter	1.52	2.79	2.03
Phosphorus % mass/mass dry matter	0.14	0.34	0.24
Potassium % mass/mass dry matter	0.54	3.09	1.82
* Chloride g/100g dry matter	0.92	1.95	1.38
Calcium % mass/mass dry matter	0.36	1.12	0.63
* Sodium % mass/mass dry matter	0.09	0.67	0.31
Magnesium % mass/mass dry matter	0.14	0.26	0.19
Sulphur % mass/mass dry matter	0.13	0.26	0.19
Boron mg/kg dry matter	5.81	16.80	9.34
Iron mg/kg dry matter	556	5990	1846
Manganese mg/kg dry matter	71	438	170

* Sodium and Chloride concentration were determined separately for most samples. However, in error, Sodium Chloride ('salt') was determined instead for samples from 15th July (Road no. A489) and 1st August (Road no. U2734). These results are determined using a voltimetric salt meter and considered to be less suitable for this type of material. Hence, these results are not presented here (see Appendix 2).

The ratio of carbon (C) to nitrogen (N) in the samples tested ranged from 11.6 to 29.1, averaging 18.7. This is slightly below the ideal range for both compost and biogas production (20-30:1), which suggests that mixing with other relatively Carbon-rich materials may be required to optimise the compost and biogas production process. Such mixing is considered normal practice for these processes. Although there was considerable variation in the C:N ratio between samples, there was no obvious trend of changing C:N ratio through the season.

It is not clear whether the levels of sodium and chloride recorded in the raw vegetation samples would present any difficulties for compost production, in terms of phytotoxicity of the end product. Guidelines for the production of growing media (Waste & Resources Action Programme) suggest limits for Sodium and Chloride levels in compost, based on the BS EN 13652 test method for compost, of <200 and <750 mg/l respectively. However, it would not be appropriate to attempt to directly compare these limits to the data presented in Table 6. The test methods used are very different and hence the results and units used are very different. For plant tissue analysis, results are expressed on a weight per weight basis (mg/kg or g/100g or %). For available nutrients in compost, values are usually expressed on a weight per volume basis (mg/l). This is because for plant material, it is usually more relevant to know the 'total' concentrations of nutrients, whereas for compost it is usually more appropriate to determine the concentration of nutrients likely to be available to the plant. Because plant roots take up a physical volume of space and because compost is usually measured on a volume basis, results are reported on a weight per volume basis. However, to convert from a weight to a volume basis would require knowledge of the density of the fresh sample, which has not been determined. Having said all this though, there could be expected to be a fairly close relationship between 'total' and 'available' amounts in this case, because both sodium and chloride are very soluble.

The PAS100 specifications for compost quality state limits for electrical conductivity of 200 µS/cm or 200 MS/m. Electrical conductivity is related to salt levels.

Typical values presented by the Waste and Resources Action Programme (WRAP) (Ward et al 2004) are indicated in Table 7. These figures were recorded for composted materials from UK producers working towards PAS 100 standards.

Table 7 Sodium and Chloride concentrations recorded by WRAP for compost of UK producers.

Sodium	Total (mg/kg)	546.7
	Total (mg/l)	180.6
	Water soluble (mg/kg)	400.3
	Water soluble (mg/l)	146.1
Chloride	Total (mg/kg)	-
	Total (mg/l)	-
	Water soluble (mg/kg)	1768.2
	Water soluble (mg/l)	620.7

Clearly, there are limits to how far the composition of raw plant material can be compared to a composted product. Sodium chloride is highly soluble and its concentration may be expected to fall during the composting process, as a result of leaching. At the same time, total mass reduction during the composting process can tend to cause increases in concentration. In any case, mixing and dilution with other raw materials would have a significant effect on the overall composition of the final product. Hence, it is not possible here to evaluate the significance of the salt levels recorded in Powys road verge vegetation, in terms of suitability for compost production. Further investigation would be required as part of any proposed composting activities.

Table 8 shows the concentrations of all the potentially toxic elements listed under BSI standard PAS100 for composted materials, within the samples of fresh road verge vegetation. The concentrations of all these elements fall well within the PAS100 limits, indicating that there is no obvious cause for concern if the material were used to produce compost commercially. However, the PAS100 limits relate to the final composted material, rather than to the raw starting material. The final concentrations of these potentially toxic elements would undoubtedly change during the composting process and it is possible that while some may some may become less concentrated, others may become more concentrated as the volume of material becomes smaller. If this were the case, it may be possible in any case to ‘dilute’ with other materials to achieve the desired quality. It was not possible, or appropriate to determine the final concentrations of these elements in the compost produced during the trial. If a specific new compost product were developed using road verge vegetation as a raw material, further testing and method development would be required, as with any new compost product. However, these initial results do not indicate any immediate cause for concern regarding potentially toxic elements.

Table 8 Potentially Toxic Elements
(all units are mg/kg dry matter)

	Minimum	**Maximum**	**Mean**	**BSI PAS100 upper limit**
Lead	5.17	19.20	9.85	≤ 200
Nickel	1.30	4.40	2.48	≤ 50
Zinc	37.3	80.5	54.8	≤ 400
Copper	7.97	20.90	11.32	≤ 200
Cadmium	0.16	0.50	0.26	≤ 1.5
Mercury	0.01	0.03	0.02	≤ 1
Chromium	0.95	3.98	2.03	≤ 100

The composition of the harvested material varied greatly between samples, as might be expected in line with a wide range of localised environmental conditions and a wide range of different plant species. This could present difficulties if the material were to be used in the production of high quality plant growth media of consistent quality, but may be less important for a product aimed at the agricultural or landscaping industries. If large quantities of road verge material are collected from a wide area, many of these variations may balance out to produce a more stable composition in the long term. However, further investigation and monitoring may be required as part of any compost product development.

The full data set for the composition analysis is presented in Appendix 2

4.3.2 Compost Production

The road verge material was considered to be high quality in terms of the levels of physical contaminants, especially when compared to the contamination observed in domestic garden waste delivered to the site.

Figure 17 An example of the quality of the collected material

It was not possible to determine the proportion of different materials combined to make the compost, or to determine the final quantity of compost produced. A mass reduction of between 20% and 25% was reported for all composted materials during the summer period at the Bryn Posteg composting site. However, advice from the Waste and Resources Action Programme (WRAP) indicates that the expected total weight loss during the composting process is usually in the region of 40%.

4.3.3 Anaerobic Digestion

Feedback from the owner/operator of the anaerobic digester at Bank Farm indicated that the road verge vegetation was a good quality feedstock for biogas production, green and leafy with very low levels of litter contamination. From visual observation, and based on the owner's experience, the material was observed to yield relatively large quantities of biogas, estimated to be in the region of 90-120 m^3/ day, which was expected to be released over a longer period compared to other feedstocks such as poultry litter.

It had been suggested prior to the trial that the cuttings might float on top of the digestate. However, in practice, no mixing problems were encountered. It has been suggested that this may be because the existing contents of the digester were of a relatively high dry matter content (thick as opposed to watery) and stirred continuously.

In initial work carried out by the Department of Civil Engineering and the Environment at Southampton University (Zou 2005), a biochemical methane production (BMP) test on the road verge material gave a yield of 0.268 m^3_{CH4} /kg volatile solids added. However, the mixture was still actively producing biogas at the end of the 48 day experimental period, indicating that a higher value could be obtained from a test of longer duration. Hence, predictive models were used to calculate the ultimate BMP based on the reaction results for the first 48 days. A predicted curve, using a parallel pseudo-first-order decay model, indicated an ultimate BMP of 0.277 m^3_{CH4} /kg volatile solids added. The 'goodness of fit' for the predictive model was 0.9977. A laboratory scale semi-continuous trial was also carried out, with the verge material added to 1 litre reactors at loading rates of 1g and 1.5g volatile solids/litre/day, with a hydraulic retention time of 20 days. The methane yield was 0.16 m^3_{CH4} /kg volatile solids, or about 63% of the BMP value, indicating that a retention time longer than 20 days would be needed to maximise gas production. The experimental AD reactions were monitored at regular intervals during the study period, to ensure that the reaction mixture was maintaining a healthy balance between the different biochemical stages of decomposition (see section 2.2.2). The concentration of volatile fatty acids (VFA's) was 50 mg/l or less throughout the process. This is very low (10% or less of a concentration that might cause concern) and indicates that the later stage, methanogenic, bacteria easily kept pace with any VFA production and that the reaction process was stable. The pH of the reaction mixture remained within the critical pH band of 6.0-8.0 required for methanogenic digestion throughout the reaction period in both the batch reactors and semi-continuous feed reactors.

These initial tests were carried out using a 1 litre scale static laboratory anaerobic digester (AD) unit and using a combined vegetation sample from the samples collected in June (week 2 of the trial). While the 1 litre reactor is a standard and widely used laboratory method, it is known in some cases to give an underestimate for the BMP. For this reason, further tests were subsequently carried out using a 5 litre scale stirred reactor and using a combined sample incorporating all the samples taken during the whole trial period (He & Zhang 2005). This provides a better indication of the likely mean gas yield across a whole mowing season, and the values estimated using the 5-litre scale stirred reactor should be more realistic. The test was allowed to run to completion in order to determine the total methane production. An analysis was also carried out on selected samples to determine a range of compositional qualities relevant to Biogas production.

The results of these subsequent tests indicated that the raw material had a mean total solids concentration of 27.8%, of which 87.4% was volatile solids. The carbon to nitrogen ratio was 21:1, which is typical of green plant material that is not highly lignified (woody). A fibre composition analysis indicated that the material was 22% hemicellulose, 30% cellulose and 6% lignin. The calorific value of the material was 18.42 MJ/kg, and the Chemical Oxygen Demand (COD) was 0.84 g O_2 /g. As expected, the BMP determined by the 5 litre scale tests was slightly higher than for the earlier tests, indicating a value of 0.271 m^3 CH_4 /kg volatile solids added, and is in good agreement with the value predicted by modelling. The test results suggested that a favourable volumetric gas production rate and substrate conversion efficiency could be achieved with a retention time (for the material remaining inside the digester) of around 70 days. Around 70-75% destruction of the input verge material would be expected during the process. It was suggested that a full-scale digester operating to this timescale might be expected to have a digestate solids concentration of 7-8% (assuming a loading rate of 4 kg volatile solids/m^3/day), and a conventional digester design would be suitable e.g. a continuously stirred tank reactor. The volumetric gas production calculated on the basis of this loading rate and retention time was around 2 m^3 biogas/m^3 digester volume/day. The actual value depends on scale and other factors but this result was considered to be a favourable performance efficiency indicator for the purposes of commercial application. While there was some variation in composition between different vegetation samples, it was considered unlikely that this would affect the overall digestibility or biogas yield.

The main non-plant feedstocks for AD are usually municipal solid wastes, sewage sludge and cattle slurry. Typical yields for these are all around 0.3 m^3 methane (CH_4) per kg volatile solids (VS), but these materials are usually digested as a treatment process rather than for energy production.

Typical biochemical methane potentials (BMP's) for plant materials are in the range 0.25-0.35 m^3_{CH4}/kg volatile solids. Studies have indicated an ultimate methane production of 0.26-0.39 m^3_{CH4}/kg volatile soilds for sorghum and 0.19-0.34 m^3_{CH4}/kg volatile solids for napier grass (Chynoweth *et al* 1993), BMP's for vegetable waste ranging from 0.19-0.4 m^3_{CH4}/kg volatiles solids (Gunaseelan 2004) and BMP's for food wastes ranging from 0.27-0.48 m^3_{CH4}/kg volatile solids (Cho *et al* 1995). Greenfinch has reported an average methane yield of 0.342 m^3_{CH4} /kg volatile solids with ensiled purpose-grown agricultural ryegrass. In practice, many materials are co-digested, which can increase yields. Nevertheless, the experimental data indicate that the BMP of 0.271 m^3_{CH4}/kg volatile solids for road verge vegetation compares favourably with other similar materials.

In agricultural terms, the fact that all kinds of green plant material generally produce methane yields within a similar range means that in practice, differences in the mass yield of harvested vegetation are likely to be far more significant than the relatively small differences in specific BMP for different plant materials. It may be that the most important factor is the quantity of plant material that can be produced, rather than the type of crop that is grown.

In a recent study carried out in Germany (Pronchnow *et al* 2005), biogas yields were recorded from harvested 'landscape management grass'. This material was harvested from areas of land not subject to intensive agricultural management, maintained for their landscape and nature conservation value. The specific methane yields recorded varied from 0.155 m^3_{CH4}/kg volatile solids for a single cut in February to 0.298 m^3_{CH4}/kg volatile solids for a single cut in June. The maximum area specific methane yield was 1604 m^3/ha/yr, using material harvested in late summer. In comparison, the average specific area yield reported by Greenfinch Ltd in their agricultural ryegrass study was 3865 m^3/ha/yr. Although the specific area yields from landscape management grass are low in comparison to other crop substrates, there is a rising demand for biogas substrates in Germany, which is increasing interest in this type of material (see Section 2.3.4). The corresponding average area yield of methane recorded for the road verge vegetation harvested in the trial is in the region of 608 to 811 m^3/ha/yr, which is lower still.

4.4 Economic Sustainability

One of the main aims of the trial was to gather information that would help to assess whether, by using the collected road verge vegetation to make a valuable product, the income generated could help to cover the costs of the harvesting and transportation operations.

This section of the report presents an estimate of the potential economic value of road verge vegetation if used for compost and/or biogas products. All calculations in this section have been based on a conservative estimated annual yield of harvested vegetation of 300 kg dry mass/ km road verge cut with a 1.2m width cutter (see Section 4.1.2 for further yield information).

The time and costs associated with the material handling and transportation operations are not presented here, because the methods used were known to be relatively inefficient and were chosen purely on the basis of what was available in the short term. These methods allowed the trial to be carried out, but were not necessarily intended as a long-term solution. Instead, this report concentrates on presenting the potential economic income from the end products, in order to clarify the target expenditure that might need to be met in order to make the whole process economically neutral. Costs associated with different operational scenarios would be relatively easy to calculate using existing information (e.g. equipment, fuel and staff costs), taking account of local or specific circumstances.

The time and costs associated with the material handling and transportation operations are not presented here. This would vary considerably depending on the work systems and equipment used, as well as the travelling distances involved. Instead, this report concentrates on presenting the potential economic income from the end products, in order to clarify the target expenditure that might need to be met in order to make the whole process economically neutral. Costs associated with different operational scenarios would be relatively easy to calculate using existing information (e.g. equipment, fuel and staff costs), taking account of local or specific circumstances.

Table 9 shows the estimated potential income from the Anaerobic Digestion of road verge vegetation. The figures have been provided by Greenfinch Ltd, based on current market values, and based on a conservative estimated annual vegetation yield of 0.3 tonnes dry mass per km travelled with a single swath cut of 1.2m. The potential income from Anaerobic Digestion per km cut is £22.01, assuming that all the products of AD (electricity, heat, solid and liquid fertilisers) are utilised.

Table 9 Potential income from Anaerobic Digestion, for an on-farm digester

Anaerobic Digestion Parameters		
Dry Matter of Crop	%	29
Biogas Yield from Road Verge Vegetation	M^3 per tonne	111.0
Biogas calorific value	MJ per m^3	23.2
CHP Electrical Efficiency	%	33
CHP Heat Efficiency	%	52
Parasitic Electricity	%	3
Parasitic Heat	%	14
Value of Electricity	£ per MW.hr	80
Oil Equivalence of Heat	KW. hr per litre	8.5
Price of Heating Oil	Pence per litre	25
Value of Heat	£ per MW.hr	29
Energy Crop Yield (Wet)	tonnes per km per year	1.03
Value of Solid Biofertiliser	£ per tonne	5
Simple Economic Analysis		
Annual Verge Collection	Tonnes per 100km	103
Total Digester Feedstock	Tonnes per year	103
Biogas Yield from Road Verge Vegetation	M^3 per day	31
Biogas Yield from Other Materials	M^3 per day	0
Total Biogas Yield	M^3 per day	31
Energy Value of Biogas	KW (fuel)	8
Potential CHP Electricity Production	KW (electrical)	3
Potential CHP Heat Production	KW (heat)	4
Process Heat	KW (heat)	1
CHP Availability	%	95
Usage Factor for Surplus Heat	%	30
Gross Electricity Production	MW.hrs per year	23
Net Useful Heat Production	MW.hrs per year	10
Oil Equivalence of Useful Heat	Litres per year	1206
Value of Electricity	£ per MW.hr	80
Value of Heat	£ per MW.hr	29
Value of Gross Electricity Production	£ per year	1848
Value of Energy Production	£ per year	2149
Value of Solid Biofertiliser	£ per year	52
Summary of Economics - £ per year		
Value of Electricity		1848
Value of Heat		301
Value of Solid Biofertiliser		52
Total Income		2201
Total Income per km	£ per km travelled	22.01

Table 10 shows the potential income from compost products using road verge material, based on current market values for different grades of compost, supplied by the Waste and Resources Action Programme (WRAP). The potential income per km travelled with a 1.2m width cutter ranges from as little as £1.24 for low quality compost up to £15.52 for high grade compost sold in smaller quantities. It is considered unlikely that road verge material would be used in the production of high-grade growth media, due to its variable composition, so the maximum value is considered to be £12.40 per km for a high grade landscaping compost.

Table 10 Potential income from Compost Production

		Units
Annual fresh yield per km travelled (mean Dry Mass + mean water content)	1.034	Tonnes/km travelled/yr
Annual compost production per km (assuming 40% mass reduction)	0.621	Tonnes/km travelled/yr
Current market price (20mm grade - landscaping)	18-20	£/tonne
Current market price (finer material)	25	£/tonne
Current market price (Agricultural uses)	2-3	£/tonne
Potential income per km (20mm grade - landscaping)	11.17-12.40	£/km travelled/yr
Potential income per km (finer material)	15.52	£/km travelled/yr
Potential income per km (agricultural uses)	1.24-1.86	£/km travelled/yr

Based on these values, it is clear that road verge vegetation has a potential economic value if used for compost or biogas production. The essential question is whether the value of the end products is high enough to justify the cost of harvesting, transporting and handling the raw material, along with any costs involved in producing and supplying the end products.

In considering the costs of the harvesting operation itself however, it is important to take account of the fact that road verges are already mown for safety reasons and that these costs are an accepted part of highways management. Hence, the important cost consideration in this case is not the overall cost of the harvesting operation, but rather the net additional cost, over and above the cost of conventional mowing.

It could be argued that the most productive and high yielding road verges (in terms of vegetation growth) offer the best opportunities for economic gains from end products. Conveniently, these may also be those verges most likely to benefit ecologically from such management (see Section 2.1). Hence, there may be scope to rationalise expenditure and resources by targeting specific locations. This would increase the average yields and therefore the potential economic value of the material collected.

It is difficult to predict whether there would be significant reductions in vegetation yield over time as a result from nutrient depletion on the road verges. Hence it is not possible to predict whether any such yield reductions could be economically significant. The degree to which soil nutrient status can be reduced by vegetation harvesting can be very variable, due to the wide range of other factors contributing to soil fertility. (This subject is discussed in Section 2.1, including an explanation of how plant species richness may be enhanced regardless of effects on soil fertility). In some areas, if yield is affected severely, it may be feasible to adjust cutting regimes accordingly.

It is current practice for private compost and biogas producers to charge a gate fee for taking in waste materials. These fees are usually lower than the cost of landfill and so are usually seen as an economically viable and environmentally sustainable option for many waste materials. However, road verge vegetation is not currently collected or disposed of by any route, so any gate fees would constitute additional costs. In order to cover some or all of the costs of the harvesting operation, it is suggested therefore that the economic viability of the collection process might depend on one of two scenarios. Either the end user of the material would pay to receive the material, or the Highways Authority (or contractor) would own, or have a stake in, the end process. It is suggested that neither scenario would be feasible unless the material acquires a significant commercial value. Hence, it seems likely that the progression of ‘cut and collect’ management on road verges may depend to some extent on developments in the waste management and energy sectors.

Travelling distances have an obvious impact on the overall efficiency of the process. Therefore, the sustainability of the process in the future could be improved if there were a larger number of local sites for utilising the material. Future developments such as farm diversification and sustainable energy initiatives may eventually lead to a more comprehensive network of suitable sites. Powys County Council also has a network of farms and highways depots it is suggested that these could be considered as potential processing sites.

This economic assessment does not take account of the considerable potential environmental benefits, both in terms of road verge ecology and sustainable energy, which should of course be considered on their merits alongside the economic factors.

It is outside the scope of this study to propose a definitive solution to this issue at this stage. It is intended that the findings presented here will fuel and inform further discussion that will generate creative ideas for solutions, involving a wide range of stakeholder organisations. Indeed, further investigation or development will be required on some aspects before a solution can be proposed (see section 4.5). The fields of waste management, sustainable energy and environmental management are currently in a state of change and development and it is likely that future solutions will involve a variety of approaches based on cross-benefits between these fields. Specific solutions may depend on local circumstances and infrastructure. Hence, the aim of this section has been purely to provide estimates of the potential economic gains associated with road verge vegetation harvesting, in order to facilitate the evaluation of different scenarios in the future.

4.5 Further Work

The trial has been successful in providing initial data relating to the efficiency of the harvesting and transportation operations and the quality, quantity and potential economic value of the raw vegetation for compost and biogas production. This data will now provide a basis on which to discuss the future feasibility of wide-scale harvesting of vegetation from road verges in Powys and to identify the next steps to be taken, if any. This section outlines areas in which further research and development may be required.

- The energy balance and overall environmental sustainability of the harvesting, material handling and transportation operations were not analysed as part of the trial, although this is an important consideration. A student project is currently being undertaken at Southampton University to investigate this aspect and the need for further work on this aspect will be assessed in due course.

- Further benefit might also be gained from a full economic analysis, including the costs associated with different methods and machinery options. However, the trial has already highlighted obvious issues with the working speed of the harvest machinery and the need to establish a means of handling and transporting cut material with the minimum of staff and machinery requirements.

- It is suggested that further development of equipment and methods is required, in order to improve the speed, efficiency and reliability of the harvesting, material handling and transportation operations. This in turn would reduce the costs associated with these activities.

- Consideration should be given to the provision of harvesting machinery for any future work. It may be possible to demonstrate an existing market for harvesting machinery such that one or more contractors or hire companies may be prepared to invest in machinery (some interest has already been indicated in this regard). A number of verge areas are already subject to vegetation collection in Powys due to their designation as ‘Road Verge Nature Reserves’ or other recognised ecological importance. Other counties are also known to manage similar areas, so it may be possible to collaborate. Once the provision of machinery is established, further development would be more feasible.

- The data gathered during the trial confirm the overall suitability of Powys road verge vegetation for compost and biogas production. However, further method development would be required in order to optimise these processes for any ongoing large-scale requirements.

- The availability of local compost, biogas or other utilisation sites is a critical issue. It will be necessary to maintain communication links with the waste management and sustainable energy sectors, in order to take advantage of any developments. Consideration should also be given to opportunities to develop existing Local Authority sites.

- Consideration could be given to setting up one or more pilot/experimental verge management areas in Powys, located near to suitable utilisation facilities. Although the biodiversity benefits of collecting cuttings have already been demonstrated in controlled studies (see Section 2.1), there may be advantages in demonstrating this at a local level. It is suggested that this exercise could be focussed on road verges where the productivity is high and species diversity low (see Section 4.4).

- Consideration could be given to prioritising road verges for the collection of cuttings, based on their level of productivity. Concentrating effort on these areas could potentially maximise the average yields of vegetation and therefore result in the highest economic gains from end products. It may be easier to demonstrate the economic feasibility in such locations, due to the relatively high potential yields of biogas per km harvested (compared to the average figures presented in this report).

- Some concerns have been expressed as to the potential impact of the harvesting process on insects and other invertebrates, compared to the impact of a conventional flail mower. Hence, this should be investigated further. The machinery used in the trial only collects material that has been thrown up by the flails. These are set at the required cutting height, so there should be no 'vacuuming' effect at ground level. However, it is certainly possible that some animals sucked into the collection trailer may be killed, that would otherwise survive passage through a conventional flail cutter. Information on this issue should also be sought from countries where the machinery is already being widely used.

- The impact of the collection process on the seed bank is also an area that may require further investigation. It is possible that the collection of seed during the process may have a significant effect on seed availability and plant species dispersal. However, any impact should be carefully evaluated against the significance of seed viability in different situations, the relative importance of seed production to the relevant plant populations, and the relative ecological impact of alternative management options.

- If harvesting machinery is used in the future, it will also be advisable to carry out further assessment and monitoring of the health and safety risks, to ensure that working practices and safety measures provide the appropriate level of protection to the public and operators.

- Continued consultation will be required with the Environment Agency, to ensure that all relevant regulations are adhered to and to consider further the current status of road verge vegetation as a waste material.

5. Conclusions

The following conclusions are presented with regard to the objectives of the trial (as stated in Section 1.2).

- The Trilo-Bomford harvesting machinery used in the trial cut and collected vegetation effectively and to a high standard. However, further development would be required to improve its efficiency, its ease of operation and especially its reliability, before it would be suitable for use in general road verge management. The requirements for road safety control measures may also need further consideration, depending on the particular circumstance in which the machinery was used.

- The resource inputs involved in the harvesting and transportation parts of the trial were not assessed in detail. This is because the methods used for bulking up and transporting the material during the trial were known to be relatively inefficient. The equipment and methods used were chosen purely on the basis of what was available in the short term and are not being proposed as a long-term solution. The resource implications of future scenarios may be evaluated relatively easily on a case by case basis, by using the other data from the trial, combined with freely available data on factors such as travelling distances, fuel consumptions, staff costs etc.

- The studies undertaken as part of the trial confirmed that Powys road verge vegetation is a suitable, high quality material for biogas production and has a methane potential comparable to other plant materials that are used for this purpose. Although compost production was not quantified in practice, the elemental composition of the raw material suggested that it would be suitable for the purpose. The sodium chloride concentration may, however, require further investigation to determine whether it exceeds acceptable limits.

- The economic value of compost and biogas products that could be produced using road verge vegetation has been estimated. It remains to be seen whether this potential economic gain could serve to balance the costs of harvesting, transporting and treating the raw material, given sufficiently efficient operational procedures and a favourable energy/waste business situation.

The trial has provided data and practical experience to support an initial evaluation of the potential for wide-scale collection of cuttings from Powys road verges. Such management would have the potential to bring about important ecological benefits (see Section 2.1). However, the feasibility of doing so on a significant scale is largely dependent on whether it can be done practically and economically. This trial has demonstrated that it is physically possible to collect cuttings from Powys road verges on a relatively large scale and that it is possible to use that material for compost and biogas production. In addition, it has identified the potential economic value of these products (based on a conservative yield estimate and on current market values). In addition to the environmental benefits associated with diverting the material from landfill, biogas production would provide a source of sustainable energy, with obvious advantages in terms of minimising global warming. (see Section 2.2.2).

However, as indicated in the previous sections, there are a number of issues on which further development or evaluation will be required before wide-scale harvesting is likely to be considered as part of general road verge management. The machinery and methods used to harvest and transport the raw material must be efficient and cost-effective, and significant improvements are likely to be required over those demonstrated in the trial. The economic and environmental cost of these operations, and of the final treatment process for the collected material, must be evaluated carefully as part of any future proposals. In order for this management practice to become feasible in the future, the efficiency and sustainability of the machinery and working systems must be optimised, in order to minimise both the economic and environmental costs. Also, any future business relationship between the harvesting operation and the final utilisation of the collected material must be economically favourable.

The findings presented in this report will now be used to inform further discussions between interested parties in Powys, in order to identify any future opportunities and any further plans for development work.

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7. Appendices

The sample codes referred to in the appended data tables have been assigned as follows. The Sample codes start with the letter T or S, depending on whether the sample was taken from a single Trilo harvester trailer load (T), or from a combined load on the silage wagon or lorry (made up of two or more Trilo trailer loads) (S). The next part of the code denotes the date upon which the material was harvested (date followed by month) and the final part of the code denotes the sequential load number harvested on that date. For example, sample code T060802 would have been taken from the 2nd Trilo trailer load on 6th August. Move this info to relevant appendix.

Appendix 1
Raw data from the harvesting operation.

Appendix 2
Raw data from the vegetation composition analysis

Appendix 1

Raw data from the harvesting operation

Date	Road no	Location	Trilo Load ref	Silage/ lorry load Ref	Length (km)	*Time taken (min)	Fresh Mass (kg)	Mean % DM	Est. Dry Mass (kg)	1st or 2nd cut of season	Dry Mass per km travelled (kg km^{-1})	Weather	Notes
23/5/05	A489	Nr Churchstoke	T230501	-	0.961	30	1120	22.9	256	1st (of 2)	266	Sun & showers	Half load
25/5/05	A489		T250501	-	1.459	51	1810	21.3	386	1st (of 2)	265	Dry, overcast, recent rain	¾ load Vegetation 50-100cm tall
25/5/05	A489		T250502	-	0.981	29	620	22.2	138	1st (of 2)	141	Hot, dry & sunny	Half load
26/5/05	A489		T260501	-	1.886	-	1540	25.2	1023	1st (of 2)	233	Sunny, dry & warm	
26/5/05	A489		T260502	-	2.510	39	2520			1st (of 2)			
27/5/05	B4385	Nr Churchstoke	T270501	-	1.809	37	1335	20.6	275	1st (of 2)	152	Dry & mild	Not full load
27/5/05	B4385		T270502	-	1.854	42	1321	19.1	252	1st (of 2)	136		
6/6/05	B4518	Llanidloes to Staylittle road	T060601	S060601	2.005	70	3240	18.6	601	1st (of 2)	110	Dry & cloudy, recent rain. Wet vegetation at start, but getting dryer	
6/6/05	B4518		T060602		3.474	71				1st (of 2)			
7/6/05	A470(T)	Nr Llanidloes	T070601	S070601	4.854	41	4200	20.0	839	1st (of 2)	153	v. hot, dry & sunny	Moved location mid-load
7/6/05	A470(T)		T070602			47				1st (of 2)			
7/6/05	A470(T)		T070603		0.646	15				1st (of 2)			Not full load
8/6/05	A470(T)		T080601	S080601	4.634	60	3340	23.0	768	1st (of 2)	166	v. hot, dry & sunny	
8/6/05	A470(T)		T080602			65				1st (of 2)			
9/6/05	A470(T)		T090601	S090601	3.344	40	4260	25.8	1099	1st (of 2)	155	v. hot, dry & sunny	
9/6/05	A470(T)		T090602		3.237	65				1st (of 2)			
9/6/05	A470(T)		T090603		0.530	50				1st (of 2)			
11/7/05	A489	Nr Churchstoke	T110701		2.640	60	2150	28.6	615	2nd (of 2)	233		
11/7/05	A489		T110702		2.640	65	2550	30.7	783	2nd (of 2)	297		

Date	Road no	Location	Trilo Load ref	Silage/ lorry load Ref	Length (km)	*Time taken (min)	Fresh Mass (kg)	Mean % DM	Est. Dry Mass (kg)	1st or 2nd cut of season	Dry Mass per km travelled (kg km-1)	Weather	Notes
13/7/05	A483(T)	Nr Abermule	T130701		6.424	60	2190	26.1	861	2nd (of 2)	134	Hot & sunny	
13/7/05	A483(T)		T130702		6.424	110	4930	38.9	1918	2nd (of 2)	299		
13/7/05	A483(T)		T130703		5.648	119	3300	35.8	1181	2nd (of 2)	209		
14/7/05	A483(T)		T140701		1.808	40	1050	38.1	400	1st (of 1)	642		**RVNR area, v. tall
14/7/05	A483(T)		T140702			-	1060	46.2	490	1st (of 1)			**RVNR area, v. tall
14/7/05	A483(T)		T140703			-	610	44.3	270	1st (of 1)			Half load (finishing RVNR)
14/7/05	A483(T)		T140704		-	-	1950	36.0	702	2nd (of 2)	-		Half load
15/7/05	A490	Nr Alport	T150701		2.802	60	2290	29.1	666	2nd (of 2)	238	Dry & mild	Tall vegetation
15/7/05	A490		T150702		2.802	72	1090	31.1		2nd (of 2)	n/a		Not full load. Cutting left-over sections, not complete lengths
1/8/05	U2734	Minor road off B4518	T010801	S010801	1.094	24	3240	30.3	982	2nd see note	264	Wet vegetation, overcast but dry all day	V. short vegetation, but mostly collected cuttings remaining from 1st cut.
1/8/05	U2734		T010802		1.094	29				1st (of 1)			v. tall vegetation
1/8/05	U2734		T010803		1.527	15				1st (of 1)			Half load Tall vegetation
2/8/05	B4518	Llanidloes to Staylittle road	T020801	S020801	4.008	53	2940	37.2	1094	2nd (of 2)	123	Fine & dry	Short 20cm vegetation
2/8/05	B4518		T020802		4.912	52				2nd (of 2)			Short 20cm vegetation
2/8/05	C2019	Staylittle to Dyliffe Rd	T020803	S030801	4.008	-	3480	32.2	1121	1st (of 1)	169		Tall vegetation
3/8/05	C2019		T030801		2.608	80				1st (of 1)			30cm sparse vegetation
3/8/05	C2019		T030802	S030802	10.196	125	2820	36.2	1021	1st (of 1)	78		
3/8/05	C2019		T030803		2.854	70				1st (of 1)			

*Excluding stoppages
** RVNR = county Roadside Verge Nature Reserve

Appendix 2

Raw data from the vegetation composition analysis

Trilo trailer Load ref	Silage wagon or lorry load Ref	Oven dry matter % m/m	Salt %	Loss on ignition % wt/wt, 100% DM	Organic Carbon % m/m, air dried	Chloride g/100g, 100% DM	Total Nitrogen g/100g, 100% DM	Total Calcium % m/m, 100% DM	Total Sodium % m/m, 100% DM	Total Potassium % m/m, 100% DM	Total Magnesium % m/m, 100% DM	Total Phosphorus % m/m, 100% DM	Total Sulphur % m/m, 100% DM	Total Boron mg/kg, 100% DM	Total Lead mg/kg, 100% DM	Total Nickel mg/kg, 100% DM	Total Iron mg/kg, 100% DM	Total Zinc mg/kg, 100% DM	Total Manganese mg/kg, 100% DM	Total Cadmium mg/kg, 100% DM	Total Mercury mg/kg, 100% DM	Total Chromium mg/kg, 100% DM	Total Copper mg/kg, 100% DM
T230501		22.9		88.1	34.1	1.95	2.19	0.58	0.67	2.53	0.17	0.30	0.21	8.38	9.22	1.9	1180	46.6	71.3	0.22	0.02	1.79	9.86
T250501		21.3		87.8	38.5	1.69	1.93	0.66	0.36	2.54	0.16	0.27	0.16	8.50	6.41	3.1	919	43.2	70.6	0.20	0.02	1.59	9.71
T250502		22.2																					
T260501	S260501	25.2		86.8	36.4	1.90	2.53	1.12	0.25	3.09	0.24	0.28	0.21	16.8	<5.00	1.7	1070	41.6	89.6	0.16	0.01	1.40	8.73
T260502																							
T270501		20.6		87.3	43.7	1.68	2.10	0.61	0.38	2.42	0.17	0.28	0.18	7.89	5.39	2.2	1550	40.8	86.1	0.18	0.01	2.43	11.7
T270502		19.1																					
T060601	S060601	18.0		88.5	38.0	1.09	2.22	0.52	0.50	1.68	0.22	0.24	0.20	14.1	7.72	3.1	2860	64.5	278	<0.10	0.01	2.51	12.6
T060602		19.1																					
T070601	S070601	21.8		91.6	39.2	1.14	2.04	0.64	0.32	1.83	0.16	0.25	0.18	9.08	<5.00	<1.0	719	40.8	87.9	<0.10	0.01	1.10	8.70
T070602		19.1																					
T070603		19.0																					
T080601		24.2		91.6	39.5	1.16	1.99	0.56	0.35	1.73	0.14	0.24	0.18	7.26	<5.00	<1.0	556	37.3	86.4	<0.10	0.01	0.95	7.97
T080602																							
	S080601	23.0																					
T090601		25.7		91.7	44.2	0.92	1.75	0.49	0.37	1.65	0.16	0.24	0.19	7.64	<5.00	1.6	754	41.6	84.8	<0.10	0.01	1.18	9.06
T090602																							
T090603																							
	S090601	25.8		89.9	41.3	1.07	1.84	0.54	0.29	1.77	0.17	0.19	0.18	7.43	<5.00	2.1	1300	43.8	168	<0.10	0.01	1.50	9.39
T110701		28.6		85.0	36.3	1.38	2.57	0.76	0.29	2.08	0.21	0.32	0.25	9.71	7.15	2.6	1660	53.3	128	<0.10	0.01	3.14	20.9

Trilo trailer Load ref	Silage wagon or lorry load Ref	Oven dry matter % m/m	Salt %, 100% DM	Loss on ignition % wt/wt, 100% DM	Organic Carbon % m/m, air dried	Chloride g/100g, 100% DM	Total Nitrogen g/100g, 100% DM	Total Calcium % m/m, 100% DM	Total Sodium % m/m, 100% DM	Total Potassium % m/m, 100% DM	Total Magnesium % m/m, 100% DM	Total Phosphorus % m/m, 100% DM	Total Sulphur % m/m, 100% DM	Total Boron mg/kg, 100% DM	Total Lead mg/kg, 100% DM	Total Nickel mg/kg, 100% DM	Total Iron mg/kg, 100% DM	Total Zinc mg/kg, 100% DM	Total Manganese mg/kg, 100% DM	Total Cadmium mg/kg, 100% DM	Total Mercury mg/kg, 100% DM	Total Chromium mg/kg, 100% DM	Total Copper mg/kg, 100% DM
T110702		30.7																					
T130701		26.1		88.0	32.3	1.52	2.79	0.74	0.35	2.34	0.25	0.34	0.26	10.6	5.17	1.3	1270	72.3	74.5	<0.10	0.01	1.75	17.6
T130702		38.9																					
T130703		35.8																					
T140701		38.1		90.4	33.0	1.05	1.81	0.75	0.19	2.00	0.19	0.25	0.18	12.4	<5.00	1.7	663	60.4	111	<0.10	0.01	1.11	11.5
T140702		46.2																					
T140703		44.3																					
T140704		36.0																					
T150701		29.1	2.46	87.5	38.7		2.27	0.85	0.15	2.40	0.26	0.29	0.25	10.8	<5.00		1120	42.4	125	<0.10	0.02	1.56	9.55
T150702		31.1																					
T010801		25.4	0.38	89.6	42.4		1.52	0.49	0.09	0.54	0.17	0.15	0.13	8.13	14.7	2.9	3250	64.0	261	0.27	0.02	2.78	14.4
T010802	S010801	33.2																					
T010803		32.3	0.84	82.8	37.1		1.63	0.56	0.14	0.96	0.23	0.14	0.15	7.58	19.2	4.4	5990	80.1	438	0.41	0.03	3.98	9.69
T020801	S020801	35.7		87.3	34.9		2.03	0.37	0.27	1.02	0.18	0.20	0.17	7.29	14.0	2.6	2940	80.5	312	<0.10	0.03	2.27	9.75
T020802		38.7		87.4	35.4		1.87	0.36	0.3	0.75	0.18	0.16	0.15	5.81	13.4	4.0	3960	56.1	357	0.17	0.02	3.93	11.6
T020803	S030801	40.2																					
T030801		24.2			37.4		1.54	0.67	0.31	1.35	0.19	0.18	0.17	8.79	5.94	2.0	1470	76.3	232	0.50	0.01	1.50	11.1
T030802	S030802	34.0																					
T030803		38.4																					
T040801																							
PAS 100 standard for finished compost															≤200	≤50		≤400		≤1.5	≤1	≤100	≤200

8. Addendum – Results of subsequent work

Subsequent to the completion of this report, further work has been completed by the School of Civil Engineering and the Environment at Southampton University. This section provides only a brief summary of the results. However, further details are available on request.

8.1 Energy Balance

(Gunton 2006)

An MSc student project investigated the energy efficiency of using roadside verge cuttings for Biogas production. An energy balance was determined for the whole process, taking into account the efficiency implications of the choice of harvesting and transportation machinery, and the potential size and positioning of AD facilities within Powys.

An energy ratio for the process was estimated. This involved estimating the energy that would ultimately be generated in the form of biogas fuel and expressing this as a ratio against the estimated amount of energy that would be used to harvest, transport and process the feedstock material, as well as energy used for gas separation and purification prior to use. (If the energy balance is greater than 1, then there is an advantageous energy balance.)

The study considered four scenarios, comparing the use of an integrated mower and collector machine with the use of separate mower and collector machines, and comparing a scenario of one single, large, central AD facility for Powys (with a scenario of several small on-farm AD facilities. The estimated energy ratios for the four scenarios ranged from 5.56 to 6.65, indicating that all four approaches would be feasible in terms of energy balance alone. The energy considerations related to the potential local use of solid and liquid AD bi-products as fertilisers and soil conditioners were not investigated, but would be expected to also be favourable compared to the manufacture, transportation and use of synthetic alternatives. The economic feasibility of these scenarios has not been determined. However, these results support the idea that the use of road verge material for AD would provide benefits not only in terms of biodiversity, but also in terms of overall energy efficiency. The study also highlights a number of ideas such as the potential use of the biogas product to power harvest machinery, haulage vehicles and local authority vehicles.

8.2 Biogas Transport Fuel

(Salter *et al* 2006)

A paper has been written based on the above study, using the data generated during the Powys trial to examine the energy requirements for collecting verge cuttings and using them as a feedstock for anaerobic digestion. It aims to determine whether the process can be both self-sufficient for energy and CO_2

neutral. The paper also derives an energy balance for using the produced biogas as vehicle fuel.

A scenario is proposed in which AD facilities provide fuel for heat and electricity, as well as fuel for transport. It is concluded that not only would the energy balance be favourable, but also, all the energy required to run the system could be obtained from biogas produced by digesting verge material. Since this verge material is a CO_2 neutral source of energy (as explained in section 2.2) and since there is no use of fossil fuels, the system as a whole would be CO_2 neutral. This is in contrast to current verge mowing operations, using tractors powered by diesel derived from fossil fuels, where there is a net contribution to atmospheric CO_2 levels.

One of the problems currently associated with the use of biogas as a transport fuel is the need to compress it to achieve an extended vehicle range, or to use prohibitively large fuel tanks. However the paper suggests that in this case, such issues would be less relevant, due to the relatively short trip distances and return frequency of vehicles to the digester site. The same could also be said for other municipal vehicles and public transport.

The paper compares a scenario of one central AD facility, receiving material from within a radius of 45km, with a network of five smaller facilities, each receiving material from within a radius of 20km. It concludes that, in energy terms, it is better to have a large number of smaller digesters than a few, large, centrally located ones. This would also have the added benefit of providing a network of fuel sites for vehicles. It is suggested that farms provide potential sites for such AD facilities and would also provide beneficial treatment sites for agricultural and other wastes. Sewage works also provide another potential source of locations and are often situated close to residential areas. Many already have anaerobic digesters to process sewage sludge and could use the verge cuttings as supplementary feedstock.

The paper also makes proposals on how the Powys-based scenarios could be applied to other locations in the UK.

Addendum References

GUNTON, Z. L. 2006. Are roadside verge cuttings a feasible source of renewable energy? MSc project report. School of Civil Engineering and the Environment, University of Southampton.

SALTER, A., DELAFIELD, M., HEAVEN, S., GUNTON, Z. Closing the CO_2 and energy cycles by anaerobic digestion of road verge material to provide fuel for transport. (Publication pending)