IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

BIOMITRE

Greenhouse Gas Benefits of Small-scale Biomass Heating Systems in the United Kingdom

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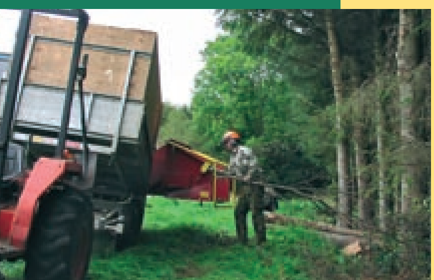
Summary

Miscanthus grass – an example of a renewable biomass energy crop. Courtesy of ADAS Ltd.

Results of research have highlighted the potential for using small-scale biomass heating systems in the UK to help with tackling climate change by reducing greenhouse gas emissions. Two systems were considered:

- A historic building in the southeast of England converted into an energy efficient office space, supplied with heat by burning Miscanthus grass.
- A complex of farm buildings in southwest England supplied with heat from wood chips.

These are real examples of biomass heating projects that could be implemented in many locations in the UK. The study estimated the energy balance and emissions of greenhouse gases for the two systems. The results show that both systems can cut inputs of fossil fuel and greenhouse gas emissions by nearly 90 % compared to conventional oil-fired systems. Clearly, biomass heating could make an important contribution towards efforts in the UK to meet greenhouse gas reduction targets.



Wood harvesting and chipping operations on a small farm to provide fuel. Courtesy of Sam Whatmore, South West Wood Fuels.

Farmhouses could benefit from small-scale heating systems fuelled with bioenergy. Courtesy of Sam Whatmore, South West Wood Fuels.

Scope and objective

Renewable energy from biomass is recognised as an important option in developing strategies for combating climate change (see references 1–3). In February 2003 the UK government published a white paper listing challenging targets for reducing greenhouse gas emissions and increasing the use of renewable energy. These included the aim of cutting carbon dioxide emissions in the UK by 60 % by the year 2050 and an 'aspiration' for 10 % of energy to be supplied from renewable sources by 2010, doubling to 20 % by 2020. Domestic and commercial heating consumes a lot of energy, and biomass systems could play an important role in supplying this, with small capital investment required for their installation and tried and tested technology already available.

In practice (using current technology), all renewable energy systems, including biomass, solar, wind and wave power, require small amounts of non-renewable energy for their construction, running and maintenance. Consequently there will be low levels of greenhouse gas emissions. When developing renewable energy projects, it is important to confirm and demonstrate how small the non-renewable energy inputs are, and how low the greenhouse gas emissions are compared to conventional fossil fuel systems.

The objective was to study two small-scale biomass heating systems, evaluate their energy balances and greenhouse gas emissions and compare these with equivalent fossil fuel heating systems. Two systems were examined, one based on growing energy crops and one based on wood fuel (harvested from forests), as these fuel types represent the potential for biomass heating in the UK.

The study was funded by IEA Bioenergy Task 38 and is one of a group of case studies of contrasting bioenergy systems in different countries. The UK case study of small-scale systems is complementary to those carried out in Australia, Canada, Croatia and New Zealand which consider different ways of using crops and wood fuel as sources of energy at different scales (see references 4–7).

Methods

A 'cradle-to-grave' approach was taken, in which the total inputs of non-renewable energy to the heating system were estimated over the full working life of the system. The emissions of three major greenhouse gases (carbon dioxide, methane and nitrous oxide) were also estimated.

The approaches used to identify and collect essential information, carry out calculations and present results were based on the methodology developed by IEA Bioenergy Task 38 (references 8 and 9) and the EU BIOMITRE project (reference 10). A major study carried out in the UK also informed the study (reference 11). The main methods include:

- Defining the bioenergy system – a list is made of all the activities and processes involved in managing land, producing the biomass, setting up and running the system over its working life. The researcher then works out how much non-renewable energy, materials and machinery are consumed in these processes.
- Defining a 'reference energy system' – this describes the system based on fossil fuel that might be used to provide energy if the bioenergy system was not chosen. By comparing the energy inputs and greenhouse gas emissions for the reference and bioenergy systems, it is possible to quantify how effective the bioenergy system should be at reducing non-renewable energy consumption and emissions.
- Defining a 'reference land use system' – this describes how the land used for growing biomass might be managed if the bioenergy system was not developed. This is used to quantify the potential impact of managing the land for biomass production on vegetation carbon stocks (see references 1, 2 and 8).

Development of historic buildings as a sustainable office complex (aerial view). Courtesy of RES Ltd.

- 'Total energy and greenhouse gas accounting' – an analysis is made of all the energy inputs to the system and associated emissions of greenhouse gases, not only due to fuel consumed directly but also energy required to produce materials (e.g. fertiliser, herbicide) and manufacture machinery (e.g. tractors).

A more complete description can be found in the UK case study technical report (reference 12).

System 1 description: Miscanthus grass

In recent years, agricultural policy in the UK has supported rural development by devising a new range of opportunities for using surplus agricultural land in a sustainable way. In areas of the UK where there is a predominance of arable agriculture, one option for diversifying land use and producing bioenergy is to grow dedicated 'energy crops' such as coppiced willow trees cut every 3 to 5 years and perennial grasses such as Miscanthus. The first case study

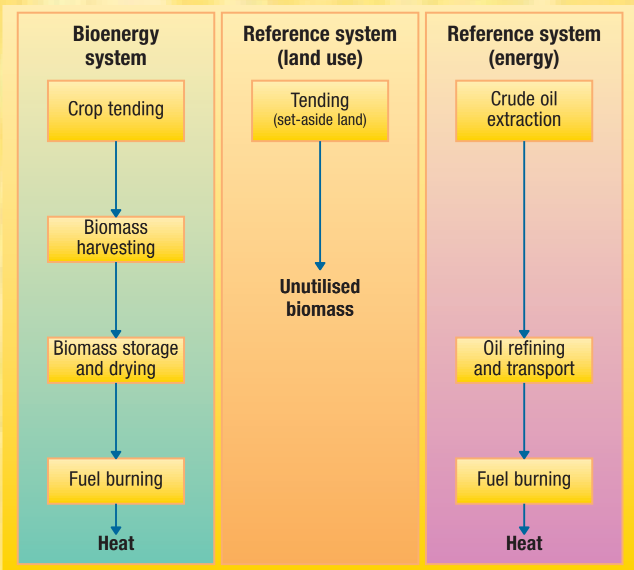


Figure 1. Main process steps involved in bioenergy and reference systems for Miscanthus grass example.

considered one such example of small-scale heat production based on biomass from Miscanthus crops.

A former egg farm and a total of 7 hectares of land in Hertfordshire, north of London, are being developed as office facilities. The land is next to the M 25 (London circular) motorway, and the project is a demonstration of how existing, historically valuable buildings can be reused in a sustainable way. The project is a low energy complex, employing an innovative, fully integrated range of renewable energy systems. As part of this initiative, a 70 kilowatt biomass boiler was installed to provide heating and 4.5 hectares of Miscanthus were planted on nearby land to provide fuel.

System 1: reference systems

An oil fired system was defined as the most realistic conventional heating technology. The oil fired boiler was assumed to have a higher efficiency than the biomass boiler. The land that would be used for growing the Miscanthus grass was assumed to be set aside (i. e. retained as unproductive land) if oil heating was installed. This involved annual cutting or mowing to prevent the land developing into a wilderness. Carbon stocks in vegetation and soil were assumed to be the same for both bioenergy and reference systems.

Figure 1 illustrates the key process steps comprising the bioenergy system, necessary for producing useful heat from the Miscanthus grass. The fossil fuel and land use reference systems are also shown for comparison.

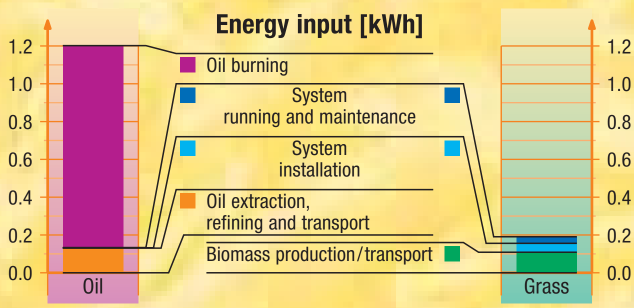


Figure 2. System 1: energy required to produce 1 kWh of useful heat.

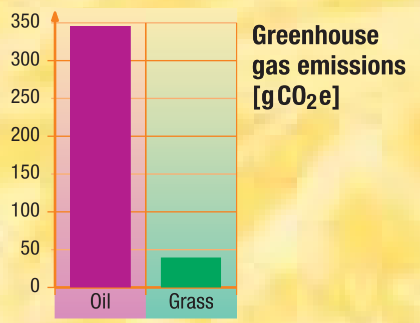


Figure 3. System 1: greenhouse gas emissions from production of 1 kWh of useful heat.

System 1 results

It was estimated that the bioenergy system required only 0.2 kilowatt-hours (kWh) of non-renewable energy to supply 1 kWh of useful heat to the offices. Clearly the largest contribution to the energy balance of the heating system must be due to the renewable biomass. By contrast, the oil system needed much more non-renewable energy – an estimated 1.2 kWh – to deliver the same heat. These results are confirmed by the detailed analysis of energy inputs illustrated in Figure 2. By far the biggest contribution to the energy balance of the reference system is due to the direct combustion of oil to generate heat. The analysis also revealed that, compared to the oil system, it takes slightly more non-renewable energy to set up, produce fuel and maintain the bioenergy system, but the savings achieved by avoiding direct combustion of oil far outweigh this.

The total greenhouse gas emissions were also calculated for the working life of the heating system (25 years) and expressed per kWh of delivered heat, as summarised in Figure 3. In order to simplify comparisons, the emissions of carbon dioxide, methane and nitrous oxide were expressed in common units of 'grams carbon dioxide equivalent' (g CO_2e) and added together. For the methane and nitrous oxide emissions, this involves working out how much carbon dioxide would need to be emitted to have an equivalent impact on global climate. The pattern of greenhouse gas emissions mirrored that for energy inputs, with the reference system involving much higher emissions (345 g CO_2e per kWh) compared to the bioenergy system (40 g CO_2e per kWh).

System 2 description: wood fuel

Compared to other countries, the afforested land area in the UK is low (about 10 %) but government policy has supported an expansion in forest area in the past 100 years. In parts of the UK with significant areas of forest, utilising low quality wood as a source of renewable fuel is one way of making more efficient use of woodland resources. In addition, the small diameter wood produced during the management of young forest stands is ideal for burning. Developing markets for wood energy could make these operations in young stands more cost effective, encouraging good forestry practice and improving the quality of woodlands. The second case study considered one such example of small-scale heat production based on wood fuel.

A 90 hectare farm in the southwest of England includes 12 hectares of long established broadleaf woodland and some recently planted conifer stands. A 150 kilowatt wood chip heating system was installed on the farm in January

Map showing location of farm buildings and surrounding woodlands. Courtesy of Sam Whatmore, South West Wood Fuels.

Stack of slabwood from the sawmill being stored on the farm. Courtesy of Sam Whatmore, South West Wood Fuels.

2003. Currently this provides heat for a 5 bedroom farmhouse and a 3 bedroom holiday cottage but there are plans to extend the system as part of the renovation of a second holiday cottage and a large barn. The biomass heating system is thus making an integral contribution to the regeneration of the farm complex and business.

As illustrated by the system diagram in Figure 4, currently wood fuel is obtained partly from small trees removed from farm woodlands as part of operations to improve stand quality, and partly in the form of 'slab wood' – a co-product from a nearby sawmill. Figure 4 shows the main process steps involved in delivering useful heat to the farm complex.

System 2: reference systems

The fossil fuel reference system is also illustrated in Figure 4. As with the Miscanthus grass example, a more efficient oil fired system was defined as the most realistic conventional heating technology. It was assumed that the farm woodlands would be left untended if the biomass boiler had not been installed. Carbon stocks in vegetation (trees) and soil were therefore assumed to be the same for the bioenergy and reference systems. If not used by the farm, the slab wood from the sawmill would go to a board mill 20 kilometres away. Utilising the slab wood locally thus saves the energy needed for transport between the sawmill and the board mill. However, the board mill would need to find other sources of wood to maintain production and these were assumed to involve longer transport distances.

System 2 results

The results were very similar to those for the Miscanthus grass case study – the biomass system required only 0.1 kWh of non-renewable energy to supply 1 kWh of useful heat to the buildings forming the farm complex. By contrast, the oil system needed much more non-renewable energy – an estimated 1.1 kWh – to deliver the same heat. A detailed analysis of the energy inputs to the two systems, illustrated in Figure 5, revealed a pattern of contributions very similar to that observed for the Miscanthus grass example. Emissions of greenhouse gases were analysed just as for the Miscanthus grass example and the results are summarised in Figure 6. The emissions of greenhouse gases per kWh of delivered heat were estimated at 307 g CO_2e per kWh for the reference system, much higher than for the bioenergy system, with emissions of just 52 g CO_2e per kWh.

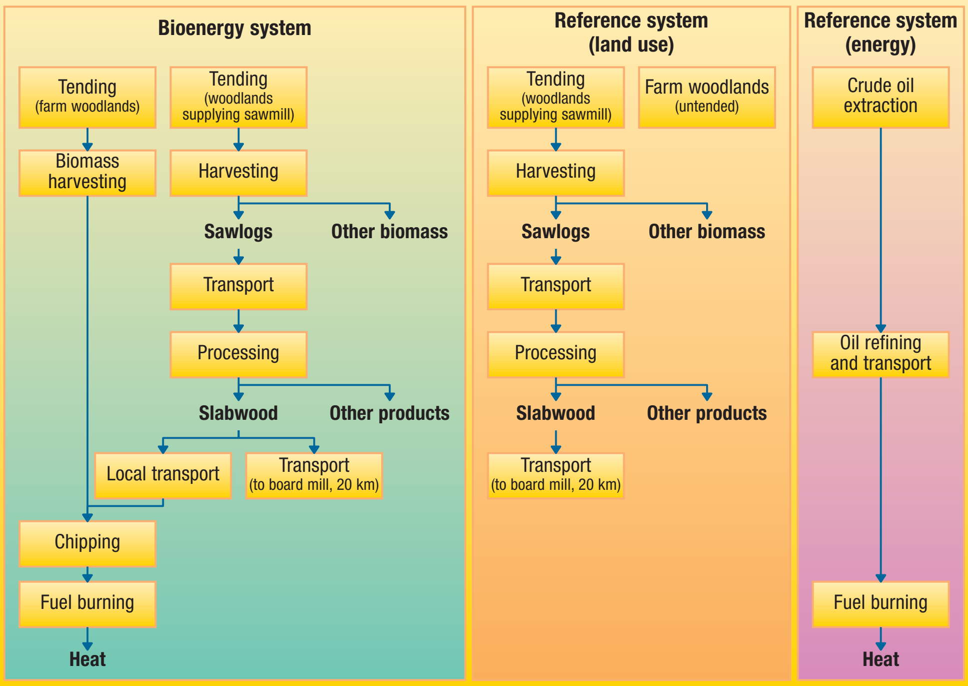


Figure 4. Main process steps involved in bioenergy and reference systems for wood fuel example.

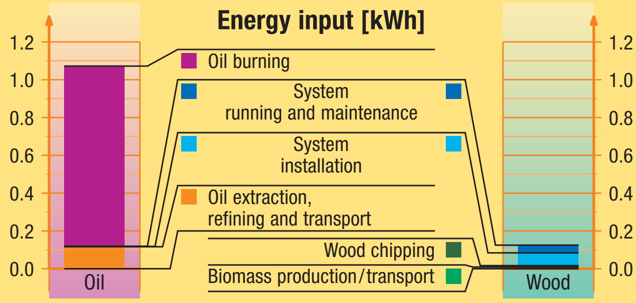


Figure 5. System 2:
energy required to produce 1 kWh of useful heat.

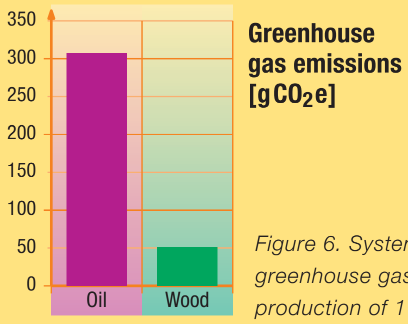


Figure 6. System 2:
greenhouse gas emissions from production of 1 kWh of useful heat.

Discussion

The case study has demonstrated emphatically how small-scale biomass heating systems can help reduce greenhouse gas emissions – in both examples emissions were cut by nearly 90 % compared to conventional fossil fuel heating systems. Over a 25-year life cycle, these bioenergy projects were found to reduce total greenhouse gas emissions compared to the fossil-fuel reference systems by 44 t CO_2e (Miscanthus) and 40 t CO_2e (wood fuel). This case study therefore demonstrates that the overall performance of bioenergy systems can be remarkably consistent for certain types of production and conversion processes when applied in appropriate situations. The range of possible ways of producing and utilising biomass can also be seen as presenting an opportunity to support 'made to measure' bioenergy projects, designed to integrate with the local economy, culture and environmental conditions, while delivering renewable energy in an efficient way.

Bioenergy projects need to be promoted and implemented with appropriate checks and safeguards. For example, it is important to demonstrate that the sources of biomass used by a project are sustainable. It is also important to recognise that the potential for sustainable use of the biomass resource is finite. Over-stimulation of demand for biomass in particular localities or regions could lead to excessive competition for the resource or unsustainable consumption. This case study also highlights the potential for improving the efficiency with which biomass is produced and utilised, suggesting that priority should be given

Biomass boiler installed on the farm site.
Courtesy of Sam Whatmore, South West Wood Fuels.

to development of technologies and practices that will make renewable energy sources even less dependent on non-renewable resources.

Solving the problem of climate change requires not just one global solution, but rather a complex package of local initiatives. Small-scale biomass heating systems are an example of one such initiative – relatively low cost projects that small enterprises can invest in to achieve real reductions in greenhouse gas emissions, with the potential to kick-start a wider biomass industry.

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IEA Bioenergy

Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD & D) programs. IEA Bioenergy aims to realize the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA Bioenergy Task 38 brings together the work of national programs in 13 participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. As one example of work, case studies have been conducted by applying the standard methodology developed by the Task 38. The case studies have assessed and compared GHG balances of different bioenergy and carbon sequestration projects in the participating countries, and the UK case study is one example.

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