

# UTILISATION OF ORGANIC WASTES FOR SUSTAINABLE ENERGY PRODUCTION (OWSEP)

Second Report July 2002

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## **EXECUTIVE SUMMARY**

The report includes the Technology Review which covers the technologies relevant to the types of green waste identified in the first OWSEP report; 'Green Waste Resource and Market Review for the Thames Valley'. The report identifies the various combustion technologies, liquid biofuels and anaerobic digestion (AD) and draws on examples of these technologies from the UK and abroad. The report recommends that for dry, woody wastes direct combustion technologies are the most suitable at present in addition to small scale gasification systems. Anaerobic digestion is identified as a suitable method of energy production from wet wastes but the potential economic barriers are highlighted and the need to regard AD for its waste management merits is also noted. Liquid biofuels are also covered in this report as they can be made from certain fractions of green waste. They can also be used as transport fuels as well as for electricity and heat production.

The website ([www.tvenergy.org](http://www.tvenergy.org)) for TV Energy includes a link to projects from the homepage and OWSEP report has its own page from this link. The page is kept up to date with the reports produced, which are downloadable in pdf format. There is also contact information on the page for interested parties to contact TV Energy directly.

## **1.0 INTRODUCTION**

### ***1.1 Dry Waste Fuel***

Thermal conversion technologies are used to convert 'dry' wastes, residues and crops to heat or electricity. This is distinct from the anaerobic digestion techniques (discussed in section 2) which are used to process 'wet' biofuels to produce methane gas which can be used as a fuel.

All biomass fuels and wastes are by definition derived from plant material and most of the dry feedstocks considered for thermal conversion are wood in its various forms. The list below gives an example of the feedstocks that fall into this category:

- Waste prunings produced by tree surgeons
- The green waste fraction from waste processing centres
- Most of commercial packaging wastes including paper and cardboard and disused pallets
- Wood processing waste from factories and workshops making wood products such as furniture
- Forestry residues produced from woodland management operations

Wood has always been used as a fuel and it is still the biggest source of renewable energy in the world. Traditionally wood has been cut into logs or converted to charcoal and then burned directly to heat buildings, to cook food and for industrial processes. Burning wood on open fires is inefficient and much of the heat energy available is wasted. Modern, clean and more convenient methods have been developed to generate heat and even electricity from dry biomass fuels in recent years and these technologies are explored in this document.

### ***1.2 Political drivers and the carbon cycle***

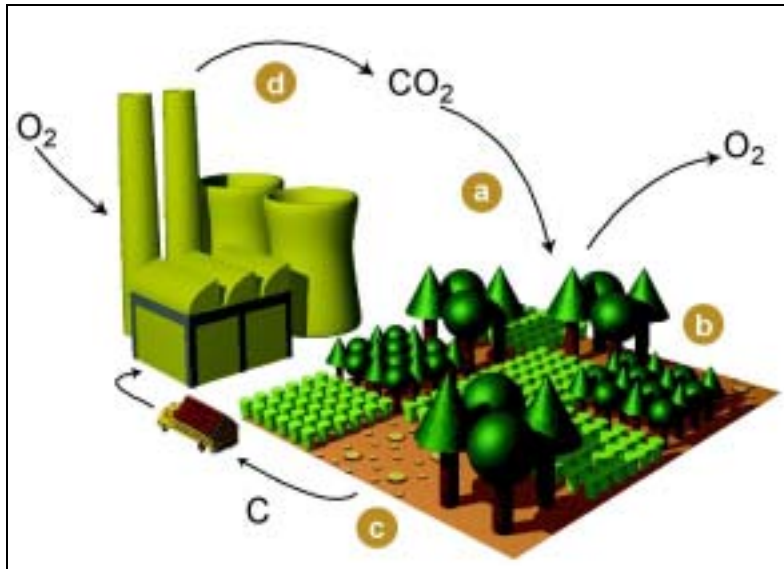
The main drivers for considering the use of biomass fuels rather than fossil fuels include a desire to:

- reduce the net emissions of carbon dioxide (the main 'greenhouse gas'),
- use a renewable fuel in order to conserve reserves of fossil fuels,
- purchase fuel close to where it is used keeping money spent on fuel within the local community,
- provide long-term local jobs,
- find a use for biomass wastes and residues - recycling them rather than disposing of them in landfill (Landfill Directive)
- encourage the management and development of woodlands to improve their amenity value and wildlife habitats.

Most of these drivers are self explanatory but some people question whether biofuels, like other renewables, result in a reduction in carbon dioxide (CO<sub>2</sub>) emissions – after all CO<sub>2</sub> is released when biomass is burned. With fossil fuels, the carbon in the fuel would remain underground and would not be released into the atmosphere if it were not extracted and used as fuel. When using biofuels, the carbon dioxide released on

burning is only that which would have been released anyway as part of the natural carbon cycle. As the plants grow, they take in carbon dioxide during photosynthesis and as they decay or are burned they release it again. This cycle is explained in the diagram below.

**Figure1: The Carbon Cycle**



Source: NREL

*The 'Carbon Cycle' is the cycle of carbon or carbon dioxide as it is absorbed from the atmosphere by plants and then released back to the atmosphere when the product made from the plant or the plant decomposes or is burnt.*

This diagram shows biomass fuels as being perfectly carbon neutral (no new carbon added into the cycle). However, as with other renewables and other energy generation sources, an amount of fossil fuel is used to build the conversion plants and, in the case of biofuels, to process and transport the fuel. However, this fossil fuel energy, and the consequent fossil carbon released is usually only a small proportion of the energy in the biofuel.

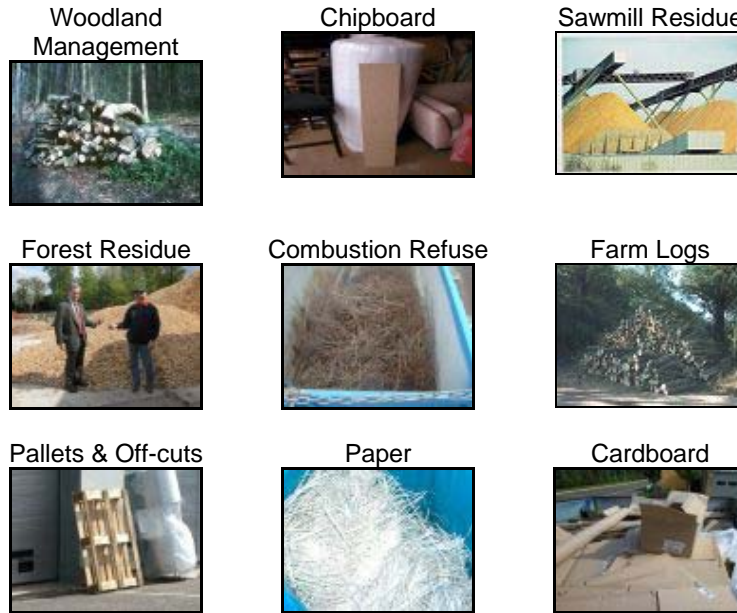
For solid biomass fuels, sourced locally, the ratio of fossil fuel energy expended compared with the energy released from the biofuels is usually around 1:30; this compares well with most other renewable energy sources.

### **1.3 Fuel sources and forms**

#### **1.31 Wood derived fuel sources**

Before considering the technologies, it is appropriate to consider the fuels that are typically found within the Thames valley region and the form in which they are available. The pictures below show dry biomass fuels in various forms.

**Figure 2: Wood Derived Fuel**



Clearly some make better and more convenient fuels than others and they often need some kind of processing before they can be fed into the energy conversion plant. Larger pieces of clean wood from a forest management operation can be made into logs. These and smaller branches and tops can be chipped to give a more homogeneous product that can be mechanically handled and burned in a clean wood burner. In order to mechanically handle the waste materials, this would normally be chipped or comminuted using a shredder or a hammer mill before being fed into a boiler's feed system.

### 1.32 Non- wood dry biomass – straw, grain and chicken litter

For completeness, it is worth mentioning some fuel sources that fall into the category of 'dry biomass' but are not derived from wood.

Straw ( a by-product of cereal farming) is used as a biofuel in Denmark and some other parts of Europe, from the scale of on-farm boilers, through district heating boilers up to power stations generating 10s of MW of electricity.

In fact, the biggest straw fired power station in the world is based at Ely in Cambridgeshire. This unit, the only one of its type in the UK, generates around 31MW of electricity from 200,000 t/yr of straw produced within 40 miles of the plant. This model could be replicated in other parts of the country where cereal farming is concentrated in one area.

Straw burners used for space heating are commonplace in Denmark and there are many different designs from farm-scale up to multi-megawatt units used to heat whole towns through district heating networks and power stations.

In Britain, some farmers use straw as a fuel in batch fired boilers and several hundred units have been installed since the 1970s. A typical modern unit is a 300-400kW unit suitable for heating a large farm house and a number of other buildings such as workshops or industrial units. Such units are typically loaded each day with a large bale of straw using a tractor. The straw is burned quickly and cleanly and the heat stored in a large insulated tank of water (a heat accumulator). The most common straw fired boiler of this type in the UK is manufactured by Teisen Products and is known as the Farm 2000 unit.

Poultry litter is used as a fuel in power stations at a number of sites around the country. The biggest one is at Thetford in Norfolk where 38.5MW of electricity is produced from 450,000 t/yr of chicken and turkey litter from a wide catchment. Another smaller 12.7MW plant at Eye in Suffolk uses a similar technology to generate electricity from a mixture of wood chips, chicken litter, racehorse bedding and chicken feathers sourced from within the region. These are conventional steam cycle power stations and serve to illustrate the point that dry biomass does not have to be wood based but that any biomass source can be considered as a fuel.

**Figure 3: Thetford Power Station**



Source: Fibrowatt, [www.fibrowatt.com](http://www.fibrowatt.com) (2002)

### **1.33 Pellets**

An alternative processing system used extensively in Scandinavia the US and Canada, mostly to process clean wood wastes is pelleting. This takes the processing of wood waste one step further and results in a very homogeneous dense fuel product that is easy to handle and burn in low-cost appliances designed for the purpose. Wood waste of a consistent moisture content (which might involve drying) is hammer-milled to dust and is then passed through a ring die to produce dry high density cylindrical pellets usually between 6 and 12 mm in diameter.

Clearly, the cost of producing pellets is higher (both financially and in terms of energy input) than simply producing chips. However, the extra cost of fuel processing infers the following advantages:

- A wide range of feedstocks can be processed to give a consistent product.
- Storage volumes are reduced because the material is dense.

- Transport and handling costs can be significantly reduced because the material is dense and can be pneumatically conveyed like grain.
- Fully automated boilers can be used and operated almost like oil boilers with thermal efficiencies up to 90%
- Materials handling equipment is greatly simplified where the fuel is used as the material flows under gravity unlike wood chips that need to be pushed through handling systems using mechanical devices.

These advantages together mean that pellets can be used as a convenient biomass fuel right down to the domestic scale. Room heaters can be fed cleanly and easily by hand using bags of pellets and central heating boilers can be installed with little more space needed for fuel storage than that for an oil fired system. They make a convenient fuel at all scales and some UK power stations are currently using imported wood pellets and co-firing them with coal. This allows them to co-fire biofuels using the same pneumatic handling systems as are used for coal.

In many parts of continental Europe and North America domestic pellet stoves are commonplace with a well-developed dealer network supplying maintaining and installing appliances and producing and supplying fuel. There have been a number of recent initiatives in the UK to spread this practice here and there is now an operational UK pellet mill in the South Wales.

## **2.0 THERMAL TECHNOLOGY REVIEW**

In this section, the technologies available to produce energy from dry biomass fuels are explained. This includes those to generate heat and those to generate electricity or combined heat and power (CHP).

The operating principles of the various technologies and the state of the art in the UK and Europe are covered with comments on important aspects of design and operation and the status of the technologies in the UK. A case study for each technology type is featured and a list of suppliers is included.

The technologies considered are:

- direct combustion of biofuels to generate heat,
- generation of electricity from biomass
- Liquid biofuels

### ***2.1 Direct Combustion to generate heat***

#### **2.11 Open fires**

When dried woody material is burnt, the stored energy in the wood is converted to thermal energy which can be used for space heating. The traditional way of burning wood is as logs on an open fire. By modern standards, this is an inconvenient and inefficient means of converting wood fuel to useful heat. Even a well operated open fire burning dry hardwood only converts the energy in the wood to heat with an efficiency of around 12% because the combustion process is uncontrolled. In addition, the need for an open chimney results in much of the heat from the room venting up

the chimney. For the same reason, the emissions from the process tend to be polluting and smoky.

For these reasons, burning wood on an open fire is rarely used as the primary fuel source for space heating in the UK. It is usually used as a decorative feature in a house and will not be considered further as an effective source of renewable energy.

## 2.12 Log burning stoves and boilers

Modern wood fired stoves and boilers are generally well designed and are a far more efficient means of converting wood logs to useful heat. Efficient combustion is achieved by controlling the quantity temperature and turbulence of the combustion air. There are many styles of appliances. They may be designed to operate as direct room heaters, boilers heating water for domestic use or to heat radiators or as a cooking stove; some designs combine these means of delivering heat. The largest scale ones, typically used on farms, can accept big logs handled mechanically and can generate up to 400 kW of heat for space heating via a hot water distribution system. Many appliances convert energy in the wood to useful heat at an efficiency of over 70%.

Provided users are prepared to store and handle logs, so that dry wood is burned, such appliances represent a realistic means of generating renewable energy. Sourcing logs from woodland management operations can generate a useful income to allow beneficial woodland management to take place thereby inferring local environmental benefits.

*Figure 4: Log Burning Stove*



Picture courtesy of Stovax Ltd

## 2.13 Larger scale heating projects using wood chips

Once the output required from the appliance exceeds a few 10's of kW then storing handling and feeding logs by hand becomes an onerous task. For larger applications, the standard form in which wood fuel is delivered is as wood chips. The advantage of chips over logs is that from the point of production in the forest, the chips can be mechanically handled throughout the supply chain. At the boiler plant, the chips are loaded into a storage bunker and fed into the boiler, normally with a screw conveyor.

Boilers are normally designed to distribute the heat using hot water but some models can be fitted with boilers to generate steam for process applications or even for small-scale power generation. Another alternative is to fit a gas-to-air heat exchanger to the burner and use this as a way of heating a building. This design is popular in wood-working industrial premises where waste wood is used as a fuel and fans are used to circulate air through the heat exchanger and distribute it throughout the factory giving a hot-air heating system.

The scale of wood chip boilers is from around 100kW up to several MW. Below 100kW output the cost of the associated fuel handling equipment tends to proportionately expensive. System efficiencies can be as high as 80% in converting the energy in the wood to useful space heating. This is a little lower than that for boilers of equivalent capacity used to generate heat from oil or gas.

Boiler, stoker and grate designs vary between manufacturers and there are also variations in the type of fuel storage and feed systems employed. The more complicated arrangements, for example with moving grate elements, tend to be built into the higher capacity boilers. The simpler designs, such as underfeed stokers tend to be built into the lower capacity units. Boiler selection appropriate to the fuel being burned and suitable for the load profile is an important element of system design. The selection of the technology depends, to a large extent on the quality of the fuel being burned with particle size distribution and moisture content being the most important aspects of quality.

In the UK, most of the boilers sold, and consequently those manufactured here, are used to burn wood waste generated the wood working industries. A typical package consists of a chipper (or other comminution device), a small storage hopper with an agitator, a boiler and a feed screw to link the two. The heat from the boiler may be distributed via hot water piped to radiators or directly to air with an air-to-gas heat exchanger. Because of this, the boilers manufactured in the UK tend to be best suited to the dry wood fuels that arise from these applications.

These systems are also commonplace on the continent but, in addition, in many parts of Europe and Scandinavia, wetter wood waste from forest residues is also burned. Consequently, boiler systems have been developed to handle and burn these products cleanly. One of the most important aspects of specifying a boiler is to ensure that the boiler is suitable for the wood fuel to be processed. Boilers to burn dry wood tend to be less sophisticated and contain less firebrick material. Consequently, they tend to be less expensive but it is a false economy to try to use a boiler to burn wood that is wetter than that at which the boiler is specified for. Many projects have failed as a consequence of this mistake.

The wood chip handling systems also need to be designed to cope with the fuel to be used. The systems used to handle, at the one extreme screened dry wood chips, and at the other, forestry residue chips, are very different. Again, many projects have failed as a consequence of mismatching the fuel material and the materials handling equipment.

## 2.14 Emissions control and gas cleaning

Burning clean wood based wastes and residues in a well specified and well operated boiler should result in few emissions other than the natural products of complete combustion – CO<sub>2</sub> and water vapour. In practice there, are often trace quantities of unburnt hydrocarbons, particulates (smoke), carbon monoxide, and oxides of nitrogen. There are limits for each of these specified in the legislation governing such installations which depend on the scale of the installation and whether the wood is clean untreated wood or categorised as a waste.

Most modern boilers have a sensor in the gas stream at the exit of the boiler to sense how well combustion is taking place. This is linked through an electronic control system to adjust the amount of air being provided for combustion. There are also other controls that can be adjusted to control the amount of air being fed through the bed of burning fuel (primary air) and that mixed with the products of combustion above the burning fuel (secondary air). These mechanisms control the combustion efficiency which will reduce the amount of smoke and the unwanted products of combustion produced. Most systems are also fitted with a cyclone that is installed in the stack and further limits the emission of particulates.

The largest systems, and those burning materials categorised as wastes, may have more sophisticated gas cleaning systems such as ‘bag’ filters, scrubbers or electrostatic precipitators. They may also have more sophisticated control of combustion air and systems to continuously monitor for potential pollutants. These more sophisticated systems add significantly to the cost of an installation and would not normally be appropriate on the smaller units burning clean wood residues.

### Case Study 1: Elvendon Priory, Oxfordshire

Figure 1a: The Priory



Talbott's Ltd, based in Staffordshire, manufacture and supply equipment for small-scale heat applications and CHP. One of these systems is located at Elvendon Priory in Streatley, Oxfordshire. The 300kW boiler was installed in 1998 and utilises wood chips from the estate's 300 hectares of woodland plus addition material from a local sawmill.

The boiler operates at efficiencies of 60 – 80% dependent on the moisture content of the wood chip used and is fully automated. Figure 2 shows the boiler and wood chip silo at the priory.

**Figure 1b: Boiler and Silo**



Source: Talbott's Ltd

The silo is top fed and has a capacity of 7m<sup>3</sup>, enough for 3 – 5 days supply and the woodchip is fed to the combustion module via a screw auger which passes under a ceramic extension of the boiler ensuring all fuel is pre-dried and pre-heated. Motor-driven fan blowers supply pre-heated primary and secondary air to the combustion zone, while an induced draught fan with integral grit arrestor is mounted downstream between the combustion unit and the stack ensuring minimal particulates in the emissions.

The pre-programmed PCC incorporates a simple panel mounted push-button control unit and visual display as the man-machine interface. This has been specially designed to enable the entire system to be easily operated and controlled by non-specialist, untrained estate staff. However, the groundbreaking computer-based monitoring and control equipment also includes data acquisition and storage, together with an on-line remote communications facility. This advanced system not only enables up to 300 hours of continuous operating data to be monitored, either on-site or remotely from Talbott's headquarters in Stafford, but also enables engineers to re-set, adjust or re-programme the complete heating system on-line from virtually any remote terminal or lap-top, without the need to visit the installation.

The system at Elvendon supplies all the hot water requirement of the priory, conference facilities, the estate manager's cottage and all other facilities. The system has proved to be highly reliable and requires minimal maintenance.

## **2.2 Electricity generation from biomass fuels**

Generation of electricity from dry biomass fuels is a much more involved process than simply burning them as fuels to generate heat. As with fossil fuelled power stations there are large economies of scale which is why economical power stations tend to have a high capacity. The main reasons for this are as follows:

- small power generation systems tend to be less efficient,
- the manning and running costs for a small power station are often little different to those for a large one,
- many of the components are the same for small and large systems just sized differently – overheads such as design and management costs and the cost of the control systems are similar whatever the capacity.

There are basically two approaches to generating electricity from biomass. The first is to adopt the same approach as used in the large coal fired power stations. That is to burn the biomass in a boiler to produce high pressure steam and then allow this to expand through a steam turbine; this in turn drives the electricity generator. Electricity

generation efficiency is reasonable at large scale. Large biomass plants generating 30MW or more achieve efficiencies over 30% however a farm-scale generator producing only 100 to 200kW would have an efficiency of only 10% or so.

The second principles used to generate electricity from dry biomass are the, so called, advanced conversion techniques of gasification and pyrolysis.

## **2.21 Electricity generation technology: gasification**

The route to electricity generation using gasification is to burn the wood in a controlled way with a restricted supply of oxygen. The result of this thermal reaction is that volatile hydrocarbon gases and carbon monoxide are given off. These flammable gases are cleaned of impurities and piped to an internal combustion engine and used as a fuel in the same way that LPG can be used as a fuel gas for car engines.

At the small scale (50-200kWe), automotive engines (dual-fuel diesel engines or spark ignition gas engines) are generally used as the prime mover with little modification. The overall efficiency of conversion of the energy in biomass to electrical energy can be as high as 25% which is over twice the efficiency that can be achieved using a steam cycle system at this scale.

At a larger scale, gasification may take place in a fluidised bed gasifier in which the controlled burn takes place in a bubbling bed of hot sand; the gas would often then be burned in a gas turbine rather than in a piston engine. A second cycle is often added where the exhaust gas from the gas turbine is used to raise steam in a boiler (the heat often supplemented by burning the remaining charcoal) which then drives a steam turbine as well. This, so called, 'combined cycle' design is used at the plant currently being commissioned in Yorkshire by First Renewables to generate around 10MW of electricity from wood chips. These designs have the potential for efficiencies higher than those achieved using the steam cycle. At the scale of a few 10s of MW, theoretical efficiencies can be between 30 and 40%.

There are a number of designs available for the gasifier reactor itself. Smaller scale units tend to be of the down-draught design (see case study below). The reactor vessel generally consists of a cylindrical steel vessel with a hopper-bottom. The fuel in the form of chips, or at least pieces of a fairly consistent particle size, is fed into the top of the reactor. Air passes down through the reactor (hence the name 'down-draft') and most of the reaction takes place in the throat of the vessel in the hopper part of the unit. The hot gaseous products of the reaction escape from the bottom of the vessel and are piped away for cleaning and for use in the engine. There is normally some kind of a grate in the bottom of the reactor vessel and any remaining char and ash is removed at this point.

This simple design has been used in developing countries for generating energy from biomass residues such as rice or coconut husks. It was also used in the second world in London to make 'producer gas' to run buses; the reactors were mounted on the back of the bus and the gas piped into the engines.

There are a number of manufacturers offering an up-draft design where the hot gas from the reaction at the bottom of the vessel passes up through the fuel in the hopper and exists at the top. This is the kind of unit that was used to produce town gas from coal. The UK manufacturer, Wellman offer a model of this design adapted for use with biomass fuels for medium scale operations typically 500-2500kWe).

### Case Study 2: Beddington Zero Energy Development (Bed-ZED)

Beddington Zero Energy Development is the first of its kind in the UK, a development of 82 homes and office space totalling 1600m<sup>2</sup>. As well as incorporating sustainable design and materials, passive and active solar energy the development will also be utilizing a CHP unit for the heating requirements of the residents. B9 Energy Biomass were awarded the contract to supply a fully automated 130kWe wood fuelled Combined Heat and Power (CHP) unit to BedZED in Sutton, London.

Figure 2a: Beddington Zero Energy Development (BedZED)



BedZED has been designed to make full use of the free, natural heat and light of the sun. Coupled with the use of energy efficient appliances, this will reduce energy demand by 80% compared to typical dwellings. The wood fuelled CHP unit being supplied by B9 Energy Biomass is designed to supply all of the electricity and heat requirements for the development, with wood fuel obtained from tree surgery operations in the London area.

Currently London produces 51,000 tonnes of tree surgery waste per year and this carbon-neutral source will provide the bulk of the electrical demand and heat for BedZED. A 130kW electric output combined heat and power plant (CHP), will operate on 1,100 tonnes of tree surgery waste each year collected from London Boroughs of Sutton and Croydon. The hot water from the CHP will be distributed around the site via a district heating system of super-insulated pipes. Should residents or workers require a heating boost, each home or office has a hot water tank that can double as a radiator.

In the longer term, tree surgery waste will be supplemented with short rotation willow coppice which will be grown on the adjacent landfill site. An area of 70 hectares planted as short rotation coppice woodland with approximately 24 hectares cut annually would meet the BedZED community's fuel needs.

The diagram shows the woodchip passing through a drier before entering the gasifier, this dries the fuel from 50% moisture to approximately 15%. The fuel is then gasified at high temperature in the down-draught unit. The gas is then cleaned and cooled for use in a 14.2 diesel engine fitted with spark ignition. This is maintained at a constant speed and used to drive a generator which is converted to ac using an inverter and is then used to provide mains electricity. At times of low demand from the development electricity can be exported to the grid and at times of high demand electricity can be imported.

The heat produced in the process is captured and used to heat water which is piped to the

properties in the manner of a district heating scheme (see Case Study 3).

**Figure 2b: B9 Wood Gas CHP**



Picture Courtesy of B9 Energy Biomass Ltd

References:

[www.b9energy.co.uk](http://www.b9energy.co.uk)

[www.challenge.vegasyms.net](http://www.challenge.vegasyms.net)

[www.refocus.net](http://www.refocus.net)

As a technology, gasification is not as well developed as using the steam-cycle route to electricity generation. It is best categorised as being at the ‘demonstration’ stage of development and it is difficult to purchase units that carry meaningful commercial guarantees of performance; this makes large gasification projects more difficult to fund.

## 2.22 Electricity generation - pyrolysis

Pyrolysis is the other, so-called, advanced conversion route to electricity generation from biomass. As with gasification, the biomass is de-natured using a thermal process and the resulting fuel used in internal combustion engines such as a diesel engine or a gas turbine. In the case of pyrolysis, the product from the process is a liquid ‘bio-oil’ rather than a gas. The advantage of this is that it can be stored, pumped and even transported from one site to another like oil derived from fossil fuel. Because of this, there is the potential to produce the bio-oil at a plant close to the origin of the biomass and use it in engines at multiple locations where the load is situated. This improves the flexibility of the process and opens up more opportunities for combined heat and power applications.

At a lab scale, the process is well proven and there are now a number of technology designs that are at the demonstration phase of development.

The basic principle of operation is as follows. When biomass is heated up to a temperature of 450 – 500°C in the complete absence of oxygen, the volatile compounds in the biomass ‘boil’ off and leave the charcoal and ash as a char. These volatile compounds are then condensed to form the bio-oil. This thermal process results in three products: the bio-oil, charcoal and the gases that have not condensed. The proportion of the three products depends on the design and operation of the reactor and the biomass that is being fed into it. The best pyrolysis units achieve a conversion to oil over 60% by mass with about 15% charcoal produced as a saleable by-product. Most of the remainder is gas that has not condensed and is used in burners to dry and heat the biomass. Between 1 & 5% of the biomass fed into the process is the inert ash and can not be burned; the exact proportion depends on the feedstock.

There are various designs of reactor type. The simplest designs work at near atmospheric pressure with more complicated designs operating under vacuum. The vacuum designs have the advantage that the biomass does not need to be heated to such a high temperature to achieve pyrolysis but the ancillary equipment needed to maintain the reactor vessel at a vacuum and feed the products into and out of the vessel are more difficult to maintain and operate.

An example of a pyrolysis process operating at atmospheric pressure is the BioTherm process produced by the Canadian technology company Dynamotive. In this process, the biomass is dried to around 10% moisture content and hammer milled to a powder. This fuel is then fed into a fluidised bed reactor and the resulting gas and powdered char are piped from the top of the bed. The char is removed in a cyclone and the bio-oil is condensed in a bath of bio-oil. The gas that does not condense is used to heat the process and the bio-oil is used in a gas turbine or other type of engine to generate electricity. Using this process at the 2-5 MWe scale results in an electrical conversion efficiency of around 18%. At a larger scale, with a steam cycle added to recover the hot exhaust gases and to burn the char, higher efficiencies should be achievable though the unit has so far only been proven at the 10t/day scale.

### **2.23 Combined Heat and Power (CHP)**

In the previous section, technologies to generate electricity from biomass were discussed. Electricity generation efficiencies from 10 up to 30% were quoted depending on the scale and the technology employed. Even our largest coal fired power stations achieve only around 38% efficiency of conversion from energy in the fuel to electricity leaving the power station. Most of the wasted energy is lost as heat at various stages of the process. The most dramatic way in which to improve the useful energy released from the fuel is to find a way of utilising this heat and designing the power plant so that it is recovered rather than simply wasted. A well designed combined heat and power (CHP) plant generating useful heat as well as electricity can have overall efficiencies (energy into electricity + useful heat compared with energy in fuel) of 70–80%.

Given that CHP offers such a big improvement in efficiency compared with generating electricity alone, it is perhaps surprising that such a tiny proportion of UK electricity generation is arranged to recover the waste heat. This is partly because of the way in which electricity generation in the UK has developed. The UK model for

electricity generation has been to build very large power stations traditionally fuelled with coal and more recently by nuclear reactors and gas. The big coal fired powers, which enjoyed a massive expansion in the 1960s, were mostly built near to coal fields, or at least on good rail links to coal fields. Because of their scale, they were generally built well away from other developments. For both of these reasons, there was little opportunity to use a significant proportion of the waste heat from the plants.

In more recent times, there has still been little incentive for developers to generate heat as well as electricity. Untaxed North Sea gas has been such a convenient and cheap way to supply most of our space heating requirements in this country. It is difficult for anything else to compete with this heat source especially as the gas distribution network is so widespread that all but the most remote users have access to mains gas.

The government driver to promote electricity generation from renewables (including biomass), known as the Non Fossil Fuels Obligation (NFFO), gave a premium price for electricity generation but did nothing to increase the value of generating heat. The consequence of this policy has been that the biomass electricity generation plants that have been developed have not found it economical to find uses for the waste heat. This is despite the fact that their scale is more appropriate to such applications.

In parts of continental Europe, provision of heat and power has followed a very different model. In Denmark, Sweden and Finland, for example, most of the power plants are small compared with the coal fired plants in the UK. They have been located close to the centres of population and, most importantly, they have been designed into an infrastructure to distribute heat around the town. This is done through a district heating network which is like a big version of the central heating system installed in most British houses distributing heat from a central source to the rooms in which the heat is to be used. Consequently, biomass power stations that have been built in these countries are generally CHP units discharging heat as a by-product into the district heating network.

### **Case Study 3 – Biomass Fuelled District Heating Plant at St. Peter am Ottersbach, Austria**

Biomass fired district heating systems are commonplace in Austria. In the region Styria alone, there are over 100 separate district heating schemes. In some cases they heat entire towns or villages and in others individual municipal buildings only or a few selected homes.

This case study focuses on the schemes in the small town of St. Peter am Ottersbach in the Styria region recently visited by a member of the TV Energy team on an educational visit funded by OWSEP.

In this town, there are two separate boiler installations. The smaller one is rated at 114kW and supplies a block of 18 apartments with space heating and hot water. The figures below show the wood chip store and the boiler.

**Figure 3a: Wood Chip Store**



**Figure 3b: 114kW Wood Chip Fired Boiler**



The wood chip is supplied by a group of 9 local farmers and a total of 150,000 kWh of heat energy is sold to the apartments each year via a heat-meters installed between the insulated hot water main around the building from the boiler and the radiator system in each flat.

The plant was built in 1991 and is still in good working order. It is fully automatic and is checked once a day to ensure there are no problems, in particular, blockages in the fuel feed.

The larger of the two plants installed in the town of St. Peter am Ottersbach is a 700kW system used to provide hot water to heat seven local municipal buildings and two residential buildings. The wood chip fuel is supplied by a group of 26 farmers with a total of 160 hectares of land.

**Figure 3c: 700kW Municipal Heating Plant: St. Peter am Ottersbach**



1200m<sup>3</sup> of chips can be stored at the plant. This is fed via a hydraulically actuated moving floor to the boiler. The boiler burns the chips to produce hot water which is distributed through a network of 670m of underground insulated hot water pipes to the users. The heat is taken off the main via a heat-exchanger and heat-meter at the site of each individual user.

The ash from the plant (around 3% by weight) is recycled back to the land as a fertiliser. The whole system is fully automatic but requires a daily check to ensure there are no problems. The project was funded with capital from the owner, the customers, the Austrian government and with a bank loan.

Because of the big overall efficiency advantages of CHP compared with straight electricity generation, especially at the small scale, developers often look for heat outlets when building small power stations. There are some examples of gas fired CHP units in the UK that have been designed and built by high energy users such as oil refineries and chemical processing plants. These units are economical because the electricity displaces electricity that would otherwise have to be bought off the national grid and because the heat load (often process steam) is well matched to the waste heat produced.

Biomass CHP in the UK is often difficult to arrange. Without a history of district heating, there are few applications where there is the infrastructure to use significant amounts of waste heat; those applications that do exist tend to be industrial processes where natural gas is the fuel of choice. The key to the successful development of biomass CHP projects in the UK is to find uses for heat close to where power plants can be built and where the heat load matches the waste heat generated in both amount of heat and the timing of its generation. In developing CHP projects, the technology issues are usually relatively trivial compared with the issues associated with planning, coordination, agreeing purchase agreements and demonstrating an economic return compared with the competing fuel sources to generate heat.

### **3.0 LIQUID BIOFUELS**

Liquid biofuels include oil derived from vegetable products and its derivatives and alcohols distilled from fermentation processes involving plant materials. Bio-oil can also be derived using the thermal process, pyrolysis discussed above or even reformed from gas from a thermal gasifier. The advantages of liquid biofuels over solid biofuels include:

- high energy density (around 36GJ/t),
- easy to handle by pumping and piping,
- cheaply transported and distributed to diverse applications in tankers,
- can be used to fuel vehicles – not just stationary plant,
- can be used directly in engines to generate electricity easily and cheaply,
- plant used to convert oil to heat is relatively cheap and efficient.

#### **3.1 Bioethanol**

The most famous large scale liquid biofuels project was the generation of bioethanol in Brazil starting in the 1970s. This huge venture was a political reaction to concerns over security of petroleum supply. These projects continued through to the 1990s but since that time, most of the processing plants have been closed and the majority of liquid fuel is now derived from petroleum.

The process to convert a sugary or starchy biomass feedstock such as sugar cane, sugar beet and even potatoes or grain is similar to the production of alcoholic beverages but on an industrial scale. A 'beer' is made from the feedstock in a yeast fermentation process and then the resulting beer is distilled to separate the alcohol (ethanol) from the water. In most countries where this has been carried out, the ethanol is blended with petrol and distributed through garage forecourts. At low percentages, no modification to vehicle engines is needed and performance changes are negligible. If ethanol is blended at higher concentrations, some engine components such as fuel hoses and rubber seals need to be correctly specified but the necessary changes are relatively trivial.

In the UK, there is little experience in the production of bioethanol as a fuel though sugar beet, currently grown in large quantities, would make an ideal feedstock for the process. If there was a financial incentive to allow such a fuel to compete with petrol there is no technical barrier to the production of industrial quantities to use as fuel. The expertise to grow the crop and process it is well established in the parts of the country where sugar beet is grown and processed to produce sugar for food.

### **3.2 Bio-oil & Biodiesel**

Vegetable oil or even animal fat (tallow) can be used directly as a fuel in internal combustion engines such as stationary diesel engines. Some modification to the engine and to the fuel storage and feed lines may be needed and some blending of the oil with refined fossil fuels, or intermittent use of refined fuels may be needed. The extent of these modifications and the changes to operating practice will depend on the oil being used and the original design of the engine. Having said this, the use of such oils as engine fuel is not fundamentally difficult provided a consistent oil sample is provided. Such oils could also be used as a heating fuel, again with some modification to the combustion plant.

Use of bio-oils as fuels is not widely practiced in the UK as most of it is currently used in animal feed which is a higher value application. However legislation is constantly under review and oil or fat derived from, or containing even traces of, animal products such as waste cooking oil, is likely to be increasingly restricted in this application.

Vegetable oil is derived from a wide range of plant species and used in foodstuffs. A typical list of sources can be taken by looking along the row of different cooking oil products in any supermarket. In the UK the most economical bulk oil-yielding crop is oilseed rape and UK farmers are well experienced in producing this efficiently for the food industry. If growing a vegetable oil crop for fuel in the UK, this would be the obvious choice.

#### **3.21 Biodiesel**

In order to use bio-oil at a significant scale in transport applications, the oil needs to be processed so that it can be used as a direct substitute for a processed fossil fuel oil (diesel and petrol) in mass production. The aim of processing the oil is so that it will

be accepted by manufacturers as acceptable in their vehicle engines without modification.

The easiest route to achieving this is to process vegetable oil in a process known as transesterification. In this process, vegetable oil is converted into a diesel substitute known as biodiesel. Pure biodiesel processed correctly can then be used in unmodified diesel engines as a direct substitute for fossil diesel although many engine manufacturers will only warrant engines using this fuel if it is in a blend of 5% biodiesel to 95% petroleum diesel and provided it meets their specification. Consequently, bio-diesel derived from virgin rape oil (also known as rape methyl ester – RME) is now commonly sold in a blend with fossil diesel on garage forecourts in France, Austria, Germany and other parts of continental Europe. Several companies in the UK are producing biodiesel using oil derived from waste cooking oil.

The process of transesterification is relatively simple and can be done economically at a fairly small industrial scale. The basic process is to mix the vegetable oil with methanol and heat it to around 50°C in the presence of a catalyst (usually sodium or potassium hydroxide). The products of this process are biodiesel and glycerine which is a saleable by-product.

Making biodiesel from virgin rape oil results in the biodiesel costing around twice as much as petroleum diesel. Because diesel for use in road vehicles is heavily taxed in Europe, it has been relatively easy to persuade some European governments to make up the difference in price by reducing the tax on biodiesel. However this is not a position that the UK government has taken and the tax incentives for biodiesel are still not sufficient to make biodiesel production from virgin rape oil a viable proposition here.

Another argument, used by the UK government, for not giving a greater tax incentive to produce biodiesel is that the energy balance (fossil fuel energy used in all the processes to produce the fuel compared with energy in the fuel) is not as favourable as for many other biofuels. The ratio of energy output / energy input for biodiesel from oil seed rape is only 3:1 even if the energy value of the by-products such as the crushed meal (used as cattle food) and the glycerine are included in the equation. Around two thirds of the energy input relates to the agricultural inputs associated with growing the crop.

Neither the economic argument nor the energy balance argument against using biodiesel derived from virgin rape oil are as relevant when considering the use of waste vegetable oil that has no other use. There may be great potential to utilise waste cooking oils as bio-oil in engines either as an esterified product in standard diesel engines as a transport fuel or as unprocessed oil, possibly in blends, in stationary diesel engines for electricity generation.

## **4.0 ANAEROBIC DIGESTION**

### ***4.1 Introduction***

Anaerobic digestion is the process used to produce a fuel gas from a biomass waste arising in the form of slurry such as sewage, animal wastes and waste products from

the food processing industry. This section explains the processes of anaerobic digestion that can be used to process these wastes and produce a fuel gas from such 'wet' biomass substrates.

In a basic system, the substrate in the form of a slurry is fed into a reactor vessel and kept at a constant temperature (either 35 °C or around 57 °C depending on the type of reactor). The oxygen is kept out of the vessel and anaerobic microbes 'digest' the organic matter in the slurry. The main gaseous products of the digestion process are methane 60-65% and carbon dioxide 35-40%, though there are often trace quantities of hydrogen sulphide.

The gas produced during the process can be used as a fuel in an engine for the generation of electricity or it can be used for heating purposes by burning it in a boiler. In the UK, and in other places where the ambient temperature is significantly below the optimum operating temperature of the digester, some of the gas is burned to keep the digester at the right temperature. For this reason, the reactor vessel is insulated to minimise this heating demand.

The other product of the process is the digested slurry which is usually more benign after the process than before it. The slurry is often separated into a solid and a liquid fraction after the digester. Properly digested material leaving the digester will be odour free and the solid portion, when separated, will be friable. Where feedstock quality is good, this digested solid material may be used as a peat substitute following a maturation period of several weeks, or alternatively applied directly to agricultural land as a fertiliser and soil improver.

#### **4.11 History of commercial development of anaerobic digestion (AD)**

Containerised anaerobic digestion (AD) was first developed in the UK at the end of the 19<sup>th</sup> century for the treatment of sewage sludge. It is now widely used by the water industry throughout the world. Over the last 20 to 30 years it has been increasingly adopted for commercial, industrial and municipal waste treatment, though large scale facilities producing several MW of electricity are rare.

Farm scale units enjoyed considerable popularity in the late 70s and early '80's with around 50 systems of between 50 and 1000m<sup>3</sup> installed in the UK. However, a range of operating problems led to a rapid fall from favour and the abandonment of many systems. Approximately, half of those originally installed are still working producing gas from pig, cattle and chicken manure for on-farm heating. Worldwide, farm scale digestion is significant and it is estimated that there are some 6 million small farm digesters in China.

Greater commercial success has been achieved at industrial operations where the dual role of waste treatment and contribution to process heat/energy requirements have improved the economics compared with farm based AD systems. Industries using AD for waste treatment include breweries and distilleries, food processing, sugar and starch processors, pharmaceuticals and paper and pulp industries.

Recent legislation is driving interest towards AD for other more difficult waste streams such as separated municipal solid waste (MSW). World wide, there are now

around 150 AD plants using MSW or industrial organic waste as their primary feedstock managing in excess of 5 million tonnes of waste and potentially generating in the region of 600 MW of electricity (IEA 2000).

#### **4.12 Microbiology of digestion**

There are three principle stages in the digestion process:

Hydrolysis – complex insoluble organic polymers such as carbohydrates, cellulose, proteins and fats are broken down and liquefied by the extracellular enzymes produced by hydrolytic bacteria. This is the rate-limiting step in digestion and is controlled by substrate availability, bacterial population density, pH and temperature.

Acidogenesis – the main products of this stage are acetic, lactic and propionic acids. Carbon dioxide and hydrogen are also evolved along with some simple alcohols, such as methanol. The proportion of the different by-products depends on the environmental conditions and more particularly, on the particular bacterial species present.

Methanogenesis – involves the production of methane by obligate anaerobic bacteria from the products of acidogenesis, acetic acid, methanol carbon dioxide and hydrogen, Acetic acid being the most important since about 75% of the methane is derived from this source. There are a wide range of potential substrates for the methane producing bacteria, depending on the type of the original organic matter present. Although hydrolysis, acidogenesis and methanogenesis are the principle biochemical processes operating within a digester, other bacterial types and breakdown pathways are also active

Digestion may take place at a range of temperatures and different classes of micro-organisms are active at each temperature range. The different types of digesters have been categorised according to the temperature range at which they operate as follows:

Cryolytic or cold digestion - <20° C ie ambient temperatures

Mesophilic – 20-45°C, typically 35°C

Thermophilic - <45°C, typically 55-60°C

The advantage of thermophilic reactors is that they process substrates 30-45% more rapidly and up to 30% more efficiently than mesophilic vessels. Another advantage is that pathogen kill is improved which may improve the value of the digested material.

#### **4.2 Digester design**

The most common type of digester, typically used for the digestion of sewage and farm wastes is the ‘continuously stirred tank’ design. In this design, the slurry is fed in and allowed out of a single insulated tank in which the digestion is taking place. It is a continuous-flow process (not a batch process) and the effective residence time of material in the reactor is adjusted by the ‘flow’ of slurry through the system. The flow rate can be adjusted according to the quality of the feedstock so that optimum

digestion is maintained. The tank is continuously stirred to maintain even digestion and temperature within the tank.

There are a wide range of more sophisticated designs of reactor and ancillary equipment which may be employed for more difficult or variable substrates. One design option is to have two separate tanks in which the acidogenesis and methanogenesis processes happen separately. This allows the optimisation of both stages thereby reducing the overall retention time. However, the increase in capital costs of two vessels and the increased complexity of the control system typically outweigh any process benefits, and two stage reactors are rare.

Anaerobic digestion of wastes is often principally carried out to process waste rather than primarily to produce renewable energy. The yield of gas is quite low and the table below gives an indication for some of the more commonly digested feedstocks.

<b>Typical gas yields and solids content of different wastes (IWM 1998)</b>		
<b>Waste</b>	<b>Gas yield (m<sup>3</sup> t<sup>-1</sup> total solids)</b>	<b>Solids content (%)</b>
<b>Household and commercial waste</b>		
MSW (30% biodegradable)	40	30-35
Biowaste	125	30-35
Paper and cardboard	100	95-100
Vegetable waste	250	10-30
Hotel and restaurants	400	10-40
<b>Industrial waste</b>		
Alcohols: ethanol, methanol	750	
Liquid concentrates: sugar, glycol	300	
Liquid wastes: beer, cultures	200	
Solid wastes: tobacco, food processing	400	
<b>Animal manures &amp; sewage</b>		
Cattle (fresh farmyard)	0.4	15-25
Pigs ( fresh farmyard)	0.1	25-40
Poultry (layers)	0.01	30
Sewage sludge	25	5

#### **Case Study 4: Centralised Anaerobic Digestion in Denmark**

Denmark is often cited as the key example of the successful adoption of digestion for organic waste management. The major biomass resource for anaerobic digestion in Denmark is animal manure (75%). Around 25% is biomass which originates from food processing industries. Four of the twenty biogas plants are capable of treating source separated household waste. Digester capacity ranges from 540m<sup>3</sup> to 7500m<sup>3</sup> with most being over 2000m<sup>3</sup> capacity. Nine operate at mesophilic temperatures and eleven at thermophilic, with seven of the ten built since 1994 operating thermophilically (DIAFE, 1999).

Significant financial and legislative measures were put in place by the Danish Government in order to facilitate the development of centralised biogas facilities. A key factor in this was the first Fresh Water Action Plan which both limited the nitrogen application rate to land and required manure storage facilities of 6-9 months, hence centralised manure handling became cost effective for farmers. Capital investment grants of between 20 and 40% are available along with low interest long term loans, and power companies have been obliged to buy electricity from biogas facilities at fixed prices. Biogas derived heat and power is exempt from tax and waste that is incinerated is taxed, but not if it is recycled. Despite the existence of these favourable conditions only 1 million of the 40 million tonnes (as produced) of animal manure produced in Denmark was directed to centralised biogas facilities.

### **4.3 Current AD activities in the UK**

This information has been collected through discussion with the people concerned and through information in the public domain, principally on the Internet. The information which was originally sought is as follows:

- description of the process;
- scale of operation / typical unit size;
- nature of end products,
- details of any independent quality testing conducted on process or outputs;
- estimated or actual costs of installation and operation,
- feedstocks handled;
- the nature of any pre-treatment required
- the location of existing facilities or pilot facilities;;
- and any other information you feel is relevant.

Most systems are at an early stage in their development and detailed information about all their operating parameters is not generally in the public domain. The following section outlines the principle players and projects. The advent of Landfill Tax funding has also prompted the development of small pilot or demonstration projects to process the putrescible portion of MSW.

#### **4.31 Greenfinch**

Greenfinch, which has its roots in the now defunct Farm 2000 digestion systems, have undertaken a number of research projects looking at household waste digestion. In 1996 they were awarded a DTI SMART grant for an 18-month project to investigate the feasibility of recycling food waste and sludge by means of a biogas plant. The project also included a novel method of aquaculture for recycling digestate using aquatic weeds and carp. The source of the food waste was the kitchen and plate waste from a café-bar and the sludge was from the public toilets serving the café-bar.

Following the success of the pilot project a second DTI grant was awarded in 1998 to design, build and operate a demonstration digester to recycle kitchen waste from 1500 households in the Ludlow area of South Shropshire. The project period was from October 1999 to April 2001, during which 300 tonnes of kitchen waste were recycled,

producing 42,000 m<sup>3</sup> of biogas. The Greenfinch Biowaste Digester has gained Millennium Product status.

The most recently commenced project (2001) is funded through the Landfill Tax Credit Scheme via Biffaward managed through the SUNRISE Environmental Body. Balancing funding is derived from South Shropshire District Council. It aims to determine whether mesophilic or thermophilic digestion in combination with a high heat phase (<70°C) to stabilise and sanitise kitchen, restaurant and catering waste. For the pilot, 50 households are source separating kitchen waste which is collected weekly and macerated to <10mm prior to digestion in two 1.5m<sup>3</sup> digesters. The project continues to 2003.

#### **4.32 IRW-EFR**

Integrated Research into Waste-Energy Feedstocks and Residuals (IRW-EFR) is a joint venture between AMEC plc and University of Liverpool part-funded by the EU and local industry which commenced in 2001. It is based at the Warrens horticultural nursery belonging to the Metropolitan Borough of Wirral where it mesophilically digests vegetable and plant waste from the nursery and from local households in five 100 m<sup>3</sup> cells. The methane is used to heat both the digester cells and the adjacent greenhouses. The CO<sub>2</sub> is also used in the greenhouses to enhance plant growth and liquors are used as fertiliser. The digestate can be used in the nursery as a peat substitute. A local food processing company also supplies significant amounts of vegetable waste to the facility and is considering installation of a similar system on-site at their factory. The IRW-EFR project had a four year lifespan under its current funding.

#### **4.33 Milbury Systems Ltd**

As one of the two partners in Agtec Ltd, Milbury Systems Ltd won four contracts under NFFO-4 for the digestion of farm wastes. As originally conceived, the projects were two 1MWe and two 0.5 MWe schemes with the provision to take up to 20% food processing wastes on dry matter basis. Their partner in Agtec Ltd, a Norwegian fertiliser company has withdrawn all its operations from the UK since winning the NFFO contracts and consequently, Agtec Ltd was disbanded. Milbury Systems have since sold the NFFO contracts to Independent Green Energy Ltd but retained a controlling interest in the design and build element of the projects. It is probable that the two 0.5 MWe schemes will be combined into one at the same site at Lemming since they were located relatively closely together. The site for the 1MWe scheme based on poultry (layers) waste and food processing (DAF sludge) is no longer available and a new site is being sought for this project. At the present time there is no fixed date for the start up of any of these projects.

Milbury have installed several demonstration schemes overseas, including Japan and Cyprus and are generally finding that AD is more readily accepted outside the UK. They own a 150t (m<sup>3</sup>) test digester located near Lemming which can be used to test different waste mixes prior to the design and build of a full scale system.

Six agricultural waste projects won contracts under NFFO-4. In addition to the four owned by Milbury Systems, LRZ Ltd and by North Tamar Business Network both obtained contracts. No information about these schemes has been obtained.

#### **4.34 Holsworthy Biogas Ltd:**

The Holsworthy project which commenced in October 2001, is joint funded by the German firm Farmatic Ltd and the EU to the tune of £3.5 million each, with £50,000 of the £7.5 million coming from Torrington District Council. This is the UK's first centralised anaerobic digestion scheme along the lines of that widely operated in Denmark (see case study 4). Thirty farms are providing dairy slurry to the scheme which requires 150,000 tonnes per year, or 400 tons per day. Food processing wastes will also be supplied to the project. Biogas fuelled turbines will supply 1.7MWe to the National Grid while hot water is supplied to local houses and public buildings via a district heating scheme. The stabilised digestate will be returned via tankers which ideally will be fuelled by biogas, to the participating farms for land application. Plans also exist for, the town of North Tawton 20 miles away to use farm wastes and leftovers from the local cheese factory to supply 5.25 MWe via AD, enough electricity to power the entire town.

A DEFRA funded Life Cycle Assessment project based on the Holsworthy scheme is being undertaken by the Silsoe Research Institute and is looking at the environmental benefits and impacts of such schemes.

#### **4.35 Bioplex Portagester**

The portagester system has been developed by Bioplex Ltd with the support of a DTI Biowise grant. Waste is loaded into a mobile tank which is transported to the site of a static digester. Liquor containing microbial biomass is added to the waste and heated to 70°C for one hour then digested thermophilically for 3 days. The liquor is then drawn off and further digested in a static tank. The solid remaining in the mobile unit is tipped out for air drying and maturation. The volatile fraction is now contained in the liquor and the solids can be regarded as stabilised. It can be seen as a centralised AD facility where the transport system also forms part of the treatment infrastructure, thereby reducing the need for expensive infrastructure.. The system is essentially a small scale, wet batch reactor. It has the advantage both of pasteurising the waste and therefore meeting standards for pathogen kill and being viable for small quantities of waste. The portagester only exists in a pilot scale at present, though there are efforts to put a demonstration project in place.

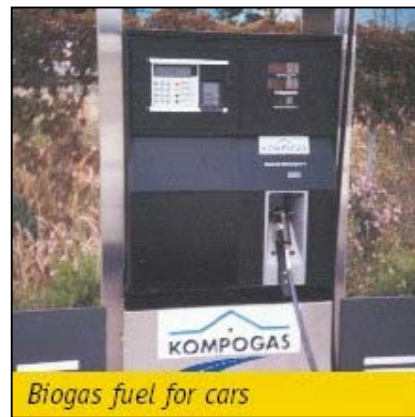
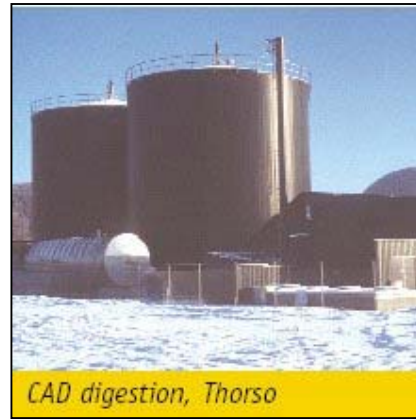
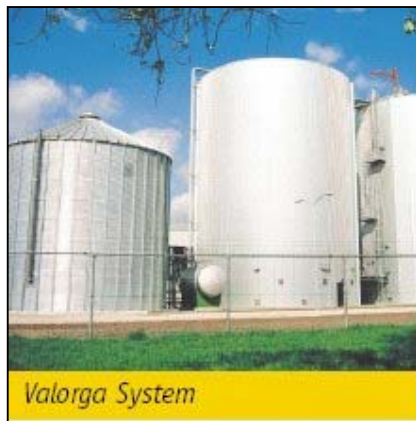
#### **4.36 Thames Waste Management Ltd**

TMW have been involved in trialling the digestion of municipal and industrial wastes in isolation and with sewage sludge for about 10 years. Full scale trials were undertaken at Maple Cross treatment works and a pilot facility developed at Rye Meads STW. A range of industrial organic wastes are now routinely co-digested at Rye Meads.

Thames Waste Management has signed a 25 year contract with Mercia Waste Management Ltd to recycle 35,000 tonnes per year biodegradable household waste from Herefordshire Unitary Authority and Worcestershire County Council. This material is to be co-digested with sewage sludge at the Oxford Sandford Treatment works. This will be the first commercial scale digestion facility handling MSW putrescibles when it comes on line in the autumn of 2004. Household waste is to be mechanically separated, slurried then screened to remove the non-digestible fraction.

A continuous feed, mesophilic system aiming at 16 days retention time will be employed.

Thames Waste management are keen to develop additional digestion schemes ranging in size from small – 10m<sup>3</sup> to 150m<sup>3</sup> or approximately 60kWe to 1 MWe. Small scale schemes of <30m<sup>3</sup> (10,000 t annually) can be housed in inexpensive glass fibre tanks. Above that size, significant investment in civil engineering is required and projects need to be relatively large to operate economically. Co-digestion with sewage sludge may overcome cost issues associated with intermediate size schemes until there is generally wider adoption of the technology.



Source: 'Biogas and More' IEA

## 5.0 CONCLUSIONS

In the first OWSEP report, two main categories of biomass wastes were identified in the Thames Valley; these were, dry (mostly wood derived) wastes and 'wet' wastes such as kitchen wastes. In this report we have reviewed the technologies for converting these wastes into useful energy in the form of heat or electricity and also considered the technologies for producing liquid biofuels. The conclusions from this review are outlined below.

### ***5.1 Thermal Techniques for Converting Dry Wastes***

Three distinct technologies have been considered to produce useful energy from 'dry' wastes, these are:

- Direct combustion
- Gasification
- Pyrolysis

Direct combustion of dry biomass to provide space-heating or even steam for process heating is well developed and modern systems achieve high conversion efficiencies and clean gas emissions. Where there is an application for space heating, combustion is the obvious choice.

At the domestic scale, logs burned in properly designed stoves (but not open fires) can be an effective and efficient means of space heating. More automatic and convenient space heating at a domestic scale can be achieved by processing the woody feedstock to produce pellets though there is no effective infrastructure in the UK at present. On farms where mechanical handlers are commonplace, batch fired boilers offer potential for heating large buildings or a number of buildings on a heating main using straw bales or wood.

At a larger scale, wood chip boilers from a few hundred kW up to a few MW offer a practical, automated approach to space heating. In parts of continental Europe and in Scandinavia, such units are commonplace for heating anything from individual buildings up to whole towns via district heating networks. There are no technical barriers to the establishment of such systems in the UK and there are a number of good examples in the UK (see case study 1).

When converting dry biomass to heat, efficiencies of 70-80% are achievable using modern equipment. When converting to electricity only, efficiencies are much lower; at the small scale efficiencies of only 10-25% can be achieved. From an efficiency point of view, the best option when converting biomass to electricity is to find application where the waste heat can be used. These are 'so called' combined heat and power (CHP) systems where efficiencies above 70% can be achieved.

In order to produce electricity from biomass, the traditional route is to use steam cycle power plants working on the same principle as those to produce electricity from coal at a huge scale. Biomass plants producing electricity using this technique at a scale around 30 MW can produce electricity at an efficiency of over 30%. However, at the

small scale (a few hundred kW) efficiencies can be as low as 10%. This is where the 'advanced' conversion technologies of gasification and pyrolysis come in. These technologies have the potential to deliver higher electrical efficiencies at the small scale. There are now a few 'demonstration' projects in the UK (e.g. the 10MW ARBRE project and the BedZED project – case study 2) but the technologies can not yet be regarded as fully commercial.

## **5.2 Liquid Biofuels**

Liquid biofuels for transport, electricity and heat production offer the convenience of petroleum oil fuels. Biodiesel can be produced from virgin vegetable oil or even from waste cooking oil by the fairly simple process of transesterification. Biodiesel is already being produced from waste cooking oil and sold as a blend with fossil diesel on garage forecourts in the UK where it attracts a 20p/l reduction in road tax duty. It may soon become even cheaper to produce if a proposed ban on including this waste in animal feed is implemented

Bioethanol is derived from biomass feedstocks containing sugar or starch. The process is very similar to that used by brewers to produce potable alcohol and has been used on an industrial scale and is being used elsewhere in the world (e.g. Brazil and the USA) to produce a bioethanol which is added to petrol for transport use. The UK would be well placed to produce bioethanol from sugar beet (or even potatoes or grain) by expanding the infrastructure currently used to produce sugar. However the tax break for biodiesel used as a transport fuel does not currently apply to bioethanol and it needs around 30p/l tax break to compete with oil based transport fuels.

Bioethanol can also be produced from a process using enzyme hydrolysis to convert biomass into sugars. This is the process used by the Canadian company, Iogen Corporation, who are potentially interested in setting up a plant in the Thames Valley.

## **5.3 Anaerobic Digestion**

Anaerobic Digestion (AD) is the biological process used produce a biogas (methane) from wet biomass slurries such as animal waste, sewage food processing waste and the putrescible portion of household waste.

The technology is well established and has been used for many years in this county and abroad as a means of processing difficult wastes and producing a useful fuel gas as a by-product. The waste, once processed through a digester tank is easier to handle, has little odour and can, under the right circumstances be used as a soil improver or peat substitute.

The technology for processing wet biomass wastes through anaerobic digesters is well understood and there is now a great deal of experience of running sewage sludge digesters successfully at a commercial scale. Small farm scale digesters, on the other hand, have not often been successful; many of those that have been installed over the last 3 decades are now unused.

In the UK, there are well established anaerobic digesters used to process sewage with the resulting biogas used to run engines and generate electricity under the premium price mechanisms that currently exist for 'renewable' electricity. There is potential to build on this base and process other appropriate wet wastes through these and possible new digesters.

The barrier to expansion of successful AD projects in the UK is not a technological one but usually a management or financial one. The amount of fuel gas is relatively small, both in terms of quantity as a proportion of the waste processed and in relation to the overall finances of the project. AD projects need to be considered primarily as waste processing facilities with renewable energy as a by-product. Most successful schemes work financially because they are paid to process the waste and because the processed material has some ready outlet; not because the power generated is lucrative.

### **5.4 Project Prospects**

Emerging from the work carried out so far for the OWSEP project are two main potential projects and coincidentally these fit into the two technology types described above.

The first is a project to with Slough Borough Council and Thames Waste Management to anaerobically digest the organic kitchen waste from domestic collections. In order to go ahead with this project TV Energy has held discussions with both TWM and Slough Borough Council and has come up with an outline plan for the project.

A supermarket chain has been approached with regards to using their green waste from the stores in the digesters at Slough Sewage Treatment Works. While this waste will be codigested with the sewage sludge, a scheme to identify suitable collection strategies for the Slough area will be implemented. A trial will hopefully be set up for a limited number of houses and the waste collected will be assessed for quality and presence of foreign objects. As part of the trial the education of the households will be vital to ensure they know exactly what can and can't go into a digester. The first few collections will probably go to the sewage works for assessment to prove that a consistent and reliable fuel source can be provided and will then go to landfill. Only when the reliability of the fuel has been proven will it then go into the digester with the supermarket waste.

Of longer term importance to supermarkets' acceptance is the need to get the 'image' of any initiative correct. Some supermarkets are very sensitive to their green waste being processed with human waste. Hence, it may be necessary to have a separate digester facility alongside another (sewage) works where it can share energy infrastructure yet still have a separate processing, entry/exit and identity. The digestate from a separate digester can then be marketed on a different and 'cleaner' basis.

The project is currently in the outline stage and nothing is currently set in stone. Potentially the project could stop at codigestion but if enough organic feedstock is available a separate digester may be the ideal route.

The second project relates to growing short rotation coppice on a landfill site at Newton Longville, near Milton Keynes, for eventual combustion in the proposed 40MW facility on-site or in other user projects (e.g. small scale boilers/ CHP – gasifiers). TV Energy is in the process of establishing a Thames Valley wide ‘producer group’ to get the wood fuel supply infrastructure in place. Part of this action will relate to accessing arboricultural material (green waste) from civic amenity sites for blending with coppice and other biomass material.

This initiative offers the opportunity to carry out comparative studies between new crop established both on and off the landfill, vertically integrated fuel supply strategies drawing in the maximum of green waste material and combustion studies. Partners are likely to be drawn from University of Reading and Cranfield, Shanks Waste Solutions, Fullers Group and B9 (developer and equipment supplier).

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