CRANFIELD UNIVERSITY

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Renewable Energy, Landfill Gas and EfW: Now, Next and Future

School of Applied Sciences

MSc Thesis

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MSc Thesis

Academic Year 2008-2009

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September 2009

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science

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Abstract

The United Kingdom (UK) has traditionally used landfill disposal as the predominant method of waste management. However, landfilling is unsustainable due to its harmful effects on the environment and public health. Under the European Union (EU) Landfill Directive (LFD), member nations are now required to divert biodegradable municipal waste (BMW) from landfills. At the same time, the UK has committed to the EU Renewable Energy Directive, which binds it to sourcing at least 15% of its energy mix from renewables by 2020. To meet these targets, the UK has to support alternative waste management options whilst achieving a considerable deployment of renewable energy technologies. The uptake of renewables displaces the use of fossil fuels and is important for climate change mitigation and future energy security. This research reviews the development of landfill gas utilisation and energy from waste (EfW) technologies as renewable energy sources in UK. The drivers, barriers and future trends of these technologies are also considered.

The main findings of this study are that the most cost-beneficial EfW applications for the UK are: 1) Biomethane use as road transport fuel and 2) Small-scale EfW deployment at community level. These two options are easily implementable and would result in substantial savings in carbon-dioxide (CO_2) emissions. Landfill gas (LFG) utilisation is currently the most important source of UK renewable energy but outputs of LFG would decline due to impact of the LFD. It is therefore crucial that the UK develops the capacity of other renewables. This study concludes that EfW technologies can contribute up to 50% of UK renewables target by 2020. However, actual results would depend on the pace of investment in EfW projects and the availability of suitable feedstock.

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Abbreviations

ABPR	Animal By-Product Regulations
AD	Anaerobic Digestion
BMW	Biodegradable Municipal Solid Waste
BOD	Biological Oxygen Demand
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
EfW	Energy from Waste
EU	European Union
FIT	Feed-in Tariff
GHG	Greenhouse Gas
H_2	Hydrogen
LATS	Landfill Allowance Trading Scheme
LFD	Landfill Directive
LFG	Landfill Gas
MSW	Municipal Solid Waste
NFFO	Non Fossil Fuel Obligation
NGV	Natural Gas Vehicle
ORED	Office of Renewable Energy Deployment
RAB	Renewables Advisory Board
RO	Renewable Obligation
ROC	Renewable Obligation Certificate
RHI	Renewable Heat Incentive
RTFO	Renewable Transport Fuel Obligation
UK	United Kingdom

Units

g	Gramme
kg	Kilogramme
KWh	Kilowatt hour
MJ	MegaJoules (i.e. 10^6 Joules)
Mtoe	Million tonnes of oil equivalent
MWh	Megawatt hour
m^3	Cubic metres
Nm^3	Normal cubic metres (i.e. volume of a gas, in cubic metres, measured at 0˚C and pressure of 1 atmosphere)
TWh	Terrawatt hour

Acknowledgements

This research was conducted as part of The Chartered Institution of Wastes Management (CIWM) Geotech Award 2009. The author is therefore grateful to the award sponsors, Geotechnical Instruments (UK) Limited and CIWM. I am indebted to my supervisors, Dr. Frédéric Coulon and Dr. Raffaella Villa for their guidance and dedication to this project. Many thanks to the lecturers and staff of the Cranfield Centre for Resource Management and Efficiency (CRME) for their help throughout the course. I was blessed to have met so many wonderful people, from all over the world, at Cranfield. They helped to make this journey so much better and for that, I owe them gratitude. My thanks also go to everyone who contributed invaluable information and advice to this research. Finally, to my wife, Akua and daughter, Afia, who have made sacrifices to enable me to do this, I am forever grateful.

1. Introduction

Renewable energy sources, including solar, tidal, wind and geothermal, occur naturally and continuously in the environment (BERR, 2009). The resurgent interest in renewable energy has been underpinned by three main factors:

i) The global drive towards sustainable development and resource efficiency as enshrined in the Millennium Development Goals (MDG) (UN, 2009).
ii) Reduction of anthropogenic greenhouse gas (GHG) emissions, in line with the Kyoto Protocol (EU, 2009).
iii) Displacement of fossil fuels as a source of energy. Global oil production has peaked and is declining (DTI, 2007). To ensure future energy security, investment in alternative sources of energy is essential.

In his “Economics of Climate Change” review, Lord Stern (2007) warns that unless decisive action is taken to reduce emissions, the amount of GHGs in the atmosphere may reach double its pre-industrial level by 2035. This would account for an average global temperature rise of between 2 and 5^{o}C with serious economic and environmental consequences. In “Climate Change Projections” (2009), the UK Department for Food and Rural Affairs (DEFRA) presents a similarly bleak outlook.

To reduce reliance on fossil fuels and mitigate anthropogenic climate change impacts, the European Union (EU) has recently promulgated the Renewable Energy Directive, which commits the EU to deriving at least 20% of total energy requirements from renewable sources by 2020. By signing up to the Renewables Directive, the UK government agreed to contribute its share of sourcing 15% of its energy from renewables by 2020 (House of Lords, 2008). To meet this target would require a seven-fold increase on the contribution of 2.25% that renewables currently make to overall UK energy mix (DECC, 2009b). Fig. 1 illustrates the percentage share of overall inland energy derived from renewable sources for EU member countries in 2005. It shows that the UK falls into the group with the lowest adoption of renewables.

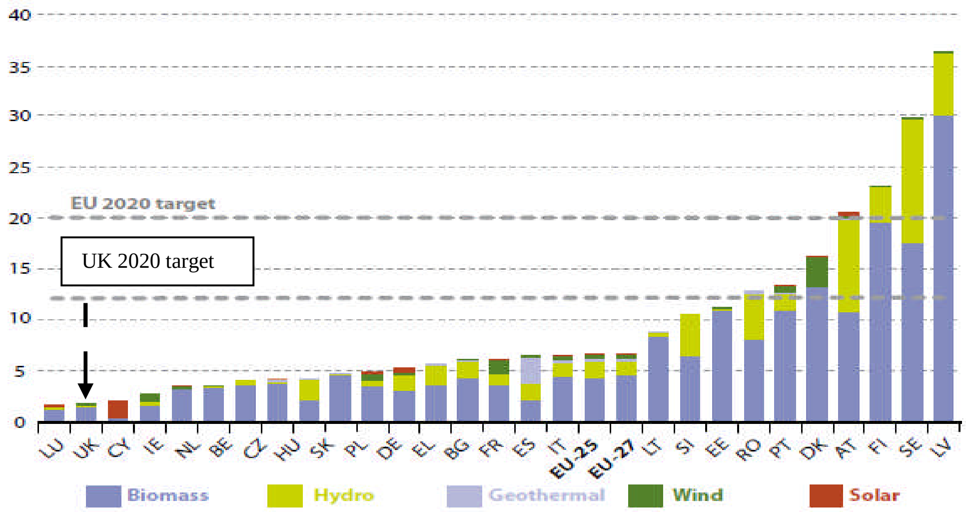

Fig. 1: Percentage share of renewables in overall inland energy consumption in 2005 [Adapted from: (European Commission, 2007)]

Total UK energy demand by 2020, with high energy efficiency measures implemented, has been forecast to be about 150 million tonnes of oil equivalent (Mtoe) (RAB, 2008). To ramp up much-needed investments in renewable energy generation, the UK government has introduced a suite of policy initiatives and incentive schemes. In 2002, the Renewables Obligation (RO) replaced the Non-Fossil Fuel Obligation (NFFO) as the main support mechanism for renewable energy generation (Bogner et al, 2007). RO obliges energy providers to produce a specified minimum of their total output from renewable sources.

Under the RO, Renewable Obligation Certificates (ROCs) were introduced as tradeable units with each ROC representing 1MWh of renewable energy produced. ROCs were later “banded” to offer extra incentive for development of emerging renewable energy technologies. Thus far, the impact of the ROC scheme on the renewable energy sector has divided opinions. Whilst the introduction of ROCs has encouraged investment in renewables (Fig. 2), opponents argue that the uncertainties around the award of ROCs may discourage long-term investments. Some in the renewable energy sector would prefer the blanket introduction of feed-in tariffs (FITs) as used effectively in Germany (Environmental Data Services, 2009a; House of Lords, 2008).

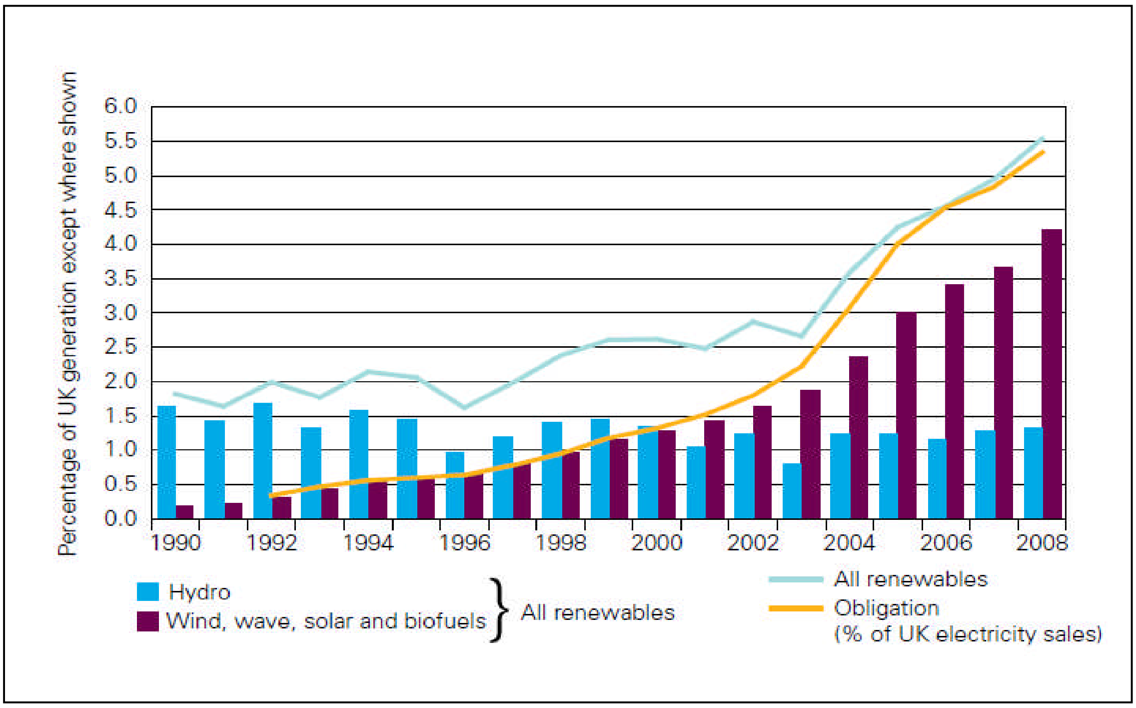

Fig. 2. Impact of Renewables Obligation on Adoption of Renewable Technologies (Source: DECC, 2009a)

Whilst acknowledging the benefits of renewable energy, many observers are skeptical about the UK's ability to achieve its targets agreed under the Renewables Directive (House of Lords, 2008; Tromans, 2009a). However in its '20 by 2020' report, the UK House of Lords' EU Committee (2008) is cautiously optimistic. The Lords' Committee justified their endorsement by arguing that without the adoption of set targets, it would be impossible to generate the momentum needed to change the culture of reliance on fossil fuels. They, however, cautioned against the concentration on technologies like wind power and advised that a diverse portfolio of renewable technologies have to be supported and deployed.

The UK Government began consultations on a Renewable Energy Strategy (RES) in June 2008 (BERR, 2008). Some of the main proposals put forward by the consultation document were:

- extending and increasing the Renewable Obligations;
- new financial incentives for renewable heat;

- increased support mechanisms for small-scale power generation and distributed energy;
- removing barriers to grid connection for renewables;
- reducing planning bottlenecks and aligning local planning requirements with national policy on renewables deployment;
- exploiting the full potential of biomass and energy from waste (EfW) technologies.

The UK RES was published on 15th July 2009, providing the framework for increasing adoption of renewables. It contends that, in addition to providing clean energy, the deployment of renewable energy technologies in UK can also create up to 500,000 new jobs by 2020 (DECC, 2009a).

2. Objectives

The specific objectives of this research are as follows:

- To provide an overview of renewable energy, landfill gas and EfW in UK.
- To identify the market, key players and drivers for EfW and renewables in UK.
- To identify barriers to EfW technology development and up-take.
- To discuss current legislation, trends and technologies.
- To give a forecast of future trends, technologies, markets and drivers.

In the consideration of renewable energy, the research has been confined to the use of wastes or waste-related products. Whilst every attempt has been made to incorporate a global perspective, the themes of this work have been considered mainly in the context of the UK. This research will provide useful insight for all stakeholders in the areas of renewable energy, landfill gas management and EfW.

3. Literature Review

3.1 Waste Management in UK

The use of waste as a resource in Europe was first proposed in the Waste Framework Directive of 1975 (Evers, 2009; Williams, 2005). The concept of the waste hierarchy was also developed to help and support decision makers to adopt more sustainable treatment options wherever practicable. The use of waste as a source of renewable energy addresses two of the most important contemporary issues facing mankind today i.e. waste management and energy security (Evans, 2001). The generation of energy from waste is an important part of the UK's Biomass Strategy (DEFRA, 2007a) and is again highlighted in the UK Energy White Paper (DTI, 2007a).

The use of waste as a source of renewable energy confers the following advantages:

- It reduces the emission of GHGs compared with landfilling and is consistent with the global transition towards low-carbon economies.
- It ensures diversity of energy supply and contributes to future energy security. Almost all other sources of renewable energy depend to some extent on weather conditions for power output. Waste, on the other hand, would always be produced as a result of human activities.
- It results in resource efficiency. Instead of disposing of wastes in landfills- with adverse environmental effects - energy is derived from it.
- It acts as a powerful driver for more sustainable waste treatment technologies based on the waste hierarchy.
- Unlike fossil fuels, waste production is ubiquitous. This makes wastes particularly suited to community level or micro-generation EfW projects.

The UK has historically disposed of most of its wastes in landfills partly due to the prevalence of non-porous, clay-rich sub-strata (Mullis, 2007). Fig. 3 (DEFRA, 2006) shows how UK municipal solid waste (MSW) was managed in 2005/06. Landfilling has also been used to fill holes left by mineral extraction works. However, with the passage of the EU Waste Landfill Directive (LFD) (Council Directive 1999/31/EC), alternative treatment options had to be adopted (Williams, 2005).

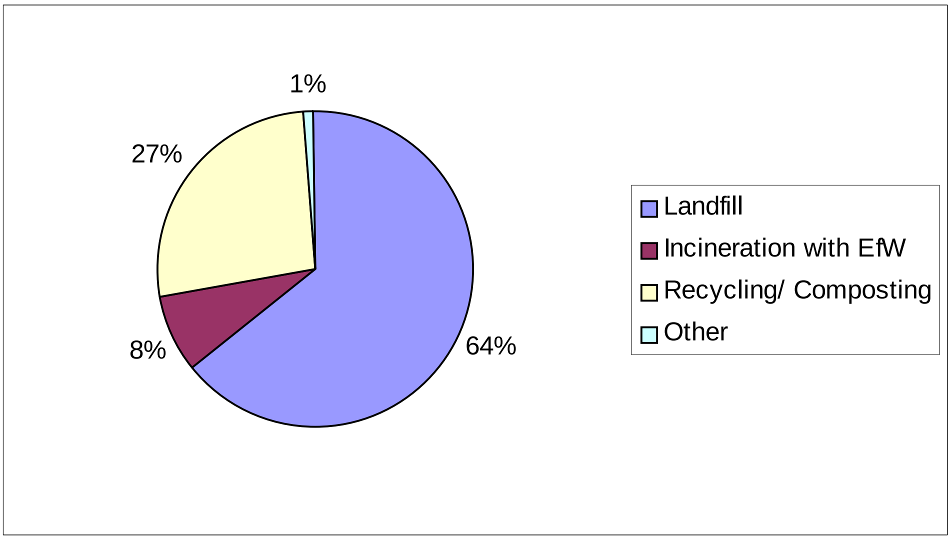

Fig. 3: UK MSW Management in 2005/06

To encourage investment in more sustainable waste management technologies, the UK government has raised the landfill tax by an annual escalator of £8 per tonne from 2008. The Landfill Allowance Trading Scheme (LATS) was also introduced under which, local authorities exceeding their landfill allowance would be charged a penalty of £150 per tonne of biodegradable matter. Meanwhile, investors in alternative treatment technologies have benefited from UK Government Capital Grants disbursed through the Waste & Resource Action Programme (WRAP). These and other drivers of renewable energy and EfW are discussed in more detail later in this document. The predominant use of landfilling has made the recovery and utilisation of landfill gas (LFG) for energy, a significant contributor to UK's current renewable energy output.

3.2 Landfill Gas

LFG is produced by the microbially mediated degradation of organic matter under anaerobic conditions within landfills. It consists mainly of methane (CH_4) and carbon dioxide (CO_2). Table 1 (Cheremisinoff, 2003) shows the typical composition of LFG.

Table 1: Typical Composition of LFG

Constituent Gas	**Concentration in LFG**	
	Range	**Average**
Methane (CH_4)	35- 60 %	50 %
Carbon dioxide (CO_2)	35- 55 %	45 %
Nitrogen (N_2)	0- 20 %	5 %
Oxygen (O_2)	0- 2.5 %	< 1 %
Hydrogen Sulphide (H_2S)	1- 1,700 ppmv	21 ppmv
Halides	NA	132 ppmv
Water vapour (H_2O)	1- 10 %	NA
NMOCs	237- 14,292 ppmv	2,700 ppmv

Notes: ppmv = parts per million by volume; NA = data not available

NMOCs = nonmethane organic compounds (assorted contaminants)

Although most landfill gas production occurs within 20 years after completion, background emissions may continue for several decades (Zamorano et al, 2007). Even in landfills with efficient collection systems, about 25% of the LFG is lost to the atmosphere during operational stages and before final capping of the waste. Barry et al (2003) found that lateral emissions via side slopes were much higher than vertical emissions from top of waste. Consequently, landfills contribute about 40% of overall UK methane emissions and 3% of all UK GHG emissions (DEFRA, 2007b). As a GHG, methane is about 23 times more than carbon dioxide (IPCC, 2001). In addition to its adverse effects as a GHG, methane can cause explosions within its explosive limits of 5-15% by volume (Cheremisinoff, 2003).
Under the Climate Impacts Programme, the UK government has set guidelines for the management of GHG emissions from landfills (Barry et al, 2003).

The recovery and utilisation of LFG as source of energy achieves both a reduction in climate change impacts and greater energy security. Landfill gas has been used for production of energy on a commercial scale since 1975 (Bogner et al, 2007). Typical calorific values for undiluted landfill gas ranges between 15 and 21 MJ/m^3 compared with calorific value of about 37 MJ/m^3 for natural gas (Williams, 2005). LFG is currently the single most important source of renewable energy in the UK. According to Jamasb et al (2008), about 29% of all ROCs issued in 2005/2006 were for landfill gas. LFG may be used to generate electricity for site operations and any surplus can be sold to the national grid. In addition to electricity, LFG may be used in district heating schemes i.e. combined heat and power (CHP). LFG can also be upgraded into biomethane for use as road transport fuel or as chemical feedstock (Persson et al, 2007).

The barriers to the uptake of landfill gas utilisation include:

- High cost of gas collection and purification.
- Need to manage LFG cleaning residues especially where wet scrubbing is employed.
- Fouling of engines and plants using LFG resulting in reduced plant availability.
- The reduction and potential removal of ROCs from LFG.

In addition to the above-mentioned barriers, increased diversion of biodegradable wastes from landfills- as a result of the LFD- would result in reduced outputs of LFG in future (Hall et al, 2005). There would also be significant changes to the composition of landfilled waste, due to increased recycling and pre-treatment of waste. Landfilled waste could consist mostly of waste treatment residues such as incinerator bottom ash (IBA) and air pollution control (APC) residues. This waste is likely to have a high inorganic fraction and significant concentration of hazardous substances (Hall et al, 2005), which may have a suppressive effect on anaerobic micro-organisms responsible for methanogenesis (methane formation).

Contrary to the widely accepted view that the UK is running out of landfill space, there is still considerable scope for landfill site development due to ongoing mining and quarrying operations. However, there is a shortage in the number of operators willing to apply for landfill management licences. The reasons for this include the stricter environmental control of emissions and increasing landfill tax. One study (Hall et al, 2004) estimates it may take up to several hundred years for some landfills to reach equilibrium i.e. when environmental emissions are not significant enough to warrant continued management. Furthermore, with rising landfill gate fees, alternative treatment options such as anaerobic digestion (AD) and combustion are increasingly becoming competitive. Looking ahead, it is reasonable to predict a decline in the utilisation of LFG as a renewable energy source. This is based on reduced outputs due to the LFD as well as competition from alternative EfW technologies.

3.3 Energy from Waste (EfW)

Waste management has changed from a disposal problem to a resource optimisation opportunity. Governments worldwide are adopting more sustainable waste treatment based on the hierarchy of waste management (Bogner et al, 2007). Where wastes cannot be reasonably recycled or reused, energy recovery from the waste is considered. EfW - also referred to as waste-to-energy (WtE)- technologies can be grouped into two main categories: biological and thermal processes (Fig. 4). The former include anaerobic digestion (AD), bio-hydrogen and biofuel production from waste whilst the latter consists of conventional mass burn incineration and advanced thermal processes such as gasification, pyrolysis and plasma technology. It is worth noting that in some literature, EfW is frequently used somewhat erroneously to refer to only incineration of waste.

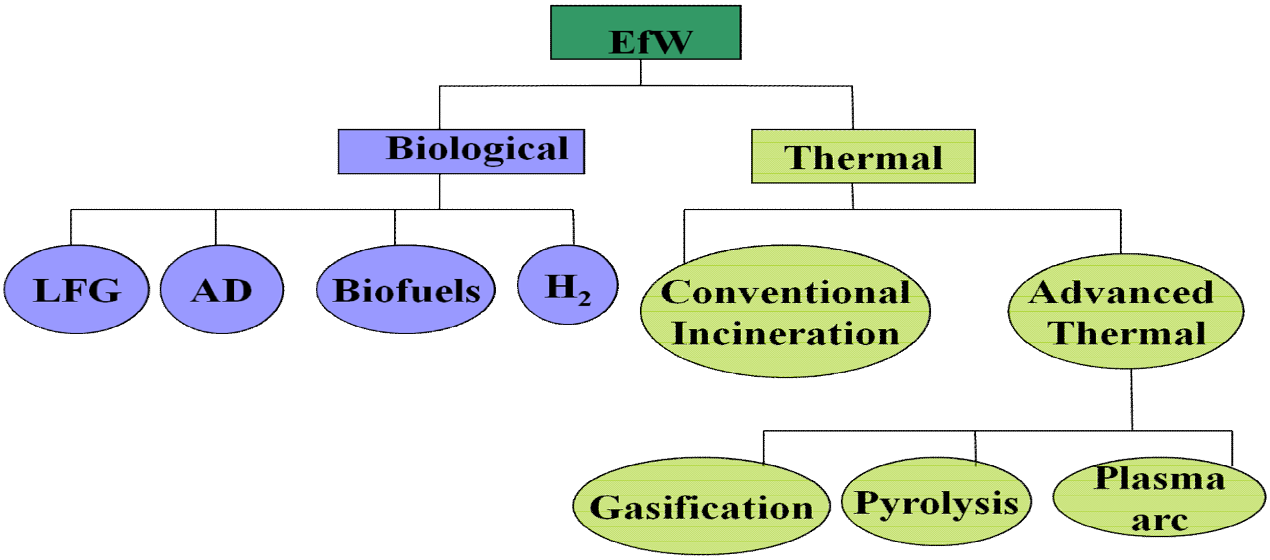

Fig. 4: EfW Technologies

3.3.1 Anaerobic Digestion (AD)

AD replicates the degradation of organic matter in landfills to produce biogas- a mixture of methane and carbon dioxide. The main difference is that with AD, unlike in landfills, this process takes place in an enclosed reactor. This allows process parameters such as temperature and pH to be closely controlled and avoids ingress of air. In addition to biogas, other useful products from the AD process include a compost-like output called digestate and liquid soil conditioner (Appendix 1). The advantage of having a ‘containerised’ process is that the degradation process takes a much shorter time (usually 2- 4 weeks) as opposed to a few years in typical landfills (McLanaghan, 2002). Another advantage of the AD process is that almost all of the biogas produced can be collected for use as fuel. In contrast, landfill gas collection efficiencies are generally lower (i.e. maximum of 50%) (Williams, 2005).

Compared to landfill, treating a tonne of food waste by AD would save between 0.5 and 1 tonne of CO_2 equivalent in emissions (DEFRA, 2009b). A study carried out by Eunomia and EnviroCentre reports that when used after a mechanical sorting stage, anaerobic digestion has the lowest carbon footprint of all the major residual waste treatment technologies (Environmental Data Services, 2008a). The adoption of AD technology has been driven by the LFD targets for diversion of biodegradable waste from landfill. To encourage investment in AD, the UK government has made grants available to cover up to 30% of capital costs under the WRAP Organics Grants scheme. Also, energy produced by AD currently qualifies for double ROCs per MWh (OFGEM, 2009).

The barriers to the commercial application of AD technology in the UK include the following:

- High capital and operating costs compared to composting. These are partly attributable to the need for effective gas seals to prevent ingress of air, which may limit the activity of anaerobes. Also the biogas has to be stored and handled in a manner that prevents potential explosions from methane gas (Evans, 2001).
- The anaerobic organisms involved in the process are highly sensitive to changes in their environment. Operators have to ensure that feedstock

complies with the specifications of the plant design. Otherwise, process failure may occur.

- The spent liquor- with high biological oxygen (BOD) and chemical oxygen demand (COD) - has to be disposed off in an environmentally benign way. There is the potential for pollution of groundwater from leaks and improper disposal. Some plant designs have attempted to address this problem by treating the wastewater and feeding it back into the front end. However this recycling cannot go on indefinitely without concentrating some heavy metals and potentially causing process failure.
- There is a lack of developed markets for digestate and liquid fertiliser. For digestate to meet the AD Quality Protocol for land application, the feedstock has to be obtained from source-segregated organic waste (Environment Agency, 2008). For some feedstock there is also the added requirement to comply with Animal By-Product Regulations (ABPR) (2005). The source-segregation of organic waste has considerable cost implications for local authorities and usually result in increased waste collection traffic.
- The continued use of AD digestate for land application in UK may be constrained by the limited amount of agricultural land that can receive further organic matter (Environmental Data Services, 2009b).

Still, AD is enjoying immense popularity as the best practicable option for the treatment of organic waste. Appendix 2 shows some treatment pathways for biodegradable wastes. A challenge for AD operators in the medium to long term may be the reduced availability of process feedstock. As more and more local authorities and private investors embrace the technology, a point may be reached in the future when there may not be enough suitable organic input material to go round. This scenario would be realised even earlier with a boom in home-composting schemes.

There is potential for the estimated 30% spare capacity at wastewater treatment works to be utilised for co-digestion of organic waste with sewage sludge. However, Sweenie (2009) found that regulatory and financial complexities would continue to impede co-digestion in the UK for the foreseeable future.

3.3.2 Bio-Hydrogen

Bio-hydrogen production from waste remains an area of huge but yet untapped potential. Fuel cells powered by hydrogen produced from renewable sources have several benefits. For example, fuel cells have lower maintenance costs because they have very few moving parts. Sperrey (2008) explains that hydrogen fuel cells are significantly more efficient than diesel generators- about 50% of the energy content of the hydrogen is converted into electricity. The ‘green’ credentials of this technology are buoyed by the fact that the only emissions from it are water and heat.

However, bio-hydrogen technology is still being developed and may take several years of research and investment before it can be delivered as a viable commercial-scale option (Mullis, 2007). Justifying the reduction of Federal hydrogen fuel cell research budget for 2010 by $100m, US Energy Secretary Stephen Chu said “We asked ourselves, ‘Is it likely in the next 10, 15, 20 years that we will revert to a hydrogen economy?’ The answer, we felt, was ‘no’.” (RSC, 2009a). Mr Chu’s assessment echoes the reference projection of the World Energy Outlook 2008 (IEA, 2008). This International Energy Agency (IEA) document projects that if current trends persist, about 80% of global energy supply would still be derived from fossil fuels in 2030.

The main constraint in the adoption of hydrogen fuel cell technology for transportation is its extremely low density (Sperrey, 2008), which makes it necessary to greatly compress it for use in fuel tanks. Apart from the technological and financial barriers to be overcome, there are also some public safety concerns over the use of hydrogen fuel cell technology in road vehicles. The technology is perceived by some members of the public as being fraught with risk and uncertainty. Although hydrogen has been used safely on an industrial scale for many years, associations with the Hindenburg airship disaster and the hydrogen bomb have fostered negative perceptions about its safety in cars (Binner, 2008). At present, the primary source of hydrogen for fuel cells is natural gas. This process is evidently unsustainable and research is ongoing to find cheaper and more environmentally friendly sources of hydrogen. One pathway of significant potential is the splitting of water (Birch, 2008) but the technique has not been mastered yet.

Pathways for production of hydrogen from waste include:

- Catalytic combustion of methane: chemists at the University of Amsterdam have discovered a pathway of producing hydrogen from combustion of methane using catalysts based on ceria (CeO_2) (Brindley, 2009);
- From Glycerine: glycerine is a by-product of bio-diesel production and has hitherto, presented a disposal burden for bio-diesel producers. A pathway has now been found for converting glycerine into hydrogen gas eg. the Linde Group plans to build a demonstration plant in Leuna, Germany that will convert glycerine into a hydrogen-rich gas mix. This H_2 will then be purified and liquefied (RSC, 2009b);
- From degradation of organic matter: hydrogen gas (H_2) is released during the breakdown of organic matter under anaerobic conditions, as shown in reactions equations (1), (2) and (3) below:

  $C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 4H_2 + 2CO_2$ ------- (1)

  Glucose Water Acetic acid carbon dioxide

  $C_6H_{12}O_6 \longrightarrow CH_3C_2H_4COOH + 2H_2 + 2CO_2$ ---------- (2)

  Propionic acid

  $CH_3CH_2OH + H_2O \longrightarrow CH_3COOH + 2H_2$ ------------------------- (3)

  Ethanol

  This hydrogen may react to form methane gas (CH_4) as shown in reactions (4) and (5) below:

  $4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$ --------------------------------- (4)

  $CH_3OH + H_2 \longrightarrow CH_4 + H_2O$ --------------------------------- (5)

  Methanol

  However, the hydrogen gas can be collected before the formation of methane.

Although hydrogen technology is considered as ‘fuel of the future’, recent advances in the storage and transport of hydrogen have increased the feasibility of its commercial application as transport fuel (Crombie, 2009). These include:

- Scientists at Nottingham University have made a porous solid with significant increases in hydrogen storage capacity. The solid is a copper (II) based metal-organic polymer and can adsorb 10 percent by weight (wt%) hydrogen;

- A research team at the Academy of Sciences, Shenyang, China have discovered that hydrogen release from ammonia borane is increased by milling with magnesium hydride. Ammonia borane has been known to have unusually high storage capacity for hydrogen but also a slow discharge rate.

Encouragingly, a number of firms have introduced prototypes of hydrogen-powered vehicles. On June 16th 2008, Japanese automaker Honda announced the first commercial production of a hydrogen-powered car called FCX Clarity. Exactly a year later, a firm called Riversimple launched a prototype H_2 car in London, UK. According to its developers, this model can travel at 50 mph and would have a range of about 200 miles. However, the most important statistic, from the customer's point of view, is that it can achieve a whopping 300 miles to a gallon in fuel economy (Palmer, 2009). When hydrogen cars are rolled-out, adequate refuelling points have to be installed to encourage patronage. Research and development (R&D) work is taking place worldwide but it remains to be seen if the much-anticipated transition to a hydrogen-economy (Binner, 2008) will ever be realised. Curiously, very little consideration is being given by proponents to the global warming potential of water vapour, which is released from H_2 engines. Water vapour is the most abundant GHG in the atmosphere but it is not listed among the six GHGs identified by the Kyoto Protocol. This is probably due to its short life cycle in the atmosphere (Chandler, 2007).

3.3.3 Biofuels

Biofuels are liquid transport fuels, which are derived from the degradation of biomass material. Biofuel production has attained significant importance in recent years due to rising cost of fossil fuels and increasing global energy demand. They are also considered as "cleaner" alternatives to fossil fuel due to their comparatively lower GHG emissions. The main types of biofuels are bio-ethanol and bio-diesel (OECD, 2007). Ethanol has been used as vehicular fuel, either alone or as an additive to petrol, for many decades (Evans, 2001). The global market leaders are Brazil and the USA where government subsidies have encouraged major investment in this area. High costs and technical difficulties associated with breaking the strong cellulosic bonds of biomass waste, led to the predominant use of primary energy crops like corn (USA) and sugarcane (Brazil) for bio-ethanol production. In the UK, bio-diesels are also produced using waste cooking oil, rapeseed oil and imported palm oil. Though economically competitive with rapeseed, waste cooking oils have limited availability (DTI, 2007b).

The advantages of biofuels include the following:

- they reduce dependence on fossil fuel use and when produced sustainably, it results in less GHG emissions;
- being in liquid form, they are easy to handle, store and transport;
- although ethanol has a lower calorific value than petrol (24 GJ/m^3 to 39GJ/m^3), it has superior combustion properties (Evans, 2001).

The disadvantages of conventional biofuel production include:

- Waste disposal: For each litre of ethanol distilled, between 6 and 16litres of stillage are produced. This stillage has a very high BOD and COD (Evans, 2001) and presents disposal challenges. Potential uses of stillage are as fertiliser and for biogas production. They may also be dried and used as feedstock in thermal power generation;
- To produce ethanol, considerable amounts of water are required and this places immense pressure on limited water resources. A typical ethanol producing facility requires about 1900 litres of water a minute to manufacture just under 19 million litres of ethanol a year (The Economist, 2008).
- There are concerns over the emissions of potentially hazardous chemicals including particulates, volatile organic compounds and nitrous oxides;
- To grow feedstock for bio-fuel production, some forests are cut down leading to reduced bio-diversity and net increases in GHG emissions. A study by consultants Scott Wilson found that when this deforestation is taken into account, biofuels produce double the carbon dioxide emissions of fossil fuels (IEMA, 2009).

In addition to these, biofuel production from primary crops has been blamed for rising food prices and, unsurprisingly, has attracted negative media and public scrutiny (Davies, 2009). However, recent advances in cellulose breakdown, using wholeorganisms or isolated-enzyme techniques, have made the use of biomass waste as a substrate commercially feasible. For example, Ineos Bio has developed a technology that uses a combination of gasification and fermentation by *Clostridium ljungdahlii* to produce ethanol from 'any feedstock with carbon in it' (Davies, 2009). Meanwhile, a team of researchers at Oxford University have developed a novel catalytic process, which converts glycerol- a by-product of biodiesel synthesis- directly into methanol fuel (Urquhart, 2008). According to the OECD (2008) if the use of biomass waste for "second generation" biofuel production becomes established, the following benefits would be derived:

- avoidance of expansion of arable land for biofuel crop production;
- reduced use of fertilisers, pesticides and water for crop production;
- reduced adverse impact on eco-systems and biodiversity.

The Gallagher Review of the indirect impact of biofuels production (RFA, 2008) concluded that whilst biofuels have a future as a sustainable energy source, their production should avoid agricultural land, which would otherwise be used for food cultivation. The initial requirement for UK transport fuel suppliers to obtain a minimum of 5% of total output by 2010, has now been revised to 3.5% (DECC, 2009a; Lalloo and Crow, 2008) to allow the potential impacts of increased biofuel use to be better investigated. For the future development of this technology, a decision has to be made by governments as to whether the economic benefits outweigh the potential adverse impacts on the environment.

3.3.4 Thermal EfW

Thermal EfW plants typically combust wastes to release heat energy, which is then used to generate electricity. Conventional mass burn incinerators have efficiencies of about 30% but this may increase to over 90% (Mullis, 2007) when the excess heat is also trapped and used in district heating schemes. EfW plants that produce both electricity and heat for an available market are called combined heat and power (CHP) systems. CHP systems may be further modified to also provide cooling for offices and homes. This is known as trigeneration CHP (Environmental Data Services, 2008b). For district heating to be feasible, the EfW facility has to be built close to the point of heat consumption (Franke, 2008). A successful example in UK is the Sheffield CHP facility, which generates up to 60MW of thermal energy and 19MW of electricity (Veolia, 2009).

The advantage of conventional incineration is that it achieves volume reduction of input waste material of about 90% and weight reduction of about 75% (Mullis, 2007; Williams, 2005). It does not release methane, unlike landfills. For some waste streams including clinical, infectious and volatile wastes, incineration is the best practicable environmental option (BPEO) (Williams, 2005).

In spite of these advantages, the widespread adoption of thermal EfW processes is constrained by the following barriers:

- Incineration facilities have poor public perception in the UK probably stemming from the poorly designed and highly polluting incinerators of the 1960s and 70s (Read, 2008). This public apathy feeds into protracted and costly planning applications processes (Amos, 2008; Tromans, 2009b). However, epidemiological studies indicate emissions from modern incineration facilities do not pose any significant hazards to human health (DEFRA, 2007b);
- Thermal processing of wastes is often considered to be in direct competition with recycling. This is because thermal plants are designed based on a minimum calorific value of input waste. Therefore when recyclables like paper and plastics- which incidentally have some of the better calorific values within municipal waste- are removed, the heat energy output can be reduced (Williams, 2005). This dependence of thermal EfW facilities on specific calorific input makes them vulnerable to future changes in waste composition (Adamson, 2008). However, some studies (Jamasb et al, 2007; Psomopoulos et al, 2008) indicate that incineration can be combined successfully with recycling and reuse. For instance, according to Psomopoulos et al (2008) US communities using incineration have a higher recycling rate than the national average;
- Incineration still produces residues namely incinerator bottom ash (IBA) and air pollution control (APC) residues, which have to be managed. Treated IBA may be used as aggregates for construction. Out of 710,000 tonnes of IBA

produced in England and Wales in 2007, about 45% was used as aggregates. However much uncertainty remains over the long-term environmental impacts of such applications (Environmental Data Services, 2009c; Finck, 2000).

3.3.5 Advanced Thermal EfW Processes

Advanced thermal processing of waste involves gasification and pyrolysis. Unlike conventional incineration, which takes place in an excess of oxygen, these occur either in partial presence (gasification) or complete absence (pyrolysis) of oxygen. Another type of advanced thermal processing of wastes is plasma arc technology. Advanced thermal processes are more suited to single waste streams but the technology is being adapted to treat unsegregated MSW. Though the technologies are proven elsewhere in Europe- most notably in Scandinavian countries- they are yet to gain a foothold on the UK waste treatment market. It is expected that given time, and a few successfully run commercial applications in the UK, they would be considered as viable alternatives to conventional incineration in the treatment of high calorific value wastes. Their advantages over conventional incineration include their smaller land requirement and lower environmental footprint. They also produce combustible products including gases (gasification); and oils, gas and char (pyrolysis).

Plasma arc technology converts wastes into a vitrified mass by heating up to a temperature of about 5000K. There is little doubt about the soundness of the technology. However, the prohibitive cost of plasma technology (Environmental Data Services, 2006; Neissen, 2002) means that it would not be the best practicable option except for specialist waste streams like nuclear decommissioning waste.

Despite continuing public apprehension about thermal EfW processes, they remain an integral part of UK’s waste strategy. Two-thirds of all participants in the Great Waste Survey 2008 organised by the Chartered Institution of Wastes Management (CIWM), believe the UK should be investing more in EfW facilities (Amos, 2008). When asked about the causes of the apathetic attitude of the UK public towards EfW projects, more than half of all respondents thought negative media reports were partly to blame. If EfW projects are to enjoy the same level of public support as exists in countries like

Germany and Denmark, their benefits have to be communicated effectively to the public.

The case study of the three new EfW plants in Hampshire (UK) demonstrates that when the public is involved from the onset, it can become an invaluable development partner (Read, 2008). Similarly, the success of the planning application for the Greater Manchester Waste PFI, underscores the need for effective stakeholder engagement (Kevan, 2009). Public acceptance of incineration facilities may also increase if the facilities are designed to look aesthetically benign. Earlier incinerator designs concentrated too heavily on functionality and this added to the stigma around them. The iconic Spittelau EfW facility in Vienna, Austria (Zinniel, 2009) is a great example of imaginative use of design in development of waste infrastructure.

3.4 Legislation and Policy Drivers

Waste policy in the UK is driven by EU legislation**.** Perhaps the most important EU legislation to impact UK waste management is the Landfill Directive (LFD). The biodegradable waste diversion targets set under the LFD have catalysed investment in alternative technology options. To facilitate the transition from a landfill-dominated strategy, the landfill tax escalator and the LATS were introduced. The recent UK government Budget confirmed that this escalator would be applied until at least 2013, when landfill tax is projected to reach £72 per tonne.

Through the Department for Environment, Food and Rural Affairs (DEFRA), the UK government set up the Waste Infrastructure Delivery Programme (WIDP). The mandate of WIDP was to help develop infrastructural capacity needed for England to meet its share of the UK’s Landfill Directive targets (DEFRA, 2007b). The programme is also in charge of awarding private finance initiative (PFI) credits to local authorities (LAs) in support of investments in alternative waste treatment technologies. Complementary national programmes set up to facilitate sustainable waste treatment, include Waste & Resource Action Programme (WRAP), Waste Implementation Programme (WIP) and the Business Resource Efficiency and Waste (BREW) Programme. The government has also recently set up the Office of

Renewable Energy Deployment (ORED) to work with all stakeholders to ensure speedy implementation of renewables projects (DECC, 2009a).

In addition to being eligible for ROCs, EfW facilities are exempt from the Climate Change Levy (DEFRA, 2007b). Under the Energy Act 2008, Feed- in-Tariffs (FITs) would now be available to small-scale energy EfW providers with output of 5MW or less (OPSI, 2009). Renewable Heat Incentives (RHI) will also be provided for the utilisation of heat generated from renewable sources including EfW. In April 2008, Renewable Transport Fuels Obligation (RTFO) was introduced to encourage biofuel production. The Renewable Fuels Agency (RFA) administers RTFO and collaborates with producers to ensure biofuels are produced sustainably. In order to improve end markets for digestate from AD, the UK Environment Agency (EA) has produced a Quality Protocol for digestate in conjunction with WRAP and DEFRA. The draft document is currently awaiting approval by the European Commission's Technical Standards Committee. A summary of UK policy milestones is given in Table 2.

Table 2: UK Legislative Targets for Renewables and Climate Change Mitigation

Year	**Milestone/ UK Government Actions**
2010	Introduction of FIT for small-scale renewable energy generation.
	EU Landfill Directive requires diversion of at least 25% BMW from landfill, based on 1995 levels.
	RTFO requires minimum of 5% biofuels to be blended into road transport fuels.
2011	Introduction of RHI and support for injection of biomethane into gas grid.
2012	UK carbon budget requires at least 22% reduction in UK GHG emissions, based on 1990 levels.
2013	EU Landfill Directive requires diversion of at least 50% of BMW from landfill, based on 1995 levels.
	Landfill tax to reach £72/ tonne for active waste.
2017	UK carbon budget requires at least 28% reduction in UK GHG emissions, based on 1990 levels.
2020	EU Renewable Energy Directive requires at least 15% of UK's total energy to come from renewables.
	EU Landfill Directive requires diversion of at least 65% of BMW from landfill, based on 1995 levels.
2022	UK carbon budget requires at least 34% reduction in UK GHG emissions, based on 1990 levels.

2050	Climate Change Act requires UK to reduce GHG emissions by at least 80%, based on 1990 levels.

Source: Adapted from (DEFRA, 2009c)

3.5 UK Waste Market and Financing of EfW Projects

The UK Waste Market has in recent years been characterised by mergers and consolidations. Today, it is dominated by five major companies namely Veolia, Biffa, SITA UK, Waste Recycling Group and Viridor, in descending order of market share. About a third of leading UK waste management firms are foreign owned (Wilson and Pearce, 2009). Though the pace of mergers and overall business activity has slowed considerably in recent months due to the economic downturn, it is expected to pick up again towards the end of 2009. The consolidation of key players within the waste market is in response to the considerable financial clout required to win major waste management contracts (Mullis, 2007). The recently awarded Greater Manchester Waste Disposal Authority (GMWDA) contract is worth around £4.4billion. This makes it the largest project tendered in European waste management history (Friedhoff, 2009).

Public Finance Initiatives (PFI) contracts remain the main financial model underpinning investment in the waste market. The ongoing economic downturn has brought the relevance of PFI contracts in the waste industry into question (Wilson and Pearce, 2009; Friedhoff, 2009). However, the introduction of the Treasury Infrastructure Financing Unit (TIFU) by HM Treasury has provided much-needed boost to PFI transactions. Although the long duration of PFI contracts allow long-term impacts of a project to be thoroughly assessed (Smart, 2009), it is blamed for stifling innovation and flexibility once a chosen technology has been deployed. For instance, if a firm invests in in-vessel composting (IVC) under a PFI, it may not be able to revert to AD technology so as to take advantage of increasing ROCs or the newly introduced FIT. Opponents of PFI contracts may therefore welcome the emergence of ‘merchant’ treatment facilities, which manage waste on a ‘pay as you go’ basis.

3.6 Benchmarking against some European competitors

If the UK is to fully utilise the potential capacity of EfW and meet its renewable energy aspirations, we have to consider the advances made by class leading nations in waste management. Lessons learnt elsewhere can be adapted within the specific UK context. European countries like Denmark and Sweden have well developed strategies for EfW using thermal processing of wastes and biomass (European Commission, 2008). This high proportion of incineration is complemented by high utilisation of waste-derived biogas.

In these and other exemplar countries, the EfW agenda is effectively driven by national policy and benefit from huge public participation. In Austria, national legislation prohibits the landfilling of wastes with more than 5% carbon content (Zinniel, 2009). This has given added incentive to an already flourishing EfW sector. Germany is also one of the leading nations in alternative waste treatment technologies. For example, the Landfill Directive (LFD) was not applied to Germany because their national targets were more ambitious than those set by the LFD.

3.7 Opportunities for Growth

Micro-generation and distributed energy production are areas of priority for the UK government (BERR, 2008). Through localised, small-scale power generation, communities can be provided with heat and electricity without the need to invest in extensive and costly transmission networks. The lack of grid connectivity is one of the main barriers to the deployment of renewable energy (BERR, 2008). The localised treatment of waste upholds both the ‘proximity principle’ and ‘producer responsibility’ tenets of sustainable waste treatment. Much of the NIMBY (“not in my backyard”) attitude of the UK public to development of waste infrastructure, stems from the unsustainable transport of waste produced in other parts of the country to treatment sites miles away.

On the contrary, use of smaller facilities close to point of waste generation ensures local ownership of waste and a more benign environmental footprint. Mullis et al (2009) identified AD, pyrolysis and gasification as the EfW options best suited to community scale deployment. To encourage small-scale power production, the UK government has introduced feed-in-tariffs (FIT) as a financial incentive to EFW facilities with output of 5MW or less. This means most UK AD facilities would be eligible for FIT support (Pöyry, 2009). The barrier to micro and small-scale EfW facilities is that economies of scale tend to favour larger plants. Also in areas where local authorities are committed to long-term PFI contracts, with the obligation to supply a minimum amount of waste, independent small-scale EfW operators may not be supported.

Nonetheless, the potential benefits of adopting community level power generation make it a viable option. The proposed plan by UK government to build 15 eco-towns presents a great opportunity to demonstrate the viability of community scale EfW schemes (Mullis et al, 2009). To overcome the diseconomies of reduced scale, a number of small facilities may be combined to serve larger communities or developments. The London 2012 Olympics also affords the UK the prospect of integrating a trigeneration CHP facility into the design of the Games Village. In a bid to become the first zero-waste- to-landfill games in history, a recycling target of 70% has been set by the Games' organising committee. It however remains to be seen what technology would be adopted for the residual waste stream (MRW, 2008).

To reduce the financial burden on investors, greater collaboration within the waste and resource management sector is needed. Biogas production and scrubbing 'rings' have been suggested (Fuller, 2009). Local producers within the ring can also sell their product on to bigger firms who usually have greater financial strength and more expertise for power generation and connection to the national grid. Local authorities can also benefit from partnerships in the area of waste management. The Somerset Waste Partnership has resulted in collection productivity gains of 10% and savings of £1.5million pa. The Baberg and Mid-Suffolk waste partnership also makes savings of £300,000 through reduced collection (Greenfield, 2009). Whilst cooperation among Waste Disposal Authorities (WDAs) is expected to increase, this may not always be possible if councils are tied to lengthy PFI contracts.

Greater cooperation among government, industry, research institutions and WDAs is a welcome development. To facilitate the development, demonstration and deployment of low carbon energy technologies, the Energy Technologies Institute (ETI) has been established. ETI is funded through a partnership of the UK public sector and some key players in the international energy industry including Shell, BP, E.ON and EDF.

The uptake of renewable energy systems including fuels derived from waste in the transportation sector is crucial in the effort to break dependence on fossil fuel imports and mitigate anthropogenic climate change impacts. Transport accounts for about 24% of the UK overall CO_2 emissions. Although, renewable fuels and hybrid vehicles are expected to penetrate the transportation market in coming decades, the global car fleet is also predicted to increase from 650 million in 2005 to 1.4 billion by 2030. This spike in car numbers would account for three-quarters of the increased demand for oil by 2030 (IEA, 2008). The UK ETI has commissioned research into the development and deployment of renewable energy technologies in the automobile industry.

If the UK is to achieve its ambitious target of 80% reduction in GHG emissions by 2050 (DECC, 2009b), the adoption of renewable transport fuels have to be combined with greater use of public transportation. At present, higher costs and unreliability of public transportation in UK make the use of private cars an increasingly attractive option for many commuters. The use of biogas in transportation has not been deployed to any significant level (Appendix 2). Considering the UK's historic reliance on landfills as the main disposal option, the potential to utilise landfill gas in vehicles is enormous. The first commercial use of LFG in vehicles has been successfully trialed in the London Borough of Camden (http://www.lowcarbonktn.org.uk/public/info_/LowCarbon/Veolia_pr.pdf).

Case Study: Biogasmax

Biogas obtained from AD or landfill gas can be cleaned and upgraded into biomethane for use in vehicles. The European Union has established a project called Biogasmax[1], which aims to provide the framework for utilisation of biogas in vehicular transport in several European cities. Participating cities include Stockholm and Göteborg (Sweden), Lille (France), Rome (Italy); and Torùn and Zielona Góra (Poland). The Lille Metropolitan area in France currently produces 4 million m^3 of biomethane annually from the Organic Recovery Centre, the largest of its kind in Europe. This output is equivalent to 4 million litres of diesel per year. Lille aspires to 100% clean public transportation by 2011 and two-thirds of its bus fleet now run on bio-methane. Similarly, Stockholm has a goal of being a fossil fuel free city by 2050. To achieve this goal, it has actively promoted the use of biogas and other clean fuels in vehicles. Incentives available to the public include free city-centre parking for clean vehicles and the lower cost of biomethane compared with petrol. The take-up of biogas energy has been so successful that in 2006, demand exceeded supply. Stakeholders involved in Biogasmax include local authorities, academia, EfW companies and the public. Evaluation is an integral part of the project and lessons learnt are shared with all partners. To communicate the benefits of EfW initiatives to the public, buses and other public transport, which run on bio-methane, are clearly marked as such. The continued success of Biogasmax demonstrates both the viability of renewable EfW systems and the advantages of partnership working.

[1] www.biogasmax.eu

The trial involved Veolia Environmental Services, UK's largest waste firm; Gasrec, UK first commercial compressed biomethane (CBM) supplier; commercial vehicle manufacturers Iveco and vehicle suppliers Stormont Track and Van. Funding and technical support was provided by Cenex, UK's 1st Centre of Excellence for low-carbon and fuel cell technologies. Compared to equivalent diesel powered vehicles, the CBM powered fleet achieved CO_2 emissions savings of over 50%. They also reduced particulates emissions by 90%, nitrous oxides by 60% and noise levels by 30%. The remarkable success of this pioneering trial has caught the attention of other local authorities and businesses, which may adopt similar fuel systems for their fleet.

Here again, the 2012 London Olympics would be an excellent opportunity to use a transport network powered entirely by biogas.

To achieve UK targets for renewable energy production by 2020 and beyond, the mass media have to be engaged as strategic partners. The debate over EfW facilities has often been dominated by scare mongering and misinterpretation of complex epidemiological data. What is need is a well-informed media who understand the need to invest in technologies that would ensure both energy security and environmental protection. To this end, there is ample scope for experts in EfW and renewable energy technology to articulately ‘make the case’ to the public. Countries with better-developed renewable energy and EfW penetration usually have citizens who are well informed on these matters.

4. Paper for Publication

Paper for publication in: Communications in Waste and Resource Management (CWRM)

Renewable Energy, Landfill Gas and EfW: Now, Next and Future

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Abstract

The United Kingdom (UK) has traditionally used landfill disposal as the predominant method of waste management. However, landfilling is unsustainable due to its harmful effects on the environment and public health. Under the European Union (EU) Landfill Directive (LFD), member nations are now required to divert biodegradable municipal waste (BMW) from landfills. At the same time, the UK has committed to the EU Renewable Energy Directive, which binds it to sourcing at least 15% of its energy mix from renewables by 2020. To meet these targets, the UK has to support alternative waste management options whilst achieving a considerable deployment of renewables. This research considers the development of energy from waste (EfW) technologies and their potential contribution to UK's renewable energy targets.

Landfill gas (LFG) utilisation is currently the single most important contributor to UK's renewable energy generation. However, its output would decline due to the impact of the LFD. To provide future energy security and mitigate climate change, alternative technologies such as anaerobic digestion (AD) and biofuels are being supported. This study found that the most cost-beneficial EfW applications for the UK are: 1) biomethane use as road transport fuel and 2) small-scale EfW deployment at community level. These two options are easily implementable and could provide substantial savings in carbon-dioxide (CO_2) emissions. This study concludes that EfW technologies can contribute up to 50% of UK renewables target by 2020. However, actual performance would depend on the pace of investment in EfW projects and the availability of suitable feedstock.

Keywords

Renewable energy, climate change, landfill gas, energy from waste, biomethane.

Introduction

The UK has historically disposed of most of its wastes in landfills. This is due to the prevalence of non-porous sub-strata and the requirement to fill holes left by mineral extraction activities (Brown and Maunder, 1994). Although a comparatively cheap option, landfilling is unsustainable due to its harmful impacts on the environment. For example, landfill gas (LFG) emissions contribute about 40% of overall UK methane emissions and 3% of all UK greenhouse gas (GHG) emissions (DEFRA, 2007a). As a GHG, methane (CH_4) is about 23 times more harmful than carbon dioxide (CO_2) (IPCC, 2001). To reduce the contribution of landfills to global warming, LFG is now collected and used to produce renewable energy. At the same time, policies have been introduced to encourage diversion of biodegradable wastes from landfills, as required by the EU Waste Landfill Directive (LFD) (Council Directive 1999/31/EC) (DEFRA, 2007a; Williams, 2005).

Today, UK waste management is evolving from a disposal problem to a resource optimisation opportunity. Wherever recycling or reuse of waste materials is not viable, energy recovery is considered, with disposal used only as a last option (DEFRA, 2007a). In addition to LFG utilisation, deployment of various energy from waste (EfW) technologies is being supported in the UK. The growing use of EfW and other sources of renewable energy globally has been underpinned by three main aspirational goals namely i) energy supply security, ii) climate change mitigation and iii) resource efficiency.

The deployment of renewable energy technologies displaces the reliance on fossil fuels and reduces the climate change impact of GHG emissions. Global production of fossil fuels is declining at a time of increasing energy demand mainly attributable to the so-called BRIICS countries namely Brazil, Russia, India, Indonesia, China and South Africa (IEA, 2008). Fossil fuels are vulnerable to price fluctuations and production is mostly concentrated in politically unstable regions. Their use is also the main source of carbon dioxide (CO_2) emissions, the principal cause of global warming (OECD, 2008).

In his “Economics of Climate Change” Review, Lord Stern (2007) cautions that unless decisive action is taken to reduce GHG emissions, atmospheric levels may reach double the pre-industrial amount by 2035. This would account for an average global temperature rise of between 2 and 5 ^{o}C with serious environmental and economic consequences (DEFRA, 2009a). To facilitate the adoption of low-carbon energy technologies, the European Union (EU) has promulgated the Renewable Energy Directive. This binds the EU to deriving at least 20% of total energy requirements from renewables by 2020. This research reviews the development of EfW technologies and considers their potential contribution to UK's renewable energy targets. The drivers, barriers and future trends of these technologies are also discussed.

Renewable Energy Development in UK

The UK government is a signatory to the EU Renewables Directive and has therefore committed itself to contributing its share of sourcing 15% of total energy from renewables by 2020 (House of Lords, 2008). To meet this target would require a seven-fold increase on the contribution of about 2.25%, that renewables currently make to overall UK energy mix (DECC, 2009b). A chart of the percentage share of overall inland energy derived from renewable sources for EU countries in 2005 showed the UK has a very low adoption of renewables (Fig. 1). It also indicates that across the EU, biomass energy- which includes EfW- is currently the principal source of renewable energy.

The UK Renewable Energy Strategy (RES) was published on 15th July 2009, providing the framework for increasing the adoption of renewables. The RES identifies EfW technologies as important potential contributors to UK's future energy security, a fact which is also highlighted in the UK's Biomass Strategy (DEFRA, 2007b) and the UK Energy White Paper (DTI, 2007). Unlike fossil fuels, waste production is ubiquitous and inexhaustible. The RES contends that in addition to providing clean energy, deployment of renewable technologies in UK can also create up to 500,000 new jobs by 2020 (DECC, 2009a).

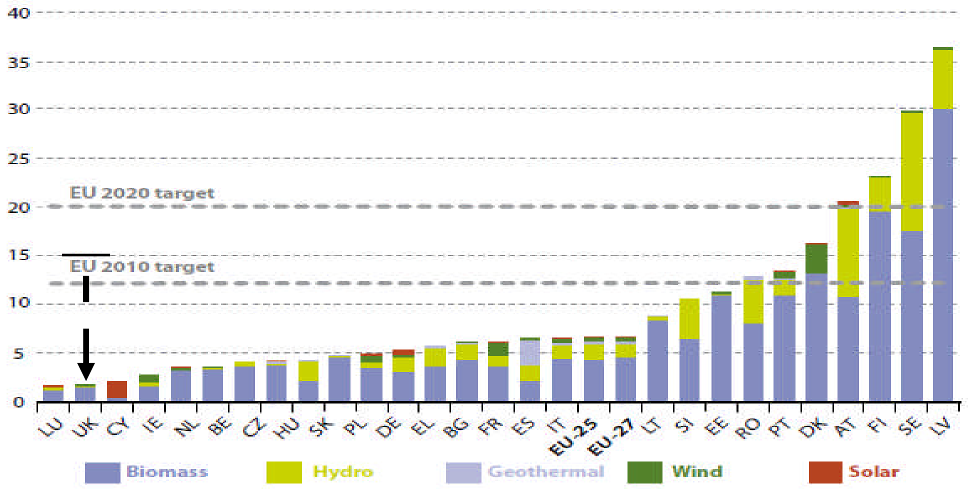

Fig. 1: Percentage share of renewables in overall inland energy consumption in 2005 [Source: Adapted from (European Commission, 2007)]

Energy from Waste (EfW) Technologies in UK

EfW technologies can be grouped into two main categories as shown in Figure 2.

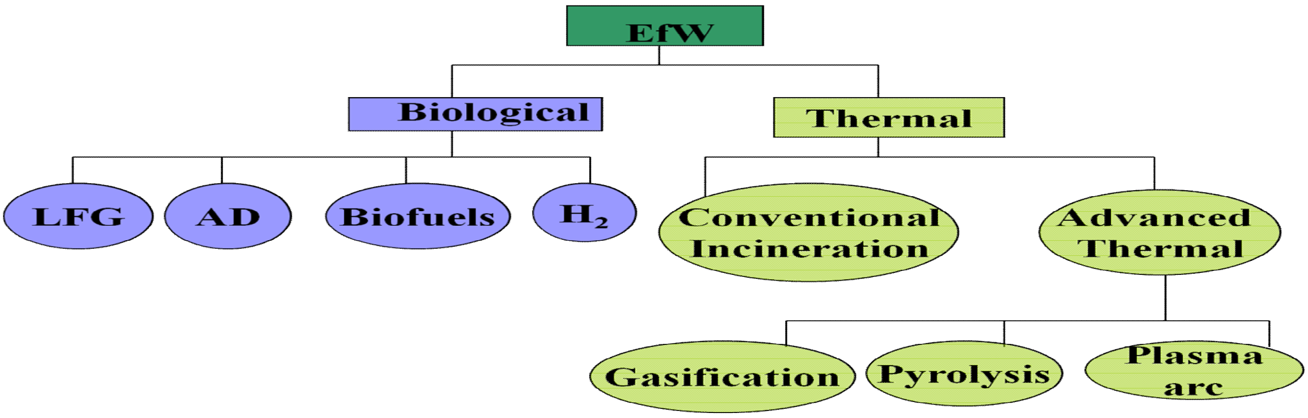

Fig. 2: EfW Technologies

Biological technologies consist of mainly anaerobic digestion (AD) (Balat and Balat, 2009) as well as bio-hydrogen (Sperrey, 2008; Yolcular, 2009) and biofuels (Davies, 2009). Thermal processes involve conventional mass-burn incineration (Cheremisinoff, 2003; Niessen, 2002) and advanced thermal processes (Mullis, 2007; Williams, 2005). The latter includes gasification, pyrolysis and plasma arc technology. Table 1 compares the main EfW technologies deployable in the UK.

Table 1: **Comparison of EfW Technologies in UK**

EfW Technology	Waste Input	Useful Outputs	Applications	Advantages	Disadvantages/Barriers
Landfill Gas (LFG)	All biodegradable wastes.	Landfill gas Biomethane	CHP Electricity Transport fuel Chemical feedstock	• Climate change mitigation. • Versatile and easy to adopt. • Established in UK.	• Output to decline due to Landfill Directive. • High cost of gas clean-up.
Anaerobic Digestion (AD)	Biodegradable waste. Agricultural slurry. Sewage sludge. Food and drink industry waste.	Biogas Biomethane	CHP Electricity Transport fuel Chemical feedstock	• Lowest carbon cost of all residual waste treatment technologies (EDS, 2008). • Established for wastewater sludge digestion.	• Not fully established for MSW in UK. • Limited availability of land for digestate application (EDS, 2009b).
		Digestate	Soil improvement		
Hydrogen (H_2)	Biomass/ Organic Waste.	Hydrogen gas for fuel cells.	Transport Fuel Cells Portable or fixed electricity generators.	• Combustion emits only water. • Fuel cells have few moving parts and require little maintenance (Sperrey, 2008). • High efficiency.	• High cost of hydrogen production from renewable sources. • Technical difficulties with low density of hydrogen gas (Sperrey, 2008). • Lack of refuelling infrastructure. • Not established worldwide.

Biofuels	Biomass waste Waste cooking oils.	Bio-ethanol Bio-diesel Bio-methanol	Transport	• Easy to handle/store because of liquid form (Evans, 2001). • Potentially a more efficient method of biomass conversion than combustion (Davies, 2009).	• Existing vehicles may not be able to run on high content of biofuels (DECC, 2009).
Thermal EfW	High calorific value wastes. Biomass MSW Secondary recovered fuels (SRF).	Heat	CHP Electricity	• High reduction in waste volume and weight (Cheremisinoff, 2003). • Best option for some waste streams (Nielssen, 2002).	• Negative public perception over health impacts (Guisti, 2009). • Does not allow much flexibility with other technology choices (Cheremisinoff).
Advanced Thermal EfW	MSW SRF High calorific value wastes.	Syngas Char Combustible oils	CHP Electricity Chemical feedstock.	• Smaller environmental footprint due to smaller land requirement (Mullis, 2007).	• Not established in UK. • More expensive than conventional incineration (Mullis, 2007).

Current Trends in UK EfW and Renewables Deployment

Contribution of Renewables to UK Energy Mix

As highlighted earlier, the UK presently has a low deployment of renewable energy technologies. In 2007, fossil fuels accounted for over 90% out of UK inland energy used of 226 Mtoe (Fig. 3). Although Government policies have stimulated investment in renewables (DECC, 2009a), the pace of deployment needs to be much faster if the UK is to meet its targets and secure its future energy security. UK government's own analysis indicates that, if current trends persist, the contribution of renewables is unlikely to exceed 5% of total energy consumption by 2020 (DTI, 2007).

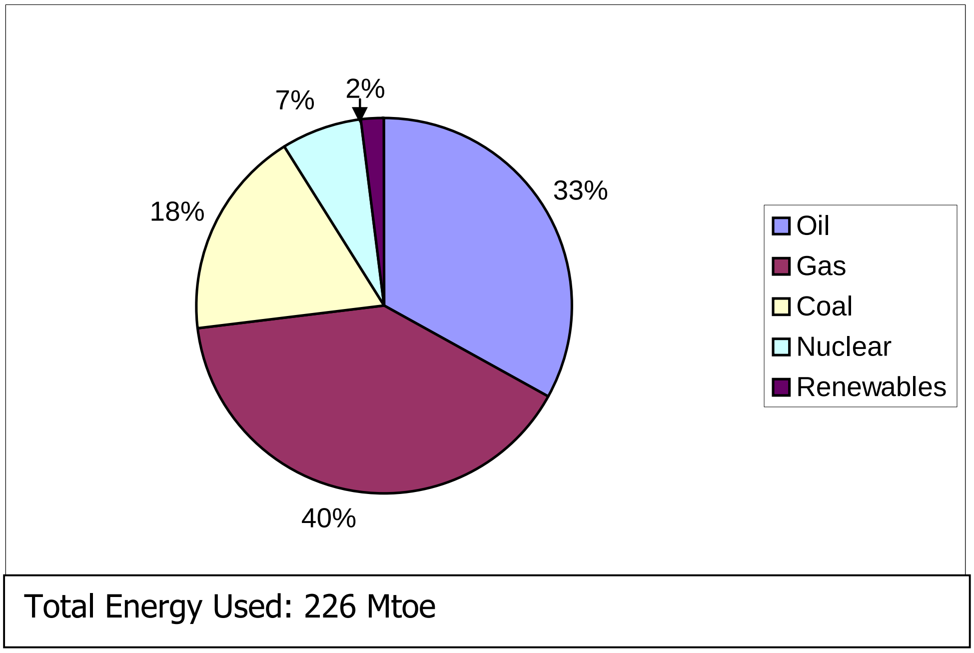

Fig. 3. UK inland energy consumption in 2007

Data: BERR, 2008a

UK Government Support for EfW and Renewables Deployment

To boost alternatives to landfilling, UK Government has increased landfill tax by an annual escalator of £8 per tonne for active waste since 2008. The Landfill Allowance Trading Scheme (LATS) has also been established. Since 2002, Renewable Obligation Certificates (ROCs) have been issued as the main support mechanism for renewable energy generation in UK (Bogner et al, 2007). In addition to qualifying for ROCs, EfW plants are exempt from the Climate Change Levy (DEFRA, 2007b).

Under the Energy Act 2008, feed- in tariffs (FITs) would be available to small-scale EfW providers with output of 5MW or less, which includes most UK AD plants, from 2010 (Pöyry, 2009). Renewable heat incentives (RHI) would also be provided for the utilisation of heat from renewable sources including EfW (OPSI, 2009). In April 2008, Renewable Transport Fuel Obligation (RTFO) was introduced to increase biofuel production. Finally, to improve end markets for digestate from AD, the UK Environment Agency (EA) has produced a Quality Protocol for digestate in conjunction with the Waste & Resources Action Programme (WRAP) and the Department for Food and Rural Affairs (DEFRA).

UK Municipal Solid Waste (MSW) Management

As shown in Fig. 4 (DEFRA, 2006) landfilling remains the predominant disposal option for UK waste. Incineration with energy recovery accounted for only 8% out of a total of 35.1 million tonnes of MSW arisings in 2005/06. These EfW facilities generated about 776, 000 tonnes of oil equivalent which is enough energy to power about 250, 000 UK homes (ESA, 2008). Although planning consents for thermal EfW and AD facilities have increased in recent years, a combination of factors including public opposition and lengthy implementation timelines, have hampered the uptake of EfW options. The prevalent use of landfilling explains why landfill gas utilisation is a key component of UK's renewable energy output.

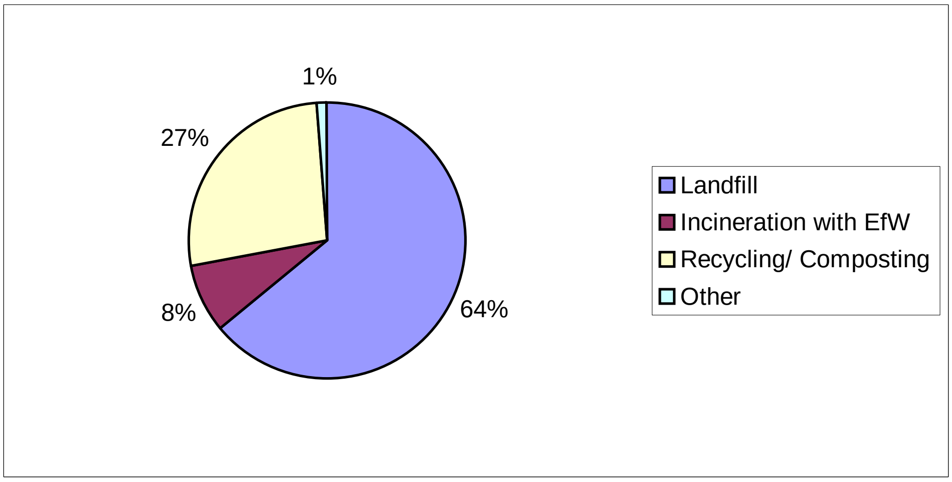

Fig. 4 **UK MSW management in 2005/06**

Landfill Gas

LFG is currently the most important source of renewable energy in UK, accounting for about one-thirds of all renewables (Fig. 5) (BERR, 2008a; Jamasb et al, 2008). It has been used for production of energy on a commercial scale since 1975 (Bogner et al, 2007). A typical MSW landfill would produce between 6 and 8 m^3 of LFG per tonne of waste per year. Calorific values for undiluted landfill gas range between 15 and 21 MJ/m^3 compared with calorific value of about 37 MJ/m^3 for natural gas (Williams, 2005). However, the actual amount and composition of LFG output depends on the composition of waste and site-specific conditions.

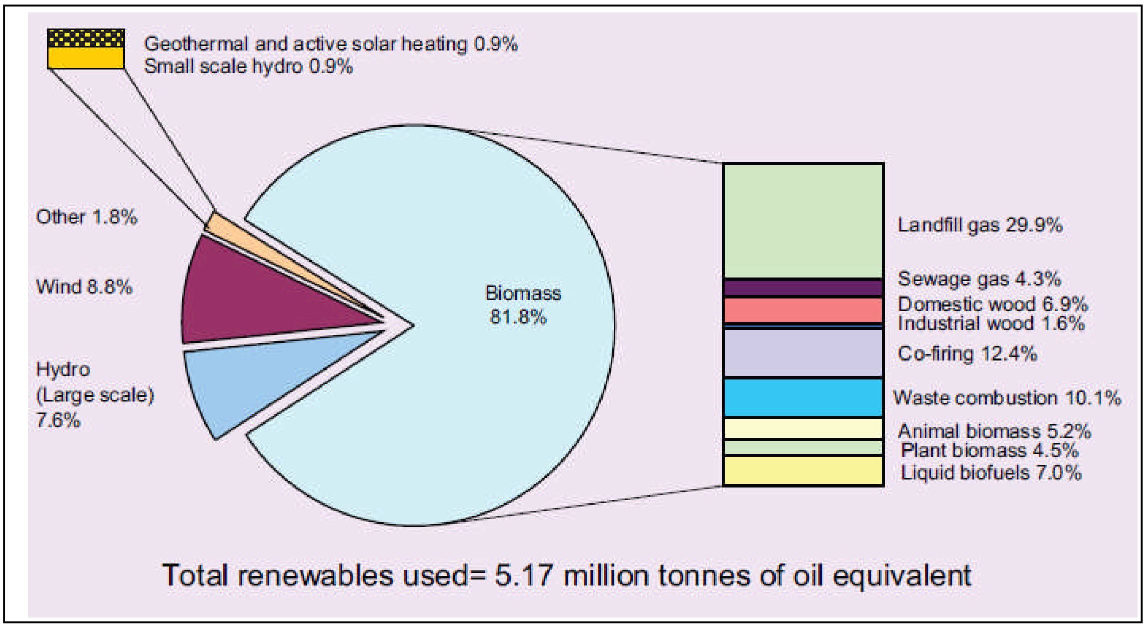

Fig. 5. UK renewable energy sources in 2007 (BERR, 2008a)

LFG can be used directly to generate electricity and in combined heat and power (CHP) systems. It can also be upgraded into biomethane for injection into the gas grid or used as either transport fuel or chemical feedstock. Table 2 (Cenex, 2009; Cheremisinoff, 2003) shows the typical composition of LFG and the required standards for use as vehicular fuel or grid injection. Apart from being an energy source, the recovery and utilisation of LFG is important for reducing GHG emissions. It also provides operators with an additional income stream, which may be used to offset costs of regulatory compliance and landfill aftercare (Brown and Maunder, 1994). The importance of LFG as a renewable energy source would decline in future due to the diversion of BMW from landfills required by the LFD (Hall et al, 2004).

Table 2: **Composition of LFG and requirements for grid injection**

Constituent Gas	**Average concentration in LFG**	**Required level for use in vehicles/ grid injection***
Methane (CH_4)	50 %	97± 1 %
Carbon dioxide (CO_2)	45 %	[$CO_2 + O_2 + N_2$] < 4%
Nitrogen (N_2)	5 %	20 mg/m^3 (max.)**
Oxygen (O_2)	< 1 %	1% (max.)
Hydrogen Sulphide (H_2S)	21 mg/m^3	23 mg/m^3 (max.)***
Halides	132 mg/m^3	NA
Water vapour (H_2O)	NA	32 mg/m^3 (max.)
NMOCs	2,700 mg/m^3	NA

Notes: NA = data not available

NMOCs = non-methane organic compounds (assorted contaminants)

* Based on Swedish Biogas Standard SS 15 54 38 (Requirement A)

** Calculated as ammonia (NH_3); *** Total sulphur

Next: Opportunities for EfW Expansion

Biomethane as Transport Fuel

The uptake of renewable transport fuels, including those derived from wastes would help reduce anthropogenic climate change impacts. Transport accounts for about 70% of UK oil demand and 24% of the UK's overall CO_2 emissions (DTI, 2007). Although renewable fuels and hybrid vehicles are expected to penetrate the transportation sector in coming decades, the global car fleet is also predicted to increase from 650 million in 2005 to 1.4 billion by 2030. This means fossil fuels may still account for about 80% of global energy supply in 2030 (IEA, 2008).

LFG and biogas from AD can be upgraded into biomethane, which has comparable quality to natural gas, for use in road vehicles or grid injection (Persson et al, 2007). According to the latest data compiled by the Natural Gas Vehicle Association Europe (NGVA Europe), in terms of biomethane use for road transport, the top four countries i.e. Pakistan, Argentina, Brazil and Iran account for over 65% of global market share. In Europe, Italy maintains its dominant position as market leader, followed by Germany and Sweden. The UK has not yet experienced any significant penetration of NGV technology (Fig. 6). There is therefore a commercial gap within the UK automotive market, which can be exploited by investors. Considering the UK's historic reliance on landfills, the potential to utilise LFG in vehicles is enormous.

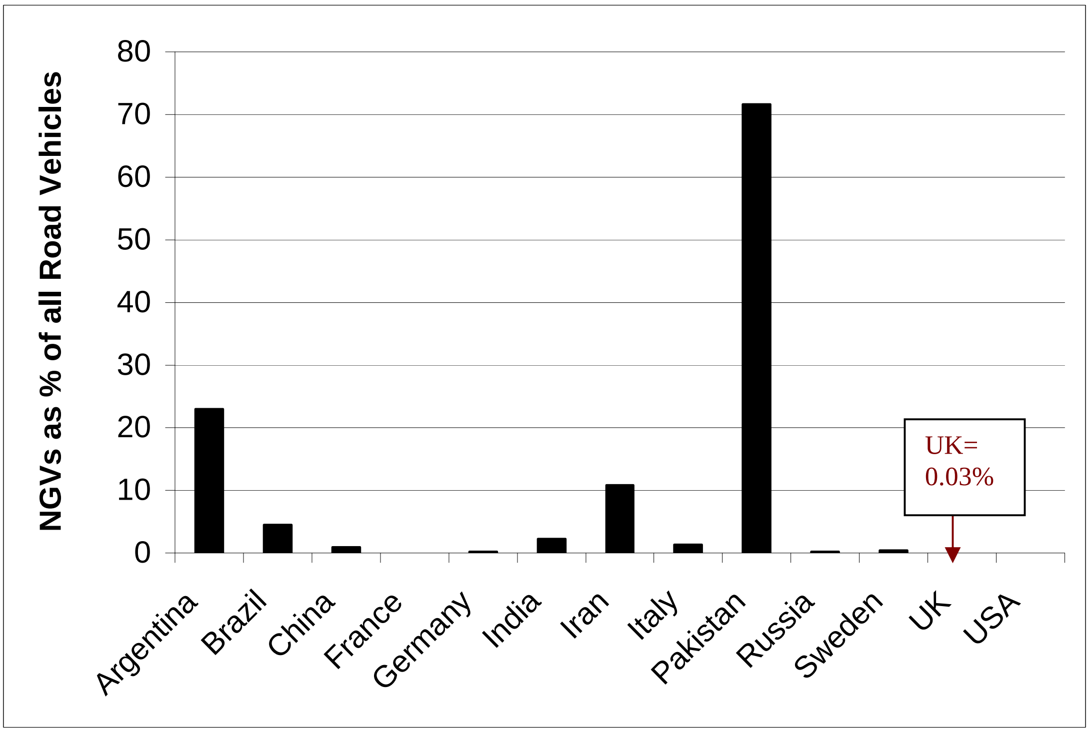

Fig. 6. Natural Gas Vehicle (NGV) adoption in selected countries as of July 2009

Data: Natural Gas Vehicle Association Europe

The use of biomethane as road transport fuel confers several advantages. Biomethane has higher energy content than fossil fuels and emits less CO_2 than fossil fuels (Table 3) (NGVA Europe, 2009). It also emits less particulates, nitrous oxides and dioxins than fossil fuels. Additionally, engines running on biomethane are quieter than those using conventional fuels, a desirable feature when using biomethane for urban transportation fleet (Eriksson and Olsson, 2007). When fitted according to approved safety standards, the use of biomethane in vehicles can be safer than petrol. This is due to the higher flammability limits, higher diffusion coefficient and auto-ignition temperature of biomethane (Cenex, 2009). Biomethane vehicles are also 40% cheaper to run than diesel and 55% more economical than equivalent petrol engines (Sustainable Transport Solutions Limited, 2006).

This research found that UK NGVs could easily be increased from the present number of 294 to about 30,000 units by 2020. NGV technology is easy to adopt and existing vehicles can be retrofitted at a cost of between £1000 and £2000 (based on quotations from some licensed converters). Biomethane can be produced from a wide range of biomass feedstock available within the EU and can also be produced through gasification of organic materials. Biogas can be upgraded into biomethane for as little as between 0.11 and 0.22 eurocents per normal cubic metre (Nm^3), depending on the size of plant (Biogasmax, 2009). 1 Nm^3 of biomethane is equivalent to 1 litre of petrol or diesel. In the event of shortfalls in biomethane production, supplies can be augmented with natural gas because they are chemically identical. As a further incentive to investors, biomethane produced for transport fuel is eligible for RTFO credits.

Table 3: **Comparison of Energy Content and CO_2 Emissions from Different Fuels**

Fuel	**% H_2**	**LHV* (MJ/ kg)**	**LHV (KWh/ kg)**	**CO_2 Emitted per KWh (g)**
Biomethane	25.0	50.0	13.89	198.0
Propane	18.2	45.6	12.67	236.8
Butane	17.2	45.3	12.58	241.2
Diesel	13.5	42.7	11.86	267.5
Petrol	13.5	42.4	11.77	279.5

Notes: * LHV = Lower Heating Value; Heating Value refers to the amount of energy released when a fuel is completely burned.

Micro-generation and Community Level Power Generation

Micro-generation and distributed energy production are areas of priority for the UK government (BERR, 2008b). Mullis et al (2009) identified AD, pyrolysis and gasification as the EfW options best suited to community scale deployment. Although small-scale EfW facilities are constrained by diseconomies of reduced scale, the potential benefits of adopting them within communities make them a viable option. Community level power generation may avoid grid connection and planning obstacles, whilst encouraging local ownership and a more benign environmental footprint. According to Porteus (2005), incineration of 1 tonne of MSW is equivalent to 500 KWh of energy or 30 tonnes of hot water. EfW technologies are integral components of eco-cities such as Masdar (UAE), Dongtan (China) and Treasure Island (USA) (Biello, 2008). The UK government eco-towns project presents a great opportunity to demonstrate the viability of community level EfW schemes (Mullis et al, 2009).

Smart Grids and Smart Meters

To cope with the variability and intermittency of renewable energy generation (Gross et al, 2007), the UK Government intends to invest in a smart grid network (DECC, 2009a). Energy providers are also starting to introduce smart meters, which can transmit real-time readings of energy consumption from point of usage. These enhancements are expected to improve supply whilst informing both demand forecast and consumer behaviour.

Future Developments

Future Trends and Technologies

By 2020, both AD and incineration are expected to be an established MSW conversion technology in the UK. UK Government analysis shows that AD has the potential to produce between 10 and 20 TWh of heat and electricity by 2020. (DEFRA, 2009c). Meanwhile, recent advances in cellulose degradation would increase the production of biomass-derived or ‘second generation’ biofuels. Waste-derived biofuels do not have the negative indirect land use impacts often associated with biofuels produced from primary crops (RFA, 2008). However, a combination of technical and financial barriers would continue to constrain large-scale adoption of hydrogen fuel cell and plasma technologies.

Potential Contribution of EfW to UK Renewables Targets in 2020

Based on Renewables Advisory Board (RAB) projections (2008), the required contribution of renewables to total UK energy demand in 2020 is about 22 Mtoe. Research carried out by Sustainable Transport Solutions Limited (2006) concluded that if AD becomes the main treatment option for organic wastes, it has the potential to produce a theoretical maximum of about 6 Mtoe of biogas. This output corresponds to half of the theoretical maximum and can supply about 16% of UK transport fuels. According to the Waste Strategy for England (DEFRA, 2007), thermal EfW could be used for 25% of MSW by 2020 (Fig. 7). Using on current figures, this would generate about 2.1 Mtoe of renewable energy.

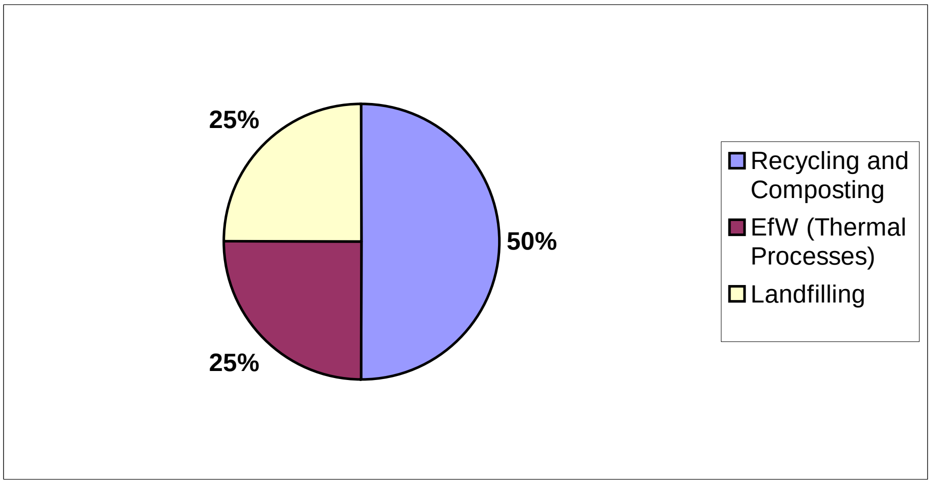

Fig. 7: UK MSW Management Targets for 2020

Assuming a 10% decline in current output by 2020, LFG can still contribute about 1.3 Mtoe in energy. Meanwhile, industrial waste conversion and ‘second generation’ biofuels can contribute about 2 Mtoe. Summing up these outputs shows that EfW can contribute up to 11 Mtoe, which would be 50% of the required contribution of renewables by 2020. The other half can be sourced from other renewables such as wind, hydro and the proposed Severn Estuary tidal project. However, actual results would depend on the pace of investment in renewables over the next decade. The availability of suitable feedstock for EfW processes would also be critical in determining how much displacement of fossil fuel use occurs. Fig. 8 illustrates how UK's energy mix could look like in 2020.

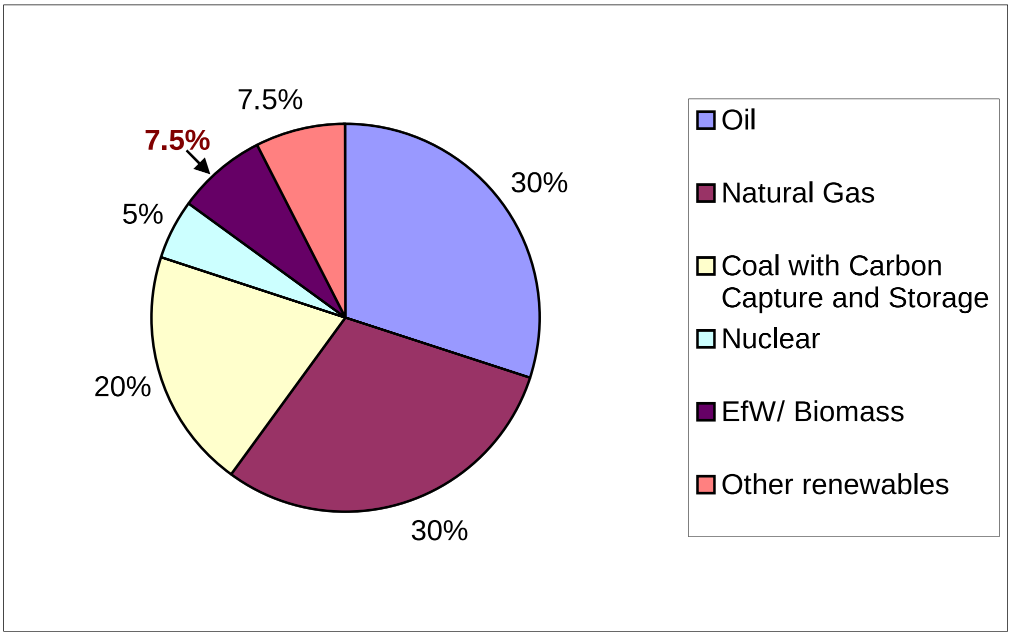

Fig. 8: Potential UK Energy Mix in 2020

Comparing Fig. 8 with Fig. 3 shows that if the UK achieves its goals of 15% of renewables in energy mix by 2020, at least 13% of the current energy consumption can be displaced. This displacement would come from oil and gas utilisation. The small drop in nuclear energy use would come from the planned closure of some existing nuclear plants.

Future Uses of Landfills

Whilst landfill gas outputs will decline in coming decades, landfills may be 'mined' for valuable raw materials, depending on favourable cost-benefit analyses. An estimated 200 million tonnes of plastics, worth around £40 billion, have been dumped in UK landfills over the past 20 years (Smith and Sherman, 2008). If the practice becomes a reality, it is expected to start with landfill sites opened after 1980 because fairly accurate records of their contents were taken. Ground source heating from landfills, is also receiving considerable attention. By inserting heat exchanger pipes within landfills, the heat generated by the microbial degradation of wastes can be harnessed and used to provide heating and/ or cooling for neighbouring buildings.

Planning for Uncertain Outcomes

The UK Waste Sector is undergoing unprecedented changes, with stakeholders having to constantly adapt to new legislation and evolving market forces. The concepts of “eco-design” and “zero waste” are becoming increasingly popular (Murphy, 2009). Meanwhile, existing treatment technologies are being updated continually to increase efficiency whilst novel methods are developed. These changes require waste management plans to be adaptable. Unfortunately most large EfW projects are funded through private finance initiative (PFI) contracts, typically spanning 25 years (Friedhoff, 2009).

This means any failure to forecast future changes in technology, legislation or waste composition, may lead to redundant facilities and cause huge financial losses to investors (Adamson, 2008). There is also potential for over-capacity of treatment technologies such as AD and thermal processing leading to shortage or increased cost of feedstock. It is, therefore, imperative that investment in technology is done in parallel with feedstock availability analyses. The full long-term impacts of changing legislation and market forces on waste firms are uncertain. However, the likely winners are the bigger firms with more diversified technology portfolio and greater financial clout.

Recommendations and Conclusion

The development of renewable energy and EfW requires considerable political will from the UK government. With the target year of 2020 only a decade away, the 2012 London Olympics (Jeffries, 2009; MRW, 2008) would be an excellent platform to demonstrate the viability of EfW and renewables to the UK public. When biomethane- powered cars become widely available on the UK market, they are expected to cost about £2,500 more than equivalent models (Cenex, 2009). To encourage patronage, the government can subsidise this premium. In Sweden, where biomethane use for transport is thriving, incentives include free city-centre parking for NGVs and tax relief for businesses. Providing incentives such as council tax discounts and free domestic hot water from EfW plants can assuage lingering public opposition to incinerators in UK.

By anticipating future policy trends and acting early, the UK can capitalise on ‘first mover’ advantages. The global market for renewable technologies is worth an estimated £3 trillion and is growing by 5 % annually (Reeves, 2009a). Many countries are now investing heavily in low-carbon technologies in order to capture a sizeable share of this market. After years of indifference to environmental issues, major GHG emitting countries like US, China and India are now investing significantly in low carbon technologies (Holdren, 2008). With only £1.4 billion allocated for green investments in the latest UK Budget, more needs to be done to de-carbonise the UK economy (Reeves, 2009b).

Greater cooperation among government, industry, research institutions and local authorities is also required to hasten the adoption of low-carbon technologies (OECD, 2008). Biogas production and scrubbing ‘rings’ have been suggested for small-scale energy providers (Fuller, 2009). Local authorities can also benefit from waste management partnerships (Greenfield, 2009). Similarly, to achieve targets, the UK public has to be engaged as strategic partners. The successful planning application for the £4 billion Greater Manchester Waste PFI contract, the largest of its kind tendered in Europe, underscores the importance of effective stakeholder engagement (Kevan, 2009).

In conclusion, EfW technologies can make significant contributions towards achieving the UK’s renewable energy targets. However, if these targets are to be met, concerted and sustained action is required from all stakeholders. Although UK government has made significant progress in encouraging renewable technology development, innovators require greater support in bringing technologies to market (CIWEM, 2009). The use of biomethane for road transport should be given more attention because it would help to improve air quality and combat climate change whilst providing much-needed energy. The ongoing global economic downturn presents a unique opportunity to curb excessive consumerism and adopt low-carbon technologies (Reeves, 2009a). It is recommended that detailed studies of reliable sources of EfW feedstock should be undertaken to inform investment decision-making.

Acknowledgement

The authors would like to thank Geotechnical Instruments (UK) Limited and The Chartered Institution of Wastes Management (CIWM) for sponsoring this research.

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6. Appendices

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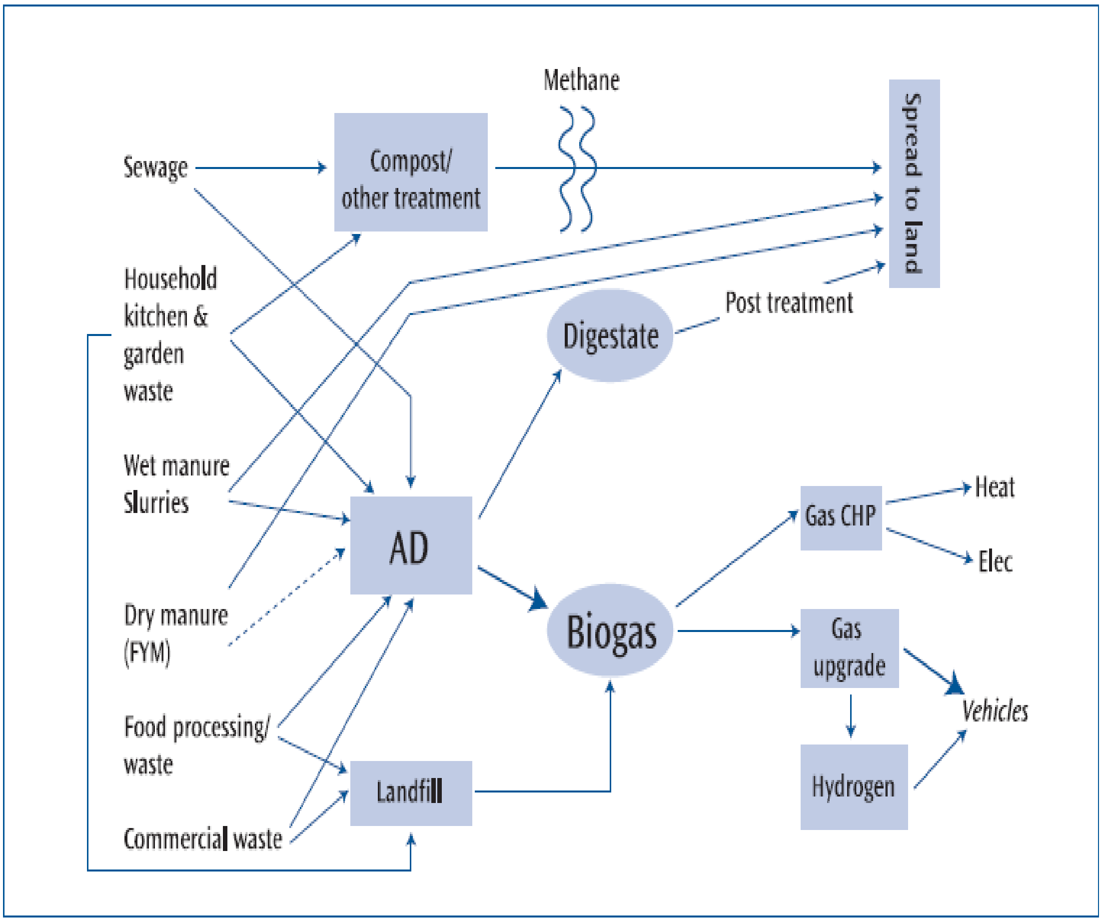
Appendix 1. Carbon Cost of Various Waste Treatment Technologies*

Technology	**£ / tonne of waste**
Mechanical biological treatment (MBT) with AD, providing heat and electricity	6.01
Autoclaving followed by gasification	8.38
MBT producing stabilised output for landfill	9.55
Incineration with combined heat and power (CHP)	10.21
MBT producing refuse-derived fuel (RDF) for gasification	10.71
MBT producing RDF for incineration	10.97
Incineration providing electricity only	11.45
Landfill	31.90

*Analysis carried out by Eunomia and EnviroCentre.
Source: Ends Report no. 397

Appendix 2. Some Pathways for Biogas Production



Source: (Sustainable Transport Solutions Limited, 2006)

Appendix 3. Natural Gas Vehicle (NGV) Adoption in Selected Countries

Country	**Total NGVs**	**Refuelling Stations**	**NGVs per 1000 human population**
Pakistan	2,000,000	2,718	11.25
Argentina	1,750,339	1,808	43.24
Brazil	1,588,331	1,705	8.09
Iran	1,215,593	764	18.45
India	700,000	325	0.61
Italy	523,100	700	9.00
China	400,000	1,336	0.30
Russia	103,000	226	0.73
USA	100,000	816	0.33
Germany	76,783	804	0.93
Sweden	16,900	122	1.87
France	12,450	125	0.19
UK	**294**	**14**	**0.00**
Subtotal	8,486,790	11,463	-
Rest of the world	1,394,460	3,408	-
Global Total	**9,981,250**	**14,871**	**1.48**

Data: Natural Gas Vehicle Association Europe, and Gas Vehicle Report (GVR)

Appendix 4. Notes for Authors: Communications for Waste and Resource Management (CWRM)

The following guidance notes can also be accessed online using the link below:
http://www.ciwm.co.uk/mediastore/FILES/13862.pdf

NOTES FOR AUTHORS

AIM

This new rapid communications journal is a peer-reviewed publication for waste professionals and researchers throughout the world, published four times each year by the Chartered Institution of Wastes Management. The journal provides new and original information for those working in the field of waste and resources management. A broad cross-section of articles from professional waste managers, academic researchers and consultants are published, with preference given to articles of significance that address practical waste management issues. Papers are selected and reviewed by the editorial board according to the significant of the insight offered as well as strict technical criteria.

SCOPE

- **Waste streams**- eg MSW, industrial, hazardous, healthcare/clinical, biodegradable, electrical.
- **Waste minimisation**- eg demonstrable case studies, strategies, sector approaches.
- **Treatment technologies**- eg recycling, energy recovery (energy from waste), composting, biological treatment.
- **Disposal technologies**- eg landfill, incineration.
- **Modelling waste management**- eg lifecycle analysis
- **Waste collection and transport**.
- **Waste strategy**- eg local/national policy, regulation and its implementation.
- **Economics of waste management**.
- **Waste law**- implications of future legislation, incentives and compliance.
- **Public attitudes and perception to waste and resource issues**- community awareness and activity, behavioural aspects.
- **Waste management in the developing world**- sustainable waste management practice in developing countries, appropriate waste management strategies, case studies.
- **Materials flow**.
- **Policy and regulation**.
- **Health and environmental impact.**
- **Materials recovery and resource use.**

PAPER CLASSIFICATIONS

Rapid communications- a concise, complete and detailed description of a particularly timely investigation, which will not be included in a later research paper;

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Targeted reviews- critical examination and review of a focussed subject area; peer-reviewed on the quality of exposition and the importance of the issues raised (4 000 words maximum).

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FORMAT

- Manuscripts must be in good English. Any translation must be carefully checked for conformity with current English usage and idiom.
- All pages must be numbered.
- All text is to be submitted as a Microsoft Word file. If graphs are produced from Microsoft Excel spreadsheets, the original spreadsheets should also be provided.
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- The resolution of images must be a minimum of 300 dpi (dots per inch) at print size.
- Colour may be used where this enhances the impact of images, graphs etc.

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- Our aim is to publish articles within six months of receipt.
- Only papers that have not been published or presented elsewhere can be considered.
- All papers will be peer-reviewed.
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Corresponding authors should submit their manuscripts electronically to the executive editor, Professor Simon Pollard at s.pollard@cranfield.ac.uk. The subject of the email should be entitled "CWRM- new submission- corresponding author name". The manuscript should be accompanied by a covering letter that explains the significance of the submission and that justifies its consideration for rapid communication. On receipt, manuscripts will be assigned to an associate editor. Manuscripts cannot be progressed unless the full addresses, including current email addresses, of three potential referees are supplied by the corresponding author at the time of submission.

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Papers will usually consist of the following sections: title, abstract, keywords, introduction, materials and method, results, discussion and conclusions.

There should be no more than two heading levels.

TITLE PAGE

The first page (title page) should contain the full title of the paper, the author (s) names- initials(s) and surname(s)- with the name(s) and address(es) of their respective affiliation(s). The chosen author for correspondence should be clearly marked with their full name, postal address, telephone/ fax numbers and e-mail address provided.

ABSTRACT & KEYWORDS

A synopsis of 200 words summarising the key insight and conclusions is required. Immediately following the abstract, the author should list five key words.

INTRODUCTION

The introductions should provide a brief background emphasising the relevance and importance of the subject area. Authors are encouraged to keep the introduction brief and to the point. Key published work that has shaped the investigation should be highlighted and the main objectives of the paper should be clearly stated.

MATERIALS AND METHODS

Research methods should be concise. It is recommended that any methodological approach is explained and that the use of new or adapted methodology is justified.

RESULTS AND ANALYSES

The results of the investigation must be described as clearly and concisely as possible. Essential data may be displayed through tables and figures, but it is recommended that attention is given to results most relevant to the research objectives. Avoid duplication of data in the text and tables or figures.

TABLES & FIGURES

All tables and figures should be numbered consecutively according to their order of appearance in the text using arabic numerals. Each should be given a brief, self-explanatory title and any sources given. The position of each table or figure should be clearly marked in the text.

DISCUSSION

In this section the significant key insights are discussed in the context of previous work. It is recommended that results are compared with published findings and, where appropriate, relationships and trends should be highlighted.

CONCLUSIONS

The author should provide concise, clear conclusions that revisit the original objectives of the paper- re-emphasising the main findings and contribution to the field.

REFERENCES

Authors are encouraged to cite essential references only. An alphabetical list of cited work should be included at the end of the paper. Journal names should not be abbreviated or translated, titles of papers should be given in their original language and, if possible, they should be immediately followed by an English translation in parentheses. Please use the following formats for references:

Books: Doggat, R M, O'Farrell, M K, and Watson, A L (1980) Forecasts of the Quality and Composition of Solid Waste, EPA- 60015-80-001 Cincinatti, OH, US, US Environmental Protection Agency.

Articles in books or proceedings: Gerking, L (1979) Separation of Unmilled Municipal Refuse by Drum Sleeve and Horizontal Air Classifier, in: Jager, B, and Thome-Kozimensky, K J (eds) Material Recycling aus Haushaltsbfall, Berlin, Germany, Technische Universität Berlin, pp 215-230.

Journal articles: Farquhar, G J, and Rovers, F A (1973) Gas Production During Refuse Decomposition, Water, Air and Soil Pollution, 2, 483-495.

CITATIONS IN THE TEXT

These must be marked by the surname of the author(s) and the year of publication, eg, "…this was supported by current literature (Farquhar and Rovers, 1973)".

If two citations bear the same name and year, they should be differentiated by a letter, eg "Gerking (1979a and 1979b)".

If a cited work has more two authors, *et al* should be used after the first author's name, eg "Doggatt et al (1980)".

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The first time that the name of an organisation, concept, chemical, etc appears in the text it should be given in full, immediately followed by its standard abbreviation in parentheses.