A Changing Climate for Energy from Waste?

Final Report for Friends of the Earth

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Executive Summary

This report lays down some challenges to conventional wisdom and some dearly held beliefs. It is a piece of work which, from the author's perspective, has been many years in its gestation, and which has a number of important implications.

Fundamentally, it challenges what has become 'conventional wisdom': that energy from waste incineration is bound to 'generate climate change benefits'. It does not, however, argue that such benefits may not be possible to derive. Rather, it highlights the fact that whether or not climate change benefits can be said to have been derived is dependent upon the assumptions used in the analysis and the performance of the relevant technologies, notably:

- the efficiency with which the incinerator generates energy (and in many UK-based studies, these have tended to be on the high side);
- the assumption concerning which energy source might be considered to be displaced by the incinerator (this will always be controversial);
- the efficiency with which these 'displaced sources' generate energy (these are tending to improve over time);
- whether or not one includes biogenic carbon in the analysis (most studies do not);
- the calorific value of the input waste; and
- what percentage of carbon (biogenic and non-biogenic, depending upon the view of the study) is in the waste combusted.

Notably, the study highlights the fact that typical UK incinerators, generating only electricity, are unlikely to be emitting a lower quantity of greenhouse gases, expressed in CO_2 equivalents, per kWh electricity generated than the average gas-fired power station in the UK. Rather, since gas-fired power stations emit a smaller quantity of GHGs per kWh, the presumption that energy from waste is always 'good for climate change' appears to imply a range of assumptions which are not always stated (or, perhaps, understood by those who presume this to be the case).

This need not necessarily imply that energy from waste incineration is bad for climate change. It could, after all, be true that incinerating waste and generating energy from it is the best way of dealing with waste. This is the more-or-less unanimous outcome of the vast majority of studies which have looked at the matter from the perspective of life cycle assessment (LCA). However, we argue that the use of conventional LCA-based approaches, and most notably, the largely unquestioned assumption that 'biogenic carbon can be ignored' (or that only what is not liberated as CO_2 after 100 years needs to be taken into consideration, which amounts to a similar assumption), is inappropriate for this type of analysis. Ignoring what happens to biogenic CO_2 during a 100 year period can only be an acceptable way to proceed if all technologies behave in a similar way over this time period, and if society is not especially interested in the time profile of emissions. Neither would appear to be true.

The work, therefore, poses a challenge to those engaged in LCA-based work, pushing them to recognise the significance – as many have already done – of time. It suggests they must go beyond merely *recognising* time as significant, and actually integrate the dimension of time into the analysis. This is important not least since the European Commission has placed considerable emphasis, in the development of its proposals for a Thematic Strategy on Waste Prevention and Recycling and a revised Waste Framework Directive, on the issue of climate change, and on the use of 'life-cycle thinking'. In its current, conventional form, life-cycle *assessment* is not a reliable indicator of the contribution of waste treatments to climate change.

The significance of this is that the alternative methodology used in this work – based upon evolving thinking on the application of cost-benefit analysis to the problem of climate change – clearly highlights the fact that how a technology performs in respect of climate change is not simply a function of how much energy is generated. Once biogenic carbon is included explicitly in the analysis – which it must be unless we take the absurd assumption that the climate responds differently to biogenic and non-biogenic CO_2 molecules – then the effects of sequestering carbon, biogenic and otherwise, and of stabilising potentially methanogenic fractions (where landfill gas captures are not assumed to be unrealistically high) become important.

Suddenly, generating energy is not ‘all that matters’, and issues such as carbon sequestration begin to matter. Closer inspection also shows that capturing materials for recycling from residual waste also has a positive impact, and that developments which enable this to happen (especially for plastics) are likely to be beneficial. The effects of stabilising biodegradable elements of waste have also been used in the report to argue for a lower rate of landfill tax for stabilised biowastes (a development which would reduce the costs to local authorities of – and speed up compliance with - Landfill Directive obligations).

Additional pieces of analysis in the report have been used to suggest that:

1. There are ways to generate energy from waste (other than incineration) which may be more acceptable to the public which have not been mentioned in the Consultation on the Review of the Waste Strategy. These include anaerobic digestion. We estimate that some 1.45 TWh electricity could be generated using this technology (which could equally be used to provide biogas for use in vehicles);
2. The proposals being advanced by the European Commission for a distinction between recovery and disposal appear to be founded on the view that neither the Waste Incineration Directive (WID) nor the requirement to demonstrate Best Available Technique (BAT) in order for an incinerator to operate, will be enforced. The proposal seeks to make the distinction based upon BAT. The obvious point is that BAT must be demonstrated for the plant to operate at all so that the proposed ‘distinction’ is actually a ‘distinction without a difference’;
3. Whilst the Renewables Obligation has given some encouragement to generate energy from incineration in CHP mode, the incentive to do so is not very well targeted. The benefits from different power and heat configurations, in terms of GHGs, appear broadly similar, but through rewarding only the power element, it is questionable to what extent the measure could encourage higher energy efficiency. In any case, the WID requires heat to be recovered ‘as far as practicable’ so switches from one mode of operation to another as a consequence of these incentives might reasonably raise questions as to why facilities were not operating in this manner in the first place.

There are challenges to bodies outside the EU and UK. The Intergovernmental Panel on Climate Change appears to have no mechanism to understand the implications – for the release of CO_2 from biogenic sources – of a wholesale switch from, for example, landfill to incineration. Waste, and energy from waste, inventory data include only non-biogenic elements other than where the emissions are of methane. Quite clearly, a switch from landfilling biogenic carbon, in which process, biogenic carbon stays in the ground over a period of many years, to incinerating it, a process which liberates the vast majority of biogenic carbon as CO_2 immediately, ought to register some interest. It is not clear how, under existing inventory guidelines, it will do so.

Contents

1.0 INTRODUCTION

Whenever environmental issues are being discussed today, it is increasingly ‘normal’ for discourse to turn to the issue of climate change. Whatever the issue being discussed, the potential contribution of the relevant activities to changes in climate through the emission of so-called greenhouse gases (GHGs) has become a critical determinant of how the environmental performance of those activities is perceived.

The recently published *Review of England’s Waste Strategy: A Consultation Document* makes this a central platform for the argument in favour of changing course for the management of waste.[1] The Consultation Document was accompanied by the release of a document prepared by ERM which sought to understand the implications of different policy changes for the impact of waste management upon climate change.[2]

The debate around climate change has also become intertwined with the discussion concerning the generation of energy. The majority of energy generation in the UK generates greenhouse gases (GHGs), and the quantity of GHGs generated per unit of energy depends both on the fuel used and the efficiency of the generation by the power stations used.

Historically, the discussion concerning energy and waste has majored on how to generate energy *from* waste. Somewhat paralleling the major thrust of debates concerning energy policy generally, whereas the question of energy *generation* predominates the issue of reducing use, the issue of how to *save* the energy *embodied within* materials, and in so doing reduce GHG emissions, has not always received the attention it deserves. Whilst the research funded by Defra credits the role of recycling with GHG savings, the potential role of waste prevention is not fully explored. Furthermore, it remains the case that whilst the potential consequences of preventing waste, or of recycling it, may be more beneficial from the perspective of both energy balances and GHGs, reputable bodies continue to play up the case for the generation of energy from residual waste.[3] On the basis that waste provides a source of ‘renewable energy’, this case is, then, supposedly strengthened in scenarios where *more* waste is generated (and, it might be argued, where less waste is recycled).[4] Neither, of course, could be considered to represent a desirable trend, and as we shall see, neither is desirable from the point of view of climate change either.

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[1] Defra (2006) Review of England’s Waste Strategy: A Consultation Document, February 2006

[2] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

[3] Oakdene Hollins (2005) *Quantification of the Potential Energy from Residuals (EfR) in the UK*, Report for the Institute of Civil Engineers and the Renewable Power Association, March 2005, http://www.ice.org.uk/downloads//energy_from_waste.pdf; CIWM (2006) CIWM Position Statement Energy Recovery From Waste, February 2006, http://www.ciwm.co.uk/mediastore/FILES/12321.pdf

[4] No one really knows what proportion of waste will be readily recyclable in ten or twenty years’ time. What was thought to be difficult or impossible twenty years ago is now seen as ordinary or difficult today.

None of this is to imply that 'energy from waste' has no role to play in managing waste within the UK.[5] What matters, perhaps, is that some of the assumptions underpinning the debates are made absolutely clear so that policy – whatever it ultimately is – can be informed by the full range of arguments. 'Sound science' does not always mean seeking an unequivocal and uncontested view of the world. As often as not, it means understanding different arguments, and the significance of different assumptions, and making judgements on the basis of *all* the available information rather than partial presentations of it.

The issue of waste management and climate change – precisely because it is accorded increasing significance in policy debates – is one where interest groups are apt to deploy those assumptions which best suit their own line of argument. For this reason, one needs to tread carefully where this issue is concerned.

Another feature of this debate is the fact that it is not just 'assumptions' which influence outcomes, but more fundamentally, methodologies. The European Commission has recently expressed enthusiasm for 'life-cycle thinking' and lifecycle analysis. The Thematic Strategy on the Prevention and Recycling of Waste states

> *the proposal is to modernise the existing legal framework – i.e. to introduce lifecycle analysis in policymaking and to clarify, simplify and streamline EU waste law. This will contribute to resolving current implementation problems and move the EU decisively onto the path of becoming an economically and environmentally efficient recycling society.*

Those who have taken the time and effort to critically review lifecycle analyses will know that assumptions influence results, so it is unlikely that a single answer would result from such analyses – making the supposed objective of clarifying and simplifying waste law through the use of lifecycle analysis a somewhat naïve one.

Since, as we will show, lifecycle analyses gives very different results to cost-benefit analyses, the choice of one methodology over another on the part of the Commission begs the question, 'why the preference for one rather than the other?' It seems ironic, after all, that in the context in which the Thematic Strategy emerged – that of concerns for competitiveness, and the elaboration of the Lisbon Agenda – the relative costs and benefits of alternative actions would be considered irrelevant.

1.1 This Report

This report explores a number of issues at the interface of energy, waste and climate change. It asks, and seeks to answer (from different perspectives) the following questions:

1. How does energy from waste incineration compare, in terms of emissions of greenhouse gases per unit of energy generated, with other technologies for generating energy in the UK? and

[5] The term 'energy from waste' could, of course, mean just about anything - landfills generate 'energy from waste'. So do anaerobic digesters, which can be used to treat source separated materials, or residual waste. So do incinerators. So do power plants and industrial facilities where they combust waste derived fuels. And so could pyrolysis and gasification facilities. 'Energy from waste' ought not to imply, necessarily, 'incineration'.

2. How does energy from waste incineration compare with other residual waste treatment technologies in terms of their impact upon climate change?

In addition, it asks the following questions:

1. What are the prospects for energy from waste being considered acceptable from the public perspective?
2. Is there a rational argument in the proposals for a Thematic Strategy and for a Revised Waste Framework Directive for a distinction between recovery and disposal, as applied to incineration?
3. Will including incineration with CHP under the Renewables Obligation improve the climate change performance of incineration?

The final Section contains Conclusions and Recommendations related to the preceding analysis.

The analysis is supplemented by additional technical information within the Annexes.

2.0 DOESN'T INCINERATION WITH ENERGY GENERATION HELP TO REDUCE GREENHOUSE GAS EMISSIONS?

2.1 The Issue

It is almost universally stated that energy from waste incineration reduces emissions of greenhouse gases. How is this statement usually justified? The ERM report accompanying the waste strategy states:

> *EfW, and other energy recovery processes, have the additional benefit of acting to provide a renewable source of electricity. This not only has implications for climate change, but also for UK energy security.*

Some of the assumptions in this report are scrutinised in Annex 4.

The document includes a statement which is typical of the majority of the discussion concerning climate change impacts of waste management:

> *Waste management makes a significant contribution to UK emissions of greenhouse gases. All waste management activities lead to the production of some greenhouse gases. The landfilling of wastes, in particular, contributes to methane emissions, a significant greenhouse gas. Reducing the UK's reliance on landfill is therefore central to the Government's new draft waste strategy.*

To the uninitiated observer, this statement might appear strange. Just because landfills emit methane (one of a number of GHGs), why should that necessarily imply the need to move material away from them? Isn't it possible that emission of other GHGs by other processes might make them worse performers in the round? Methane, after all, is not the only GHG. Incinerators emit nitrous oxide. So do compost facilities. Do those facts suggest the need for waste to be 'diverted from' those facilities too just because nitrous oxide is a more potent GHG than methane?

The CIWM, in a statement on energy from waste, stated:

> *The UK's capacity to recover valuable energy from its waste is under-developed. Rapid planning and commissioning of appropriate plants and technologies is needed to support three vital policy areas: meeting tough landfill diversion targets; combating climate change; and meeting energy demand through secure and sustainable supply. The Chartered Institution of Wastes Management (CIWM) is urging Government to recognize the important contribution of energy from waste in addressing these issues and to take urgent practical steps to support its expansion.*[6]

Again, assumptions in this statement are scrutinised in Annex 4.

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[6] CIWM (2006) *CIWM Position Statement Energy Recovery From Waste*, February 2006, http://www.ciwm.co.uk/mediastore/FILES/12321.pdf

The Institute for Civil Engineers also produced a report which sought to make a case for more energy from residual waste. A critical review of key assumptions used in the report is given in Annex 4.

These documents tend to support the view that energy from waste incineration is 'good' for climate change, generally without much by way of clear qualification.

The European Commission in its Thematic Strategy on the Prevention and Recycling of Waste, is more equivocal, arguing that energy efficiency is a key determinant of the relative performance of energy from waste:[7]

> *A definition of recovery that takes into account that energy produced by a municipal incinerator substitutes the use of resources in other power plants will better reflect the environmental benefits of incineration. However, the energy efficiency of municipal incinerators can vary dramatically. At low energy efficiencies incineration might not be more favourable than landfill. At high energy efficiency incineration could be as favourable as mechanical recycling or composting of certain waste flows.*

This seems reasonable under the assumptions that are usually employed in life cycle analyses. Essentially, if one assumes that energy generated 'displaces' emissions which would otherwise be generated in other power stations, the greater the efficiency, then the larger is the quantity of polluting emissions displaced.

The question is, though, in the UK, how valuable is energy from waste incineration in the battle to combat climate change?

2.2 Analysis

Energy from waste plants generate either:

- Electricity only;
- Electricity and heat; or
- Heat only.

The assumption is that energy from waste generates energy in such a way that a lower quantity of greenhouse gases are emitted per unit of energy output than is the case with conventional fossil fuel energy generation. So how well does energy from waste really perform in this regard?

Figure 1 below shows how energy from waste incineration fares against fossil fuel sources in the current context. The details for the calculations can be found at Annex 1. In this illustration, the value of each kilowatt hour (kWh) of heat is deemed to be equivalent to 0.4kWh of electricity. The rationale for this is that the average rate of conversion from heat to electricity is of the order 40% in the UK.[8] This shows that if energy from waste

[7] European Commission (2005) *Taking Sustainable Use of Resources Forward: A Thematic Strategy On The Prevention and Recycling of Waste*, Communication From The Commission To The Council, The European Parliament, The European Economic And Social Committee And The Committee Of The Regions, Brussels, 21.12.2005.

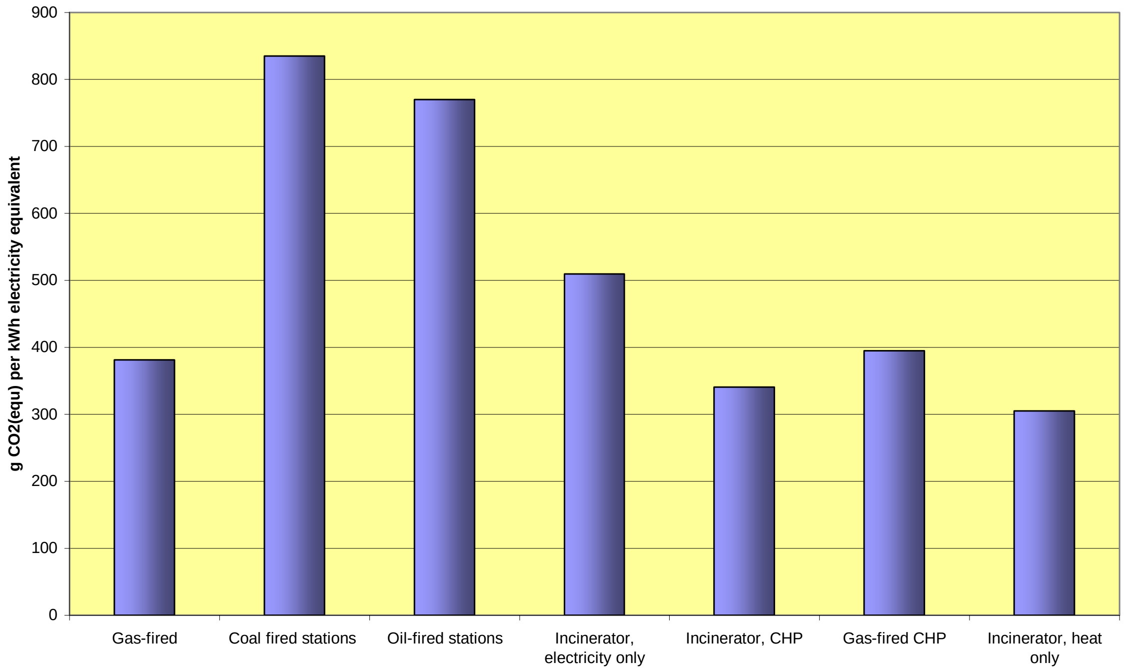
[8] As we shall see, the European Commission, in proposing an efficiency criteria to distinguish between 'disposal' and 'recovery', attributes a weighting of 1.1 to heat and 2.6 to electricity, a ratio of 0.42.

generates electricity only, then when one excludes emissions of CO_2 from biogenic sources of carbon in waste, the emissions from incinerators are actually greater than those from conventional gas-fired power stations.

The position improves considerably if the incinerator operates in CHP mode, or where it generates heat only at high efficiencies, but in both cases, the performance relative to gas is still only marginally better. It should be noted that in both cases, it is assumed that the majority of heat generated is put to good use, and this has not always proved possible at incinerators outside areas where the demand for heat is much higher (than here), such as in Scandinavia.

Evidently, performance relative to coal and oil is very good under these assumptions.

Figure 1: Excludes CO_2 from Biogenic Carbon, Heat=0.4 x Electricity



2.2.1 Sensitivity Analysis

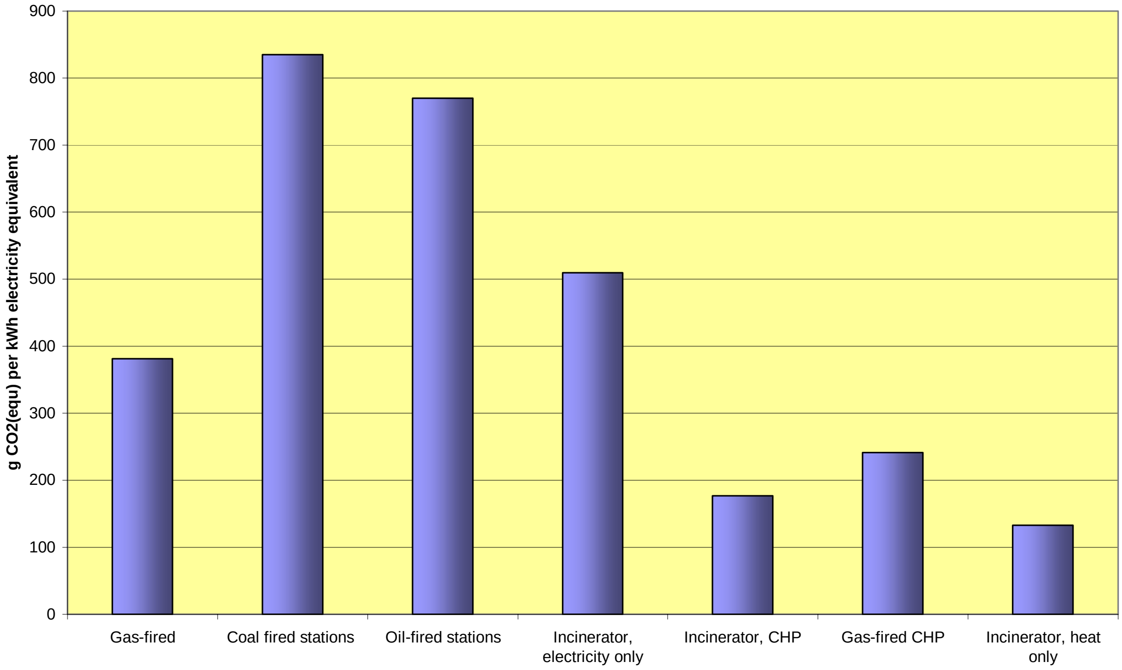
Heat Counted On the Same Basis as Electricity

In the above case, reflecting an (approximate) average electricity generation efficiency in the UK of 40%, each unit of heat energy generated is assumed to count for 0.4 units of electricity equivalent. If heat is counted on the same basis as electricity, then the figures appear as in Figure 2 below. The incinerators generating heat improve, in relative terms, considerably. However, there is no effect (for obvious reasons) on the incinerator generating electricity only.

Biogenic Carbon Included

It has become 'normal' to assume that the emissions of CO_2 from biogenic sources of carbon should be ignored. In some comparisons, this may be valid. In others, it almost certainly is not (see Annex 2). In particular, where, as with some processes, biogenic emissions occur over many years, and where comparisons are being made between technologies which deal with biogenic carbon in different ways, the assumption is almost certainly not valid. It becomes important to account for time-limited sequestration effects.

Figure 2: Excludes CO_2 from Biogenic Carbon, Heat=1 x Electricity



These are – arguably - not important in the case where one is comparing different thermal energy generating processes. However, it is worth highlighting what happens to the picture if one includes biogenic CO_2 emissions. The figures are shown in Figure 3. What happens, of course, is that the performance of the incinerators worsens.

This is important since this figure effectively captures emissions of CO_2 associated with *all* carbon in waste. It suggests that if the proportion of non-biogenic carbon in waste changes without changing the net calorific value to the same degree, then even under the case where CO_2 from biogenic sources are ignored, the CO_2 emissions per unit of energy will increase. This will generally worsen the performance of incinerators. This is taken up below in considering what may happen in the future.

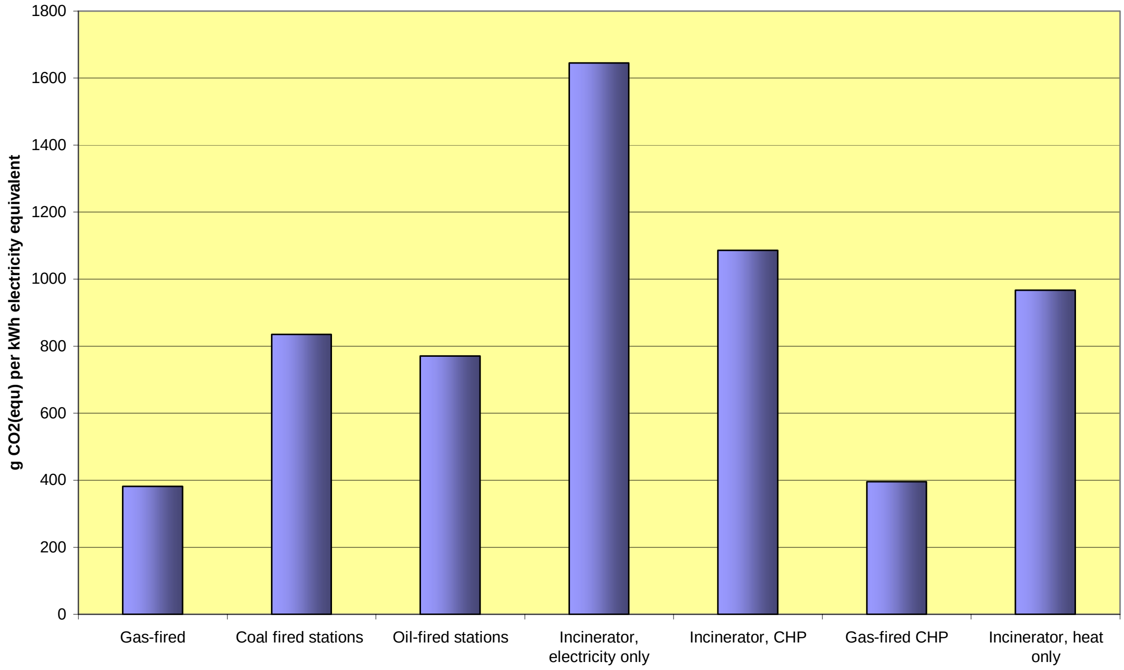
2.2.2 A Look to the Future

Suppose we look forward to 2020 and consider a scenario where England meets the 50 % recycling target proposed in the Consultation Draft Waste Strategy.[9] In the most plausible scenarios, performance at household waste recycling centres is in excess of this, and performance at kerbside collections lags slightly. If we assume that incinerators would be most likely to take residues from ‘bin waste’, whilst residues from HWRCs might continue to be landfilled, then under the most plausible scenarios, the net calorific value of waste increases, but the non-biogenic carbon content increases too. This is because – reflecting experience in more or less every situation where recycling reaches high rates,

[9] Defra (2006) Review of England’s Waste Strategy: A Consultation Document, February 2006.

plastics are not captured so well as other materials. Their 'concentration' is apt, therefore, to increase in residual waste.

Figure 3: Includes CO_2 from Biogenic Carbon, Heat=0.4 x Electricity



Of course, the efficiency of incinerators might increase. But equally, so might the efficiency of other generation technologies, including those using fossil fuels. In what follows, the same figures as were estimated for the current period are estimated for the future. Again, the underlying assumptions are to be found in Annex 1.

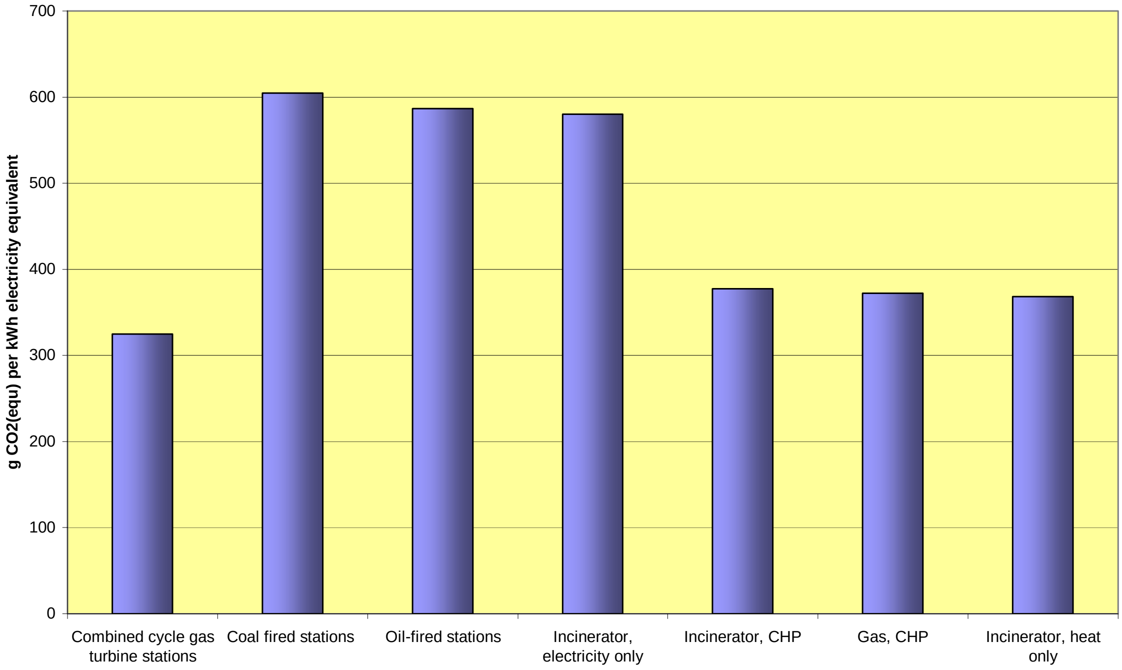
Figure 4 shows that under the scenarios considered, the performance of incinerators may worsen relative to the fossil fuel generating technologies. In this case, where only electricity is being generated, the performance is more or less on a par with oil-fired and coal-fired generation, with gas-fired generation performing far better. Gas-fired generation actually performs better than the case where the incinerator operates in CHP and heat-only mode also.

The reasons for this are:

- The efficiency improvements anticipated in the fossil fuel generation technologies are no less important – possibly more so - than those anticipated for incinerators;
- Whilst the net calorific value of the waste increases, so does the non-biogenic carbon content. The latter rises more quickly than the former. This is principally due to the fact that the assumption concerning the capture rates of materials in the waste stream are such that these are lower for plastics than for other targeted recyclables. The proportion of plastics in residual waste therefore rises. Some might suggest this is speculation, yet rather, it reflects experience in advanced situations in Europe (where, for example, 50% recycling rates are already being

met) and in UK schemes.[10] An important corollary of this is that, contrary to the oft-stated mantra that one should burn plastics to generate energy from them, from a climate change perspective, this would possibly be the least desirable thing to do on the basis that fossil carbon is being burned in facilities with a relatively low level of efficiency of energy generation.

Figure 4: Excludes Biogenic Carbon, Heat=0.4 x Electricity, Future Scenario



It should be noted that some of the fossil fuel technologies – most likely, coal - would improve their performance – at least by this measure – if they were to co-fire with biomass / gasified biomass. In the same way as the incinerators' performance worsens as a result of the higher non-biogenic carbon content of waste, so the performance of the conventional fossil fuel technologies would be improved by reducing the non-biogenic carbon content of the input fuel (though the net calorific value would decline to some extent).

Heat Counted On the Same Basis as Electricity

If heat is counted on the same basis as electricity, then the figures appear as shown in Figure 5. As before, the performance of the incinerators operating in CHP and heat generation modes are improved in relative terms.

Biogenic Carbon Included

The inclusion of biogenic CO_2 has the effect of worsening the position of all the incinerator scenarios (see Figure 6). Fossil fuel generation appears improves significantly in relative terms. The significance of including biogenic carbon will be taken up further below.

[10] One of the reasons why the targets for plastics recycling under the revised Packaging Directive were set so low relative to other materials was related to the low level of capture actually being achieved.

Figure 5: Excludes Biogenic Carbon, Heat=1 x Electricity, Future Scenario

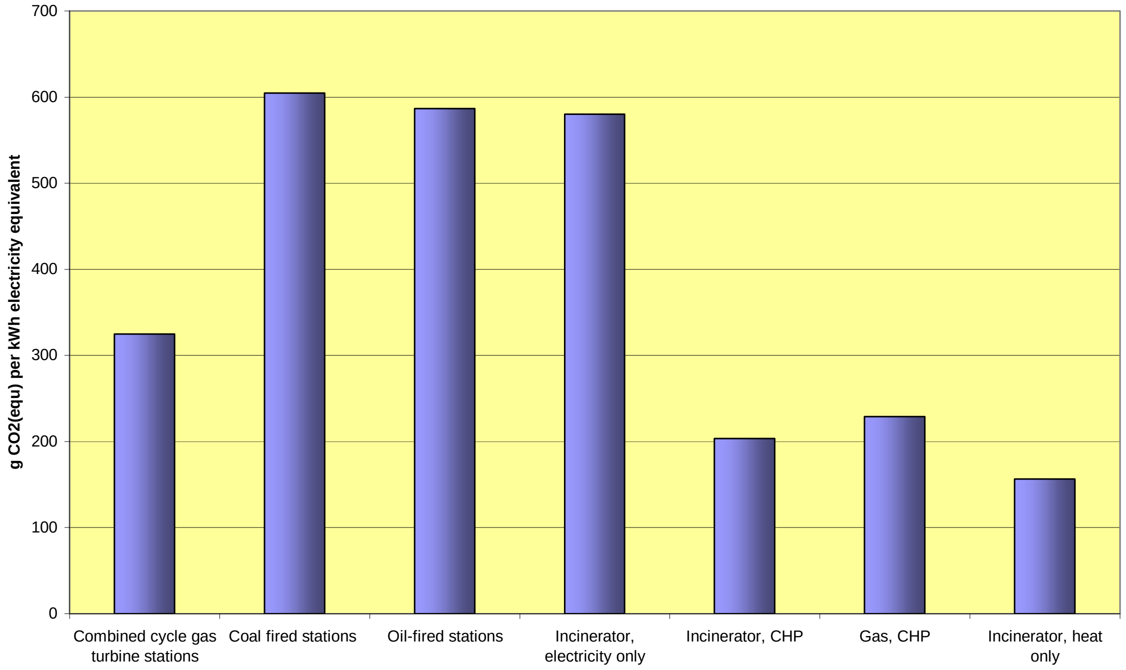
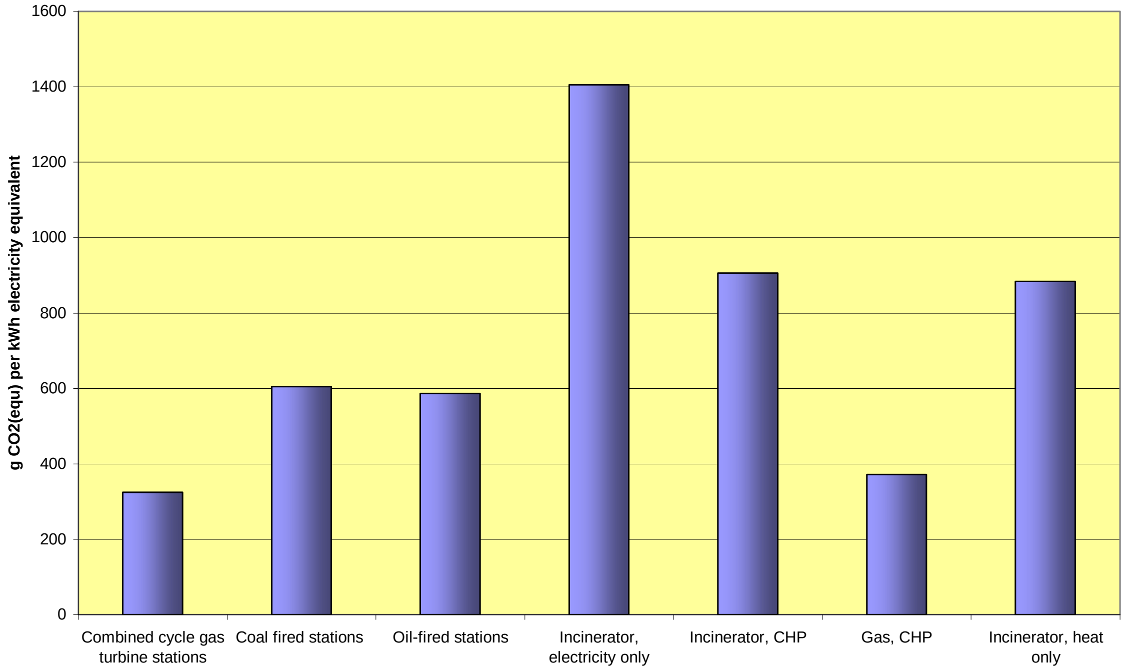


Figure 6: Includes Biogenic Carbon, Heat=0.4 x Electricity, Future Scenario



2.3 Summary

Summary data is provided in Table 1.

Table 1: GHG Emissions (g CO_2 equ per kWh)

Excludes Biogenic Carbon, Heat=0.4 x Electricity	**Current**	**Future**
Gas-fired	382	325
Coal fired stations	835	605
Oil-fired stations	770	587
Incinerator, electricity only	510	580
Incinerator, CHP	341	377
Gas-fired CHP	395	372
Incinerator, heat only	305	368
Excludes Biogenic Carbon, Heat=1x Electricity		
Gas-fired	382	325
Coal fired stations	835	605
Oil-fired stations	770	587
Incinerator, electricity only	510	580
Incinerator, CHP	177	203
Gas-fired CHP	241	229
Incinerator, heat only	133	156
Includes Biogenic Carbon, Heat=0.4 x Electricity		
Gas-fired	382	325
Coal fired stations	835	605
Oil-fired stations	770	587
Incinerator, electricity only	1645	1405
Incinerator, CHP	1086	906
Gas-fired CHP	395	372
Incinerator, heat only	967	884

The assumption that energy from waste incineration ‘helps to combat climate change’ is not so obvious from the above analysis. In particular, where incinerators generate electricity only, as is the case with the majority in the UK:

1. The emissions of GHGs, when biogenic CO_2 is excluded, are likely to be greater for each kWh of electricity generated than those from currently operating average gas-fired power stations (we estimate them to be around 25% higher) though they are likely to be lower than those from currently operating oil-fired and coal-fired generation;
2. In future, the emissions of GHGs per kWh, excluding biogenic CO_2, may, in relative terms, worsen as:
    a. efficiencies of fossil-fuel powered generation increase; and
    b. the proportion of non-biogenic carbon in residual waste increases. This is what is estimated to occur – at least in this analysis - as recycling rates increase over time (though clearly, this is based upon an unrealistic assumption of constant waste composition over the next 14 years).

As regards the future scenarios, much clearly depends upon how the composition of waste changes over time (it may be that plastics production shifts to bio-derived materials, etc.). No one knows *how* waste composition will change over the next fifteen years, but we do know that it will.

The picture is somewhat different where incinerators operate in either CHP, or heat only, mode and where they are operating at high efficiencies of generation with a clear use for the energy generated. In this case:

1. When biogenic CO_2 is omitted, both emit a lower quantity of GHGs per kWh electricity equivalent than any of the fossil fuel technologies. However, even with what are effectively high operating efficiencies (and much higher than the average efficiency of a CHP facility in the UK), the performance gives only a 25% saving relative to average gas-fired generation, raising questions as to the conditions under which this could really be sustained in the UK context;
2. Whether or not this remains the case in the future seems unclear. Much depends upon the relative improvements in efficiency of the fossil-fuel technologies relative to the incinerators. Since the 'heat only' case has been based – for the future - upon an assumption of 100% efficiency relative to the lower heating value of the feedstock, this seems unlikely to be improved greatly (not least since the gross calorific value of waste is typically only 10% or so higher than the net calorific value, and there is likely to be greater convergence as more of the higher moisture content materials are removed for recycling). Consequently, there is a possibility that the benefit that these technologies would appear to deliver in the current context might be eroded in the future.

All of the above assumes that heat is converted to an electricity equivalent through multiplying by a factor of 0.4. The rationale for this is related to the higher quality of energy provided by electricity and the fact that heat is being converted to energy at roughly 40% efficiency. If the factor used is 1, then though the picture for incinerators generating electricity only is unchanged, whilst the picture for those generating CHP or heat only is improved considerably.

It might be argued that the value of heat, relative to electricity, increases as the efficiency of generation of electricity increases. If this view was taken, this would further improve the performance of the processes generating heat where one awards heat a weighting equal to average electricity generation efficiencies.

Crucially, of course, most UK incinerators are currently generating electricity only. Such incinerators cannot unequivocally be said to be contributing to solving the problem of climate change. This depends upon various assumptions, notably – as is clear from the analysis above - the source of energy which one assumes is being 'displaced' by the generation of energy from waste by incinerators.

We have commented elsewhere that this argument is not likely to be easily resolved, precisely because lobby groups – including the incinerator industry and environmental

NGOs – know that the assumption used has a material influence on the outcome of any comparative analyses:[11]

> *The significance of this discussion is that, depending upon the viewpoint adopted (and it seems unlikely that there will be agreement as to which assumption should be carried forward because of the different interests involved), the 'avoided emission' credited on the basis of energy produced from waste can change radically.*

Over recent years, the Environment Agency has, in its life-cycle tool, WISARD, upheld a view that the displaced source of energy was coal, and sensitivity analysis was rarely ((if ever) applied.[12] Customs & Excise assumed an 'average mix' of power generation was being displaced, though some sensitivity analysis was applied to look at the cases where coal-fired and gas-fired generation, respectively, were assumed to be displaced.[13] ERM, in recent work for Defra, assumed it was electricity from combined cycle gas turbine (CCGT) generation that was being displaced.[14]

Clearly, there is something less than unanimity across different Departments and Agencies where this matter is concerned. However, if one takes the same assumption used by ERM in the context of their analysis supporting the Consultation Draft of the Waste Strategy, then where incinerators generate electricity only, they almost certainly do *not* lead to a net reduction in GHG emissions, even if one ignores those emissions associated with biogenic materials. This casts some doubt, therefore, upon the virtually unanimous claim that energy from waste incineration is 'good for climate change'. It is reasonable to state that it might not be, and that where such claims are made, they ought to be based on analysis of the facts.

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[11] Eunomia et al (2002) *Economic Analysis of Options for Managing Biodegradable Municipal Waste*, Final Report to DG Environment, European Commission.

[12] See, for example, the letter from the Environment Agency in the context of the Public Inquiry into the East Sussex and Brighton and Hove Waste Local Plan, 'Comments on Eunomia's Report for FoE in Relation to the Criticisms and Comments on WISARD', 10 June 2003. This letter sought to justify the choice of coal as the displaced source, and made little reference to any need for, let alone the desirability of, sensitivity analysis. The justification was based around 'marginal' sources of energy even though incinerators are not sources of energy that tend to be switched on or off at any given time.

[13] HM Customs & Excise (2004) Combining the Government's Two Heath and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration, December 2004

[14] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

3.0 ISN'T INCINERATION THE MOST CLIMATE-FRIENDLY FORM OF RESIDUAL WASTE TREATMENT?

Even if one accepts that energy from waste incineration might not deliver the climate change benefits some have claimed for it relative to other energy generation technologies, surely, some might say, it is the best thing to do with residual waste? It has become common to state that we should treat waste 'as a resource'. This is frequently deemed to be synonymous with generating energy from waste, and improving the position in respect of climate change. Shouldn't we seek to incinerate waste to generate energy? Isn't the energetic content of plastic just too good to pass up?

This is often the logic used to promote the combustion of material for the purposes of generating energy. Indeed, it is almost taken as axiomatic, for example, that incineration is preferable to landfill when the two are compared from the perspective of climate change. However, a number of studies are starting to challenge this assumption.[15] Not least amongst these is the work by HM Customs & Excise, based upon work commissioned by Defra.[16]

One of the reasons for this is that Defra studies appear to suggest a very high rate of capture of landfill gas. Ministers, officials, journalists and some environmentalists, not to mention many consultants, routinely refer to the fact that landfills are poor performers when it comes to climate change because '*they generate methane*'. But generating methane does not mean that landfills *must* be poor performers when it comes to climate change. It is well-known that landfills collect landfill gas from the generation of energy, and indeed this is a requirement of the landfill directive. Consequently, *if* methane was assumed to be captured at a high rate of efficiency, then the fact that landfills generate

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[15] Two Dutch studies carried out recently make interesting reading. The first, by Dijkgraaf and Vollebergh, suggested that on a cost benefit basis, landfill was rather superior to incineration but principally on the basis of its lower cost. The second, by Bartelings et al, was undertaken with the support of VROM, and this seemed to confirm the findings of the first study. See Dijkgraaf, E., and H. Vollebergh (2004) Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods, *Ecological Economics*, 50, pp.233-247; Bartelings, H., P. van Beukering, O. Kuik, V. Linderhof, F. Oosterhuis, L. Brander and A. Wagtendonk (2005) *Effectiveness of Landfill Taxation*, R-05/05, Report Commissioned by Ministerie von VROM, November 24, 2005. For additional review and comment, see Dijkgraaf, E. and H. Volleberegh (2005) Literature Review of Social Costs and Benefits of Waste Disposal and Recycling, in *Rethinking the Waste Hierachy*, EAI: Copenhagen, pp. 80-98 and D. Hogg (2005) *Costs and Benefits of Residual Waste Management Options – What Should We Do?* Paper presented to the ORBIT / ECN Conference on the Future of Residual Waste Management in Europe: Future Challenges Regarding Climate Change and Sustainable Material Flow Management, 17-18 November, Luxembourg, http://www.orbit-online.net/orbit2005/vortraege/hogg-doc.pdf

[16] This includes the body of work consisting Enviros, University of Birmingham, RPA Ltd., Open University and Maggie Thurgood (2004) *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*, Final Report to Defra, March 2004; HM Customs & Excise (2004) *Combining the Government's Two Heath and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration*, December 2004.

methane, which can be used to generate energy, far from being a problem, potentially becomes a virtue.

It is interesting to note, therefore, that the most recent studies being carried out on behalf of government propose levels of landfill gas release to the atmosphere of 15% or so. At these levels of capture, if one could believe them, the generation of methane might be something to be encouraged, not to be seen as problematic.

Given that the statement that 'energy from waste incineration is good for climate change' might not necessarily be true, it is interesting to see how incineration compares in a comparative analysis with other residual waste treatment technologies.

These and other issues are explored in what follows.

3.1 Methodological Issues

Before embarking on the analysis, it is worth teasing out some of the key methodological issues regarding the relative performance of waste management technologies as regards climate change. These are discussed in more detail in Annex 2.

1. In a comparative analysis of different waste treatment technologies, the assumption that emissions of CO_2 related to biogenic carbon should be ignored cannot be valid where the technologies deal with biogenic carbon in different ways. The atmosphere does not distinguish between those CO_2 molecules which are from biogenic sources and those which are not. Consequently, if one type of technology 'sequesters' some carbon over time, then this function needs to be acknowledged (it effectively negates the basis for distinguishing between biogenic and fossil sources of carbon on the basis that the one is 'short-cycle' and the other is 'long-cycle' – after all, how long is 'short' and long is 'long', and when could one period said to become the other?);[17]
2. The timing of emissions of GHGs is important in understanding impacts. There is a clear difference, from the point of view of impacts and from the perspective of policy, between a process which emits all associated GHGs after one hour, and one that emits the same GHGs in one day after fifty years;
3. For these reasons – that the time profile of emissions is important – conventional life cycle analysis is unhelpful. Conventional lifecycle analysis determines (somewhat arbitrarily) a cut-off time and counts all emissions occurring before that cut-off, and none that occur after it. Those that occur before are treated equally, irrespective of whether they appear in the first second, or in the last second before the cut-off point.
4. The correct approach would be to allocate emissions to different years and understand the contribution of GHGs to climate change through understanding their contribution over time. This implies use appropriate application of discounting. Though the appropriate rate of discount is still under discussion (and has a bearing upon the social costs of carbon calculated), we have followed the approach recommended by the Treasury in the Green Book. Such an approach

[17] Further explanation of the approach is given also in Eunomia et al (2002) *Economic Analysis of Options for Managing Biodegradable Municipal Waste,* Final Report to DG Environment, European Commission.

provides, it is argued here, a far better basis for understanding relative impacts than life-cycle studies which arbitrarily draw a cut-off point in time. Other things being equal, society might prefer – in the current context – a delay in emissions rather than their immediate increase (and this is captured through discounting). Equally, the most recent work on the Social Costs of Carbon proposes discusses the application of different scenarios using different rates at which the social costs might be estimated to increase over time;[18]

The following analysis, therefore, includes all sources of greenhouse gases, biogenic and non-biogenic, and compares their contribution over time through assuming:

- Unit damage costs, and escalation in these, given by Table 2. These have been taken from the recent review of the social costs of carbon. These were, in turn, devised to assist in policy-making. Only the 'Central Guidance' figures which appear in the Table have been used for ease of presentation of results. This would be appropriate for project-type appraisals where a basis for a decision would be sought (as, for example, in real-world local authority decisions being taken today);
- A time profile for the discount rate as recommended in the Treasury's Green Book which shows a decreasing discount rate over time.

It should be noted that the rate of escalation in the unit damage costs (which depends upon the scenario used from Table 2) relative to the effects of the discount rate will have a bearing upon the relative performance of processes for which emissions occur over an extended period of time, against those processes where emissions occur on day one.

All electricity generation is assumed to displace gas-fired generation at current average performance. All heat generation is assumed to displace gas-fired heating. All electricity use is assumed to lead to emissions based upon UK average electricity generation. These are the same assumptions as were made in the ERM study.[19]

Table 2: Example Shadow Price Values from the Study, consistent with Recommendations (£/tonne carbon)

Year of emission	Central guidance	Lower central estimate	Upper central estimate	Lower bound	Upper bound
2000	55	35	130	10	220
2010	65	40	160	12	260
2020	80	50	205	15	310
2030	100	65	260	20	370

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[18] See Paul Watkiss, David Anthoff, Tom Downing, Cameron Hepburn, Chris Hope, Alistair Hunt, and Richard Tol (2005) *The Social Costs of Carbon (SCC) Review: Methodological Approaches for Using SCC Estimates in Policy Assessment*, Final Report, November 2005.

[19] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

2040	140	90	330	25	450
2050	210	130	420	30	550

Source: Paul Watkiss, David Anthoff, Tom Downing, Cameron Hepburn, Chris Hope, Alistair Hunt, and Richard Tol (2005) The Social Costs of Carbon (SCC) Review: Methodological Approaches for Using SCC Estimates in Policy Assessment, Final Report, November 2005.

3.2 Analysis

The following residual waste treatments have been examined:

1. Incineration generating electricity only with no recovery of metals;
2. Incineration generating electricity only with recovery of steel;
3. Incineration generating electricity only with recovery of steel and aluminium;
4. Incineration generating heat with recovery of steel and aluminium;
5. Landfill with a life-time rate of gas capture of 75%;
6. Landfill with a life-time rate of gas capture of 50%;
7. Landfill with a life-time rate of gas capture of 25%;
8. Aerobic MBT configured to:
    a. extract steel and aluminium;
    b. stabilise material prior to landfilling;
9. Aerobic MBT process designed to:
    a. extract steel and aluminium;
    b. dry material, prepare a refuse-derived fuel (RDF[20]) for subsequent use in a dedicated (i.e. to treating waste) fluidised bed incinerator;
10. Aerobic MBT process designed to:
    a. extract steel and aluminium;
    b. dry material, prepare a RDF for subsequent use in a cement kiln;
11. MBT process making use of:
    a. Using fines in an anaerobic digester to generate energy; and
    b. Stabilising digested material and larger sized organic fraction prior to landfilling;
12. As 11, but including segregation of metals;

[20] There are all sorts of terms being used to describe 'the stuff which might be burned' in power plants that is derived from waste through pre-treatment. RDF seems to us a reasonable one, even though there are debates ongoing as to whether this is really a fuel. The term Solid Recovered Fuel begs the question as to whether the material is a fuel, and whether it has been or will be 'recovered'. This takes us into the definition of recovery, which is taken up in greater detail in Section 4.2.

13. As 11, but including segregation of metals and plastics.

This is by no means a complete list of possibilities. However, it will serve the purpose of highlighting which factors make the performance of a residual waste treatment facility better or worse, and how this might influence research into future developments in residual waste treatments. Additional details are given in Annex 3.

The results are shown in terms of damage costs - expressed in £ per tonne associated with the greenhouse gas emissions from different treatments - in Figure 7.

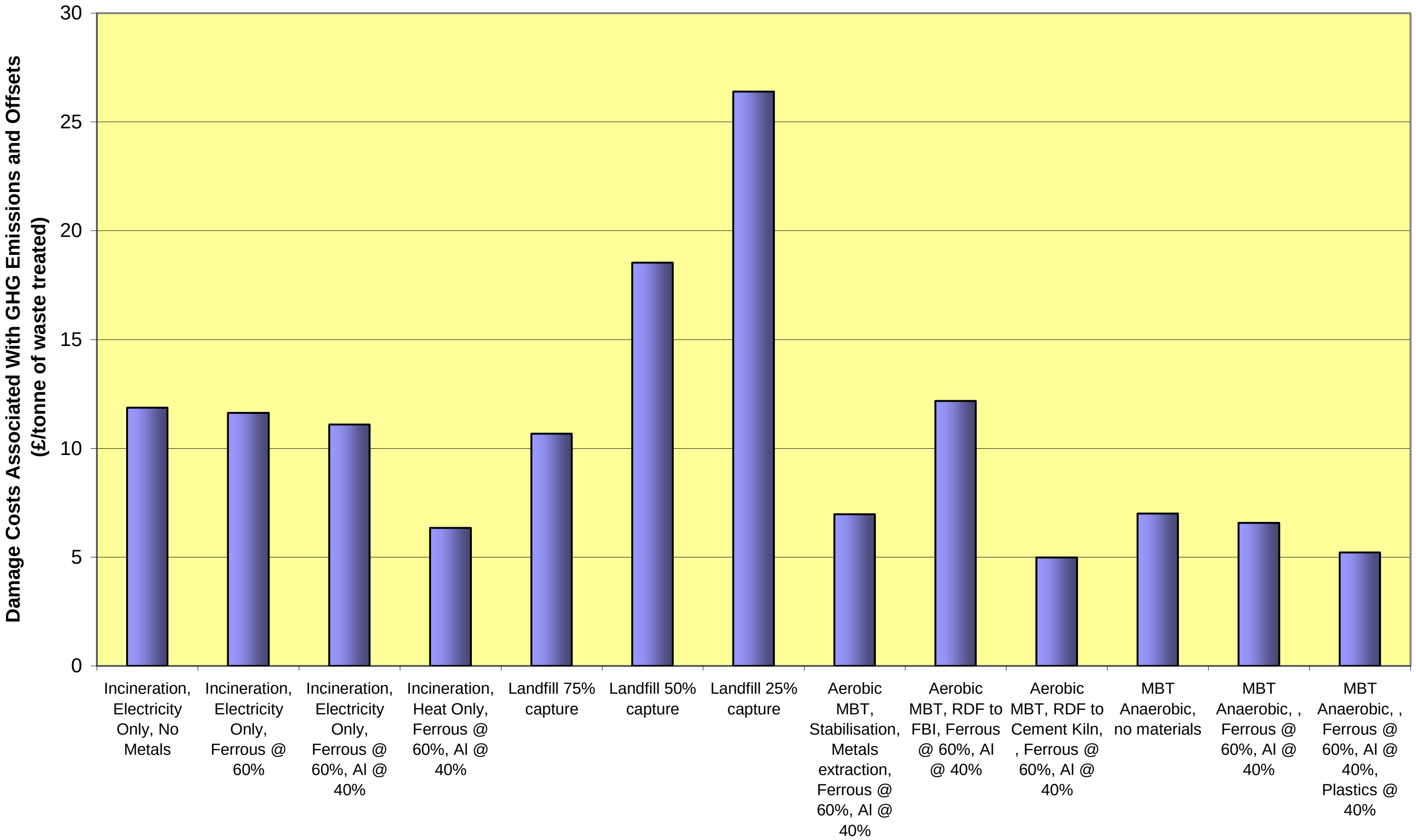
The results are noteworthy for the following reasons:

- The differences between landfill and incineration – where the incinerator generates electricity only - are barely discernable where the captures of landfill gas are assumed to be high (as they have been consistently in work for Defra over recent years). However, as the captures are reduced, then the performance of landfills worsens considerably.
  This is important since there is very little by way of field measurements to substantiate the use of the high gas captures being posited in Defra studies over the lifetime of the landfill (and hence, over the period during which gases are being emitted from a tonne of waste in the landfill). Instantaneous gas capture rates may reach, even exceed, 50%, but instantaneous rates are certainly not the same as lifetime rates. Dutch field measurements give figures between 10-55% for instantaneous gas capture rates, and average rates of around 25%, whilst default figures for reporting to IPCC are likely to be specified at around 20%.[21] A forthcoming report in the US, co-authored by one of the early installers of landfill gas capture systems there, suggests the amount captured over the landfill's lifetime is likely to be around 19%.[22]

[21] Personal communication with Hans Oonk.

[22] Personal communication with Peter Anderson. This type of analysis is beginning to acquire significance in the context of Joint Implementation projects involving landfill gas capture systems. The credits, in terms of GHG reductions which these can be credited with, depend upon the gas capture efficiencies being assumed.

Figure 7: Social Costs of GHG Emissions from Residual Waste Treatments



This makes the figures used in Government studies appear rather high, one effect being (interestingly) to undermine one of the principle arguments for changing how the UK manages its waste (i.e., that based upon climate change benefits);[23]

- Where the incinerator generates heat only – the 'maximum' position as far as energy generation is concerned (and the assumption used here is that 90% of the lower heating value of the waste is actually put to a useful purpose as heat) – then the performance is much improved. Indeed, perhaps as expected, this performs better than any other 'dedicated' thermal option. Only a process generating RDF for combustion in cement kilns, in which the material is clearly shown to displace coal, and an AD-based MBT process which recovers metals *and* plastics, performs better. At these performance levels, the differentials are small and a clear decision as to whether one is 'better' or 'worse' is likely to be difficult to make in any hard and fast manner;
- The basic MBT stabilisation techniques perform quite well. Stabilisation processes lead to emissions of CO_2, and small quantities of nitrous oxide (N_2O) and methane (CH_4) in the short-term. They also use energy. However, none of the fossil carbon is released. The biogenic carbon which remains in the landfilled waste is (by definition) of a slowly degrading nature. If the material is landfilled in a cell with an active composting layer on the surface, oxidation rates through the cap may be sufficient to ensure that the relatively slow methane fluxes are oxidised prior to their release to the atmosphere;
- Where RDF is prepared for use in a fluidised bed incinerator (FBI), the performance is marginally worse than at the incinerator. The situation is, again, somewhat marginal, and sensitive to assumptions made concerning the relative efficiency of the two types of incinerator (amongst other things) and the quantity of fuel, and its net calorific value, derived from the pre-treatment process;
- The situation is improved where the material is combusted in a dedicated industrial or power generation facility, such as a cement kiln, but this is only the case as long as the material genuinely displaces fossil fuels which are being used at the plant (as is assumed here). This might not *always* be the case, for example, where the RDF displaces other waste materials (for economic reasons), or cleaner fuels. Where it does happen, the reason for improved

[23] In the work by ERM, it appears that only 15% of the emissions escape to the atmosphere (it is not clear what is assumed regarding oxidation at the cap) (ERM (2006) *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions*, Final Report for Defra, January 2006). In work for Defra by Enviros, best practice was assumed to be an efficiency of gas capture of 80% (Enviros, University of Birmingham, RPA Ltd., Open University and Maggie Thurgood (2004) *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*, Final Report to Defra, March 2004). As we show below, even without any discounting of the emissions, work by HM Customs & Excise based upon the study by Enviros et al shows, at these rates of capture, that incineration performs worse than landfill in terms of GHGs (HM Customs & Excise (2004) *Combining the Government's Two Heath and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration*, December 2004).

performance is that the displacement effect is 'direct'. Where the displacement is 'indirect', and is of electricity (at incinerators), the relative efficiencies of the different processes – incineration and power generation - in generating electricity is an important factor in suppressing the relative performance of incinerator.

- Where MBT processes employ anaerobic digestion as part of the process, it is possible to generate energy in the process. However, the quantities generated are not great, though more than sufficient to offset requirements to operate the plant. If the material from the digester, as well as oversized organic fractions, is stabilised prior to landfilling, the performance is rather similar to that of the aerobic stabilisation process.
- Importantly, where the MBT facility seeks to extract plastics from the residual waste stream, and where that material is deemed of adequate quality for recycling, then the performance improves quite significantly. This is a potentially important point. Many separation processes are increasing in terms of their efficiency, especially where wet materials are targeted effectively for source separation (improving the effectiveness of separation techniques). It remains unlikely that paper and card and organics can be separated from residual waste in such a way that the quality of the material so derived will be acceptable to end users (though it may be possible to do this for some of the organic fraction using more advanced wet separation techniques, which may be particularly appropriate following digestion). Consequently, this type of approach should be considered not as a substitute for, but rather as a complement to, quality source separation schemes. This point is examined in more detail in Box 1.

3.3 Results

For some, it will come as a surprise that incinerators which generate electricity only perform relatively poorly in the analysis. Yet perhaps one should not be so surprised. The government's own research would tend to suggest that at high levels of methane capture, then as long as a reasonable proportion of the gas which is captured is used to generate energy, then even in studies where time is accorded no significance, landfills actually perform better than incineration where climate change is concerned. This work – by HM Customs & Excise[24] – was based upon emissions data from what was presented as an authoritative work on the health impacts of waste management.[25] The study clearly indicated that the climate change impacts of incineration were worse than those of landfill, even taking into account the offsets associated with energy recovery. Given that the purpose of the body of work was to elicit whether incineration should be subject to an environmental tax, then given that – according to the analysis – landfill performs better, it

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[24] HM Customs & Excise (2004) Combining the Government's Two Heath and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration, December 2004.

[25] Enviros, University of Birmingham, RPA Ltd., Open University and Maggie Thurgood (2004) *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*, Final Report to Defra, March 2004.

is not clear why the decision was taken not to introduce such a tax given the outcome of the study.

Box 1: What's the Best Thing to do With Plastics Remaining in Residual Waste?

It is interesting to look at the plastics in residual waste. In the waste stream at present, within a typical tonne of waste, plastics might contribute some 2.6GJ of energy (expressed in terms of lower heating value). This is equivalent to 724 kWh of energy. If 100% of this was converted to electricity, the displaced emissions of GHGs would account for some 276kg of CO_2. At typical efficiencies of generation (net), the displaced emissions are of the order 58kg CO_2.

These plastics (within a tonne of residual waste) are estimated to contain 59kg of carbon. Their combustion would therefore release around 217kg CO_2, all non-biogenic, into the atmosphere. It is quite clear that only if the efficiency of electricity generation at the incinerator approached 100%, which no one is suggesting is remotely possible, could the combustion of plastics in incinerators recovering electricity only be seen to do anything other than contribute to increases in CO_2 emissions into the atmosphere. Indeed, at typical efficiencies of electricity generation in incinerators, the net contribution of CO_2 to the atmosphere from the plastics is around 159kg CO_2 equivalent, even though this material constitutes only 8.8% of the waste stream in our modelling.

If the same plastics were recycled, then using figures from ERM's report for Defra (which are from the Ecoinvent database), the *savings* in CO_2 emissions would be of the order 205kg CO_2 equivalent. Assuming a 40% capture of these materials – which begins to look possible as separation technologies improve – this would imply savings of the order 82kg CO_2 equivalent.

Table 3 illustrates the point further by showing the potential CO_2 savings to be gained from capturing different materials in the residual waste stream at a 100% capture rate. The figures are shown in a quite deliberate order in that the first two are already being captured by various residual waste treatment plants (MBT facilities and incinerators). Plastics are not being captured by many facilities but the possibilities here exist at MBT plants. Glass is also being separated off from residual waste but usually as part of an 'inerts' stream including grit and gravel. Consequently, recycling back into container glass is not usually possible (so the savings suggested here are not being realised). Textiles and paper and card present other problems associated with quality. Plastics, therefore, not only present possibilities, but offer the greatest potential for savings of all the materials likely to be present in residual waste.

It would seem that there might be quite interesting implications to be drawn from this analysis for the future development of technologies for treating residual waste in the United Kingdom. It would appear that the preferred approach to dealing with plastics from a climate change perspective is not 'using them to generate energy' in incinerators equipped to deliver electricity only since it is extremely difficult – impossible at present – to generate energy from the plastics in such a way that the emissions of CO_2 which result could be sufficiently offset by the generation of electricity from their combustion. On the other hand, the possibility for 'climate credits' from recycling plastics is possible, and with separation technologies improving, this is becoming quite feasible.

Table 3: Potential CO_2 (equ) Savings at 100% Capture from Residual Waste

Material	CO_2 (equ) Savings (kg CO_2 (equ) per tonne residual waste)
Ferrous metals	24
Non-ferrous metals	81
Plastics	205
Glass	64
Textiles	157
Paper and card	113

The debate concerning whether landfills or incinerators perform better or worse in respect of climate change turns on a number of key variables:

- the rate of capture of landfill gas;
- the quantity of landfill gas that is captured that can be usefully employed in the generation of energy;
- assumptions concerning the rate of oxidation through the cap (and in leachate) of methane which is not captured by the gas collection system;
- whether or not one includes biogenic carbon in the analysis;
- whether or not one incorporates an approach based upon discounting to account for the time profile of emissions;
- the efficiency of generation of energy associated with the incinerator;
- the source of energy one assumes is being 'displaced' by the energy generation process; and
- to a degree, though this is probably only decisive where other assumptions bring the performance of the two technologies close together, the composition of the waste.

Each one of these has an important bearing upon the analysis. However, because Defra has been inclined to use high figures for lifetime gas captures from landfills, the performance of landfills and incinerators regarding GHGs is rather similar, and indeed, as Table 4 below shows, the work by HM Customs & Excise, based upon emissions data from the Defra-sponsored Health Effects study,[26] clearly illustrated landfill's impact as being less than that of incineration. It can be seen from the Table that even if *all* the benefits (from energy generation) were related to climate change emissions (some are related to SOx, NOx, VOCs and particulate matter), the climate change impacts of incineration would still be greater than those from landfill (under either landfill scenario).[27]

The relative performance of incineration improves where (as with the ERM report) biogenic carbon is omitted, and time is rendered more or less irrelevant through the adoption of a life-cycle approach which counts all emissions equally if they occur before a cut-off point, and ignores them if they occur thereafter. But omitting biogenic carbon from the analysis can *only* be justified if biogenic carbon is treated in the same way by the technologies being compared. Since this is clearly not true, the assumption cannot be deemed valid and essentially biases the analysis against those treatments which act as

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[26] Enviros, University of Birmingham, RPA Ltd., Open University and Maggie Thurgood (2004) *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*, Final Report to Defra, March 2004

[27] The report assumed, in the central scenario, displacement of electricity generated by 'UK average mix', but carried out sensitivity analysis in which coal was assumed to be the displaced source of energy. As expected, and as other studies show, the use of the assumption that coal is the displaced source of energy is favourable to technologies which generate energy relative to those which do not.

what one might describe as 'time-limited sinks' for biogenic carbon (such as landfill, processes involving the stabilisation of waste followed by landfilling, and – though not considered here – composting, where material containing organic matter is spread on land, and the carbon is mineralised from more- and less-stable pools of carbon over time).

Table 4: Externalities from Landfill and Incineration, Including GHG-related Externalities

Externality	Incineration with Energy Recovery	Landfill (medium) – Gas Flared	Landfill (medium) – Gas Used to Generate Electricity
Costs	-19.11	-9.83	-12.04
Of which			
CO_2	-£19.09	-£3.82	-£5.73
CH_4	-£0.01	-£5.99	-£6.30
Benefits	£6.16	n/a	£2.15
Net Costs	-12.95	-£9.83	-£9.89

Source: adapted from HM Customs & Excise (2004) Combining the Government's Two Heath and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration, December 2004

All this having been said, the levels of landfill gas capture being used within UK studies do not appear to be justifiable on the basis of field measurements. It is important to distinguish between the levels of gas capture that might be achievable at a given moment in time where a landfill is performing in a relatively well-behaved manner, and the levels that are likely to be achieved over the lifetime of waste once it is deposited in the landfill. It is not clear that the significance of this distinction has been appreciated, either for comparative analyses of waste treatment technologies, or for the reporting of emissions of (uncaptured) methane from landfills in the UK in any given year.

Ironically, the presumption of high levels of capture of methane from landfills largely undermines the argument for moving residual waste away from landfill and towards incineration for reasons based related to climate change. If one assumes low rates of capture of landfill gas, then the (relative) case for incineration with electricity generation improves. Incineration with electricity generation only is, however, far from being the best approach from a climate change perspective.

Of the energy generating technologies, incinerators which generate heat at high rates of efficiency, and put this to good use, fare best. Also performing well are approaches which derive RDFs for use in industrial facilities, these performing well subject to the caveat that they a) genuinely contribute to energy generation in the facility (which depends upon the quality of the RDF) and b) displace fossil fuels (as opposed to, for example, other waste materials), the performance being best where the displacement is of coal. Evidently, if the former is untrue, or if the latter is questionable, performance is much worse than suggested here

The above discussions concerning landfill gas captures do not affect the relatively good performance of basic stabilisation processes which seek to reduce the potential for methanogenesis once waste is deposited in landfills (which again, would be of less benefit if landfills really did capture methane at very high rates). The majority of the GHGs emitted in these processes are CO_2 emissions before the material is landfilled (these are also those which are undiscounted as they occur in a matter of weeks following the commencement of the process). Consequently, even though this process uses energy, and even though it does not *generate* energy (though it recovers some aluminium and steel), the net position as regards GHGs is relatively good (partly because the carbon in the non-biogenic materials is not released to the atmosphere, and as Box 1 shows, it is very difficult to offset these through the generation of energy).

This performance will vary with the level of stabilisation which is achieved through such processes, and will also vary with the way in which the landfill to which the material is sent is actually managed. It is, perhaps, interesting to note that one effect of the Environment Agency's approach to the assessment of MBT facilities in respect of their contribution to reducing the biodegradable content of waste being landfilled is that those operating stabilisation processes can send material to landfill which is more, or less stable. This is potentially problematic for the handling of such residues delivered to landfills. The whole concept of stabilisation was developed on the basis of seeking to make landfills less problematic. Depositing stabilised material into landfills and using active layers of cover material can have the effect of reducing emissions of methane close to zero. But allowing material with varying levels of stability to be sent from stabilisation processes to landfill potentially foregoes some of the beneficial performance of the concept for the sake of an interesting accounting convention.

There would seem to us to be a clear case for differentiating the rate of landfill tax so that a lower rate – although not necessarily the rate applied to inert waste – applies to material which is landfilled following a stabilisation process, subject to specific standards for the output material being met. These could easily be set given that stability measurements will already have been made under the Environment Agency's performance measurement system, at least where municipal waste is being treated.

The clear advantage of such a policy would be that those local authorities seeking to introduce technologies to improve their balance of landfill allowances, and to do so in the short-term, have, in stabilisation technologies, a fairly simple and - from a climate change perspective - effective solution with a relatively short lead time. However, the costs are currently unreasonably inflated by the application of a landfill tax to material which barely generates methane at all, even though the basis for the tax has largely been predicated upon the likely emissions of methane from landfills.

The existing situation simply makes an obvious solution less affordable for local authorities, and could, arguably, be encouraging the marketing of processes on the basis of their contributing to 'composting' targets, when the responsible approach would be to landfill the residue or, in circumstances where certain (yet to be established) standards could be met, in one-off landscaping applications (e.g. to restore eroded slopes etc.).

4.0 CLIMATE CHANGE AND WASTE MANAGEMENT – OTHER KEY ISSUES

4.1 What are the Prospects for Energy from Waste Being Considered Acceptable from the Public Perspective?

The recent consultation draft waste strategy proposes that energy from waste might be responsible the 25% of municipal waste management in the year 2020. Some express concern at this figure. Somewhat more worrying is the fact that the strategy appears to give considerable emphasis to the role of incineration in respect of the generation of energy from waste. It is, after all, well-known that incineration is not an especially popular technology when it is proposed in the context of waste strategies within the United Kingdom.

A more generous reading, however, might suggest that Defra has in mind a broader concept of energy from waste. Incineration is not, after all, the only way of generating energy from waste. The consultation draft waste strategy appears to acknowledge that there is little prospect of England meeting its landfill directive targets without a considerable increase in the rate of recycling and composting in the short to medium term. Given the lead-times associated with incineration, the likelihood of considerable growth in capacity over the next five years or so is limited.

So where will the best prospects for energy from waste lie? Are there any technologies for generating energy from waste (other than landfill) which might be more popular, and which might have a role to play in the short to medium term?

As hinted at above, the strategy appears to acknowledge that in the short to medium term, greater separation at source of wastes, especially biodegradable wastes, will be desirable, not least since this has a major role to play in delivering landfill directive targets. Currently, nearly all source segregated biowastes are being sent for aerobic treatment. Yet source segregated biowastes are a potential source of energy. The consultation draft waste strategy is relatively silent on the role of anaerobic digestion. The technology does figure in the ERM report, but the data in use in that report suggests a figure for gross electricity generation which is approximately one tenth of what most suppliers would be aiming for.[28]

If, in the near future, more and more local authorities begin to focus on the source separation of biowastes, including food wastes, then surely this might be a sensible source of energy? Those who might otherwise object to energy from waste on grounds that it 'crowds out recycling' could hardly be taken seriously when the source of energy is source-segregated biowaste. It seems strange, therefore, that the potential role of anaerobic digestion is not the subject of greater debate, or indeed, that it is not pursued more enthusiastically as a treatment for biowastes. It is quite well established that food

[28] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

waste is one of the largest fractions, if not the largest fraction, of the household waste stream. Such material, as well as some garden wastes and cardboard which is of too low a grade to recycle (e.g. because of food contamination), is ideal for digestion.

Suppose that one assumes that 20% of 'bin waste' is food waste (an average of the figure used in the ERM report, based on work undertaken for the National Assembly for Wales, and that produced for the Strategy Unit by Julian Parfitt). Suppose also that garden waste constitutes 14% of 'bin waste' arisings. Data for the different administrations in the UK suggests that total 'bin waste' arisings are likely to have been of the order 25 million tonnes in 2005/6. From this, bin waste might be assumed to contain:

- 5 million tonnes food waste; and
- 3.5 million tonnes garden waste.

Some estimates of biogas generation from suppliers which were gathered in the context of work in Northern Ireland are shown in Table 5. It seems reasonable, on the basis of these figures, to use a figure of 80m^3 methane per tonne of wet waste input from either kitchen waste only or kitchen and garden waste combined.

Assuming 33% efficiency of electricity generation from the biogas, and assuming a parasitic load of 7.5% of energy generated (figures are typically between 5% and 10%), then some 244kWh per tonne of wet waste is generated. It almost goes without saying that with the exception of any fuels brought in from off-site, the electricity is generated without emissions of non-biogenic CO_2, and the methane is captured for combustion.

If UK authorities were collecting and digesting 70% of the available biowaste today, then this would generate a total of 1.45 TWh of electricity under the assumptions above. This is around half of what was estimated by Oakdene Hollins to be possible from residual waste by 2010 under assumptions taken from the Strategy Unit analysis (including a 2% per annum growth rate in total waste) and using what are very high efficiencies of generation, which were also applied (erroneously) to gross, as opposed to net, calorific values.[29] Evidently, a greater quantity of electricity could be generated if one included industrial and commercial organic wastes, whilst alternative outputs could include heat, the use of biogas (once upgraded and compressed) as vehicle fuel, and possibly in the context of fuel cell development.

The argument here, therefore, is that since the Review of England's Waste Strategy appears to have recognised the need to move to higher recycling and composting rates, then why not take the opportunity to generate energy from the process of biowaste recycling? AD provides an opportunity to generate both a soil improver and energy in the process. Is this not a sensible option to pursue?

[29] Oakdene Hollins (2005) *Quantification of the Potential Energy from Residuals (EfR) in the UK*, Report for the Institute of Civil Engineers and the Renewable Power Association, March 2005, http://www.ice.org.uk/downloads//energy_from_waste.pdf; CIWM (2006) *CIWM Position Statement Energy Recovery From Waste*, February 2006, http://www.ciwm.co.uk/mediastore/FILES/12321.pdf. See Annex 4 for further discussion of the report.

Table 5: Biogas Production in Plants

Feedstock	**Kitchen and Garden**	**Kitchen and Garden**		**Kitchen and Garden**		**Kitchen**	**Kitchen and Garden**
Retention Time (days)	21	16	21	14	16	25	25
Gas production per kilogram wet waste (m3 biogas/tonne input waste)	120	110	150	122	138	140	170
Methane production per tonne wet waste (m3 methane / tonne input waste)	55%	56%	62%	60%	65%	61%	59%
Methane production per tonne wet waste (m3 methane / tonne input waste)	66	75		76	86	85	100

Source: Eunomia (2004) Feasibility Study Concerning Anaerobic Digestion in Northern Ireland, Final Report for Bryson House, ARENA Network and NI2000.

4.2 Proposals for a Thematic Strategy and for a Revised Waste Framework Directive

Much discussion recently, within Europe, has centred on the Commission's Proposals for a Thematic Strategy on Waste Prevention and Recycling, and for a Waste Framework Directive. In particular, the issue of what should be defined as 'recovery' and what should be defined as 'disposal' has become a hot issue. This has been made all the more important because Article 5(1) of the proposal states:

> *Member States shall take the necessary measures to ensure that all waste undergoes operations that result in it serving a useful purpose in replacing, whether in the plant or in the wider economy, other resources which would have been used to fulfil that function, or in it being prepared for such a use, hereinafter "recovery operations". They shall regard as recovery operations at least the operations listed in Annex II.*

Currently, following the rulings of the European Court of Justice[30], the incineration of waste is not defined as recovery, but disposal. The Commission has had reason to be concerned about this because of the implications for meeting targets for recovery set in certain Directives (notably the Packaging Directive). However, the wording of the revised Packaging Directive was changed so that targets no longer apply to 'recovery' alone. Instead, they refer to the need for packaging to be '*recovered or incinerated at waste incineration plants with energy recovery*'.[31]

The significance of Article 5(1) is that for incinerator operators / technology providers, the distinction between recovery and disposal is no longer simply one of being 'in' or 'out' of some targets (which could have been amended). Article 5(1) now requires Member States to take necessary measures to ensure *all* waste is recovered, rather than being sent for disposal. Evidently, if incinerators continue to be classified as disposal, the implications of Article 5(1) would appear to be that measures which encouraged incineration would at the very least be scrutinized closely.

It is important to note that there appears to be some acceptance, even now, that incinerators linked to district heating schemes can be regarded as recovery facilities since the absence of the incinerator would, most likely, imply the need for a different energy source to be combusted to serve the district heating scheme. Consequently, even the existing distinction appears to allow incinerators, under certain conditions, to be considered as 'recovery' facilities.[32]

The Proposal for the Thematic Strategy introduces the Commission's approach thus:

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[30] Judgment of the Court (Fifth Chamber) of 13 February 2003 in Case C-458/00: Commission of the European Communities v Grand Duchy of Luxembourg. *Official Journal of the European Union*, C83, p.2, 5 April 2003.

[31] See the consolidated text of the Directive http://www.europa.eu.int/eur-lex/en/consleg/pdf/1994/en_1994L0062_do_001.pdf

[32] It is not clear, however, whether this 'accepted view' has any formal status (and hence, whether it ought to be accepted, and under what conditions).

The Commission is proposing an amendment to the Waste Framework Directive to include an energy efficiency threshold above which municipal incineration is considered a recovery operation. The threshold takes BAT as guidance and takes into account the recommendation in the BREF (BAT reference document) on waste incineration to use an equivalence factor of 2.6 to compare energy in the form of electricity to energy in the form of heat, i.e. 1 kWh of electricity is equivalent to 2.6 kWh of heat, and a factor of 1.1 for district heating.

Consequently, in Annex II of the proposed WFD, the following criteria is proposed for drawing the distinction between 'recovery and 'disposal'.

R1 Use principally as a fuel or other means to generate energy.

This includes incineration facilities dedicated to the processing of municipal solid waste only where their energy efficiency is equal to or above:

- *0.60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009,*
- *0.65 for installations permitted after 31 December 2008,*

using the following formula:

Energy efficiency = (Ep -(Ef + Ei)) / (0.97 x (Ew + Ef))

In which:

Ep means annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (GJ/year)

Ef means annual energy input to the system from fuels contributing to the production of steam (GJ/year)

Ew means annual energy contained in the treated waste calculated using the lower net calorific value of the waste (GJ/year)

Ei means annual energy imported excluding Ew and Ef (GJ/year)

0.97 is a factor accounting for energy losses due to bottom ash and radiation.

There are a number of problems with this approach:[33]

1. The Waste Incineration Directive (which preceded the ECJ rulings, and hence, the outdated use of the term 'recovered') itself states, at Article 4(2) ('*Application and permit*') that:

[33] These are quite apart from the technical ones – why municipal waste only? Why is it that the *delivery* of electricity factored up by 2.6, but the use of electricity is not? Why is there a need for a factor to deal with losses to bottom ash and radiation? (why not simply set an overall criteria where these are not allowed for explicitly?) Why does Ep speak only of 'energy produced' (and produced where? Many plants generating heat do not always have a year-round outlet for the use of the heat energy)? Over what period will the efficiency be measured? (What happens if a plant is above for some of the year and below for the rest?).

*Without prejudice to Directive 96/61/EC, the application for a permit for an incineration or co-incineration plant to the competent authority shall include a description of the measures which are **envisaged to guarantee that**:*

(a) the plant is designed, equipped and will be operated in such a manner that the requirements of this Directive are taking into account the categories of waste to be incinerated;

(b) the heat generated during the incineration and co-incineration process is recovered as far as practicable e.g. through combined heat and power, the generating of process steam or district heating;

and at Article 6(6) (operating conditions), that

Any heat generated by the incineration or co-incineration process shall be recovered as far as practicable

The proposal for the Thematic Strategy had as one of its aims, an improvement in the implementation of existing legislation. To the extent that the Commission saw fit to distinguish between 'disposal incinerators' and 'recovery incinerators' on the basis of energy efficiency, one might argue that the rationale for such a distinction is founded upon the basic fact that implementation of the Waste Incineration Directive needs to be improved;

2. Notwithstanding the issue that these Articles are not being as closely enforced as they might be, it is clear that incinerators should not be allowed to operate unless they are being as efficient as is 'practicable'. Drawing a distinction between 'recovery' and 'disposal' on the basis of efficiency would imply, therefore, distinguishing between those incinerators where high levels of efficiency 'are practicable' and those where they are not. It is less than clear that this should be seen as an appropriate basis for distinguishing 'recovery' from 'disposal', not least since meeting the Commission's efficiency threshold might imply lower efficiencies than what is 'practicable', leading to the utterly absurd position that a theoretical incinerator could, on the one hand, meet the Commission's efficiency threshold which ensured that it could be defined as 'recovery', even though it was not allowed to operate because it was not recovering heat as far as was practicable; and
3. The Proposal for the Thematic Strategy notes that the efficiency criteria 'takes BAT as Guidance' for the threshold level. Yet incinerators require a PPC permit to operate, and in order to acquire that permit, they ought to demonstrate BAT. So, it is not clear how this efficiency threshold effectively distinguishes between 'recovery' incinerators and 'disposal' ones, since all the disposal ones, by virtue of not demonstrating BAT, should not be operating. In order to operate, the plant must demonstrate BAT. If the Commission is simply re-iterating what is BAT, then in reality, the position it will come to is that all incinerators are recovery ones. This is not a means of distinguishing one thing from another. It is to completely reverse the decision of the European Court.

To further highlight these points, it is perhaps worth considering the position of an incineration plant where the desire is to 'become' recovery rather than disposal through increasing the efficiency of energy generation as measured through the equation set out in

Annex II of the proposed WFD. The act of making such improvements suggests improvement was possible, one might say, 'practicable'. Consequently, these might have been considered requirements of the Directive, not to mention a PPC permit. Accepting that incinerators cannot permanently operate at the 'frontier of efficiency' because of the lifetime of investments involved, efficiency improvements made 'well within' that frontier ought, arguably, already to have been in place. Consequently, the idea that any incinerator is about to radically alter its energy generation configuration as a consequence of the definition is unlikely. These investments will typically be made at the planning stage, or where there is a complete retrofit, and will be heavily influenced by relative prices of heat and electricity, though properly, for reasons highlighted above, they ought to be more significantly influenced than they are by the attitudes of the regulators towards the use of the heat being generated.

An interesting consequence of the debate has been that representatives of the incinerator industry are moving to reduce the efficiency threshold from 0.6 to 0.5. CEWEP has responded to the Directive by stating that: [34]

> *'However, the energy efficiency factor of 0.6, which is proposed in Annex II (R1 formula), is too high. The factor 0.5 would be* ***absolutely sufficient and ambitious enough*** *for the WtE sector.'*

This is interesting, not least since the criteria which would need to be met would be achieved by plants generating electricity as long as their net electrical efficiencies exceeded a figure of 19% or so (as opposed to 22-23% in the current proposal – still well below what is assumed in the work for Defra by ERM[35]). Probably, it also reveals that many publicly quoted efficiencies of electricity generation in various studies are above levels that are, in practice, achieved.

Similarly, FEAD (the European Federation of Waste Management and Environmental Services) has stated its position. This is set out below:[36]

> *FEAD supports the fact that municipal waste incinerators may be considered as recovery operations and that this status is determined by a criterion based on energy efficiency. However, FEAD requires that this criterion is accessible under the conditions prevailing in all EU Member States.*
>
> *The proposed formula must be easy to apply and acceptable from a thermodynamics point of view. Moreover, it should take into account different local conditions without discriminating between the North and South of Europe and without discriminating more advanced flue gas treatment installations (i.e. leading to lower emissions).*

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[34] CEWEP (2006) *Statement on the Waste Framework Directive*, Brussels, 23rd February 2006, http://www.cewep.com/storage/med/media/statements/66_CEWEPstatement.pdf?fCMS=816af985d0828c7799a40c92e62fd11d

[35] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

[36] FEAD (2006) Position Paper: Revision Of The Waste Framework Directive, Commission Proposal of 21 December 2006, April 2006 http://www.fead.be/docs/FEAD_Position_Paper_WFD_130406.pdf

Therefore, FEAD advocates for a simplified formula and threshold based on the energy efficiency performances which are achievable when using the Best Available Techniques (as given in Chapter 5 of the Waste-Incineration BRef). FEAD proposes to use a formula effectively based on the Waste-Incineration BRef which compares the effectively used energy (export and self demand, i.e. what is actually a substitution of resources) to the energy of waste.

The demands on energy efficiency must be fulfilled by all types of plants incinerating waste and not only to facilities dedicated to the processing of municipal solid waste.

As well as making some salient remarks related to the trade off between flue gas cleaning and energy efficiency, it essentially argues for the use of the BRef figures for efficiency. The BRef note proposes, for municipal waste incinerators (in Chapter 5), the following measures:[37]

61. *The location of new installations so that the use of CHP and / or the heat and/or steam utilization can be maximized, so as to generally exceed an overall total energy export level of 1.9 MWh per tonne of MSW based on an average NCV of 2.9 MWh per tonne*
62. *in situations where less than one 1.9 MWh per tonne of MSW (based on average NCV of 2.9 MWh per tonne) can be exported, the greater of;*
    a. *the generation of an annual average of 0.4-0.65 MWh electricity per tonne of MSW (based on an average NCV of 2.9 MWh per tonne processed, with additional heat/steam supply as far as practicable in the local circumstances, or*
    b. *the generation of at least the same amount of electricity from the waste as the annual average electricity demand of the entire installation including (where used) on-site waste pretreatment and on-site residue management operations*
63. *to reduce average installation electrical demand (excluding pretreatment or residue treatment) to be generally below more 0.15 MWh per tonne of MSW processed and based on an average NCV of 2.9 MWh per tonne of MSW.*

It is clear that the incineration BREF note lists ranges of efficiency. The fact remains that in order to operate, an incinerator must have a permit and must demonstrate BAT. It seems meaningless, therefore, to propose, as a means to distinguish recovery facilities from disposal facilities, a criterion with which all facilities have to comply anyway.

Certainly, this debate is likely to continue and is being considered by Member States in the context of the wider proposals. Fundamentally, there must be questions raised about the wisdom of seeking to set a distinction between recovery and disposal based upon energy efficiency criteria. The reason for adopting this view is quite straightforward – existing legislation, the Incineration Directive and the IPPC Directive – effectively

[37] European Commission (2005) Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques For Waste Incineration, July 2005

requires measures to be taken at incinerators to make use of heat ‘as far as is practicable’ as a condition of their being allowed to operate at all.

4.2.1 Recovery Targets in the Waste Strategy

As an aside, it is worth re-emphasising the point that the current state of play in EU law is that incineration is effectively classified as ‘disposal’. The discussion above relates only to proposals, not to a finalised position.

In the midst of this lack of clarity on what will, or will not be classified as ‘recovery’, it seems somewhat odd to seek to specify a ‘recovery target’ in the review of the Waste Strategy. There are many rules for setting targets, and a basic one would appear to be that the targets are specific to an activity which is clearly defined. Recovery is not (yet), and it is certainly worth pondering whether it makes sense to discuss the nature of such a target in the absence of a discussion about what the implications of different possible definitions of ‘recovery’ might be for a strategy.

The lack of recognition – from within the UK – of what is ‘the law’ is somewhat surprising. Municipal waste survey statistics continue to report incineration under the heading ‘recovery’. This is all the more surprising given the quite clear position stated by the Commission in a letter from Margot Wallstrom in May 2003, published as Appendix 4 to a Consultation Paper on Changes to the Packaging Regulations:[38]

> *The European Court of Justice has decided in its judgement in case C-458/00 that the primary objective of incineration in a dedicated municipal waste incinerator is waste disposal. The Court added that this classification as a disposal operation is not changed if, as a secondary effect of the process, energy is generated and used.*
>
> *The consequence of the Court Decision is that the definition of the recovery target provided for in Article 6 of the Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging[30] waste should be interpreted as follows:*
>
> *The word recovery is defined in Directive 94/62/EC as any of the applicable operations provided for in Annex IIB to Directive 75/442/EEC. The Court’s judgement in case C-458/00 has by applying the concept of the primary objective of the operation excluded dedicated incineration in municipal incinerators from this list of operations.*
>
> *Energy recovery defined as .the use of combustible packaging waste as a means to generate energy through direct incineration with or without other waste and with recovery of the heat. is excluded from the concept of recycling as it is defined in Directive 94/62/EC.*
>
> *On this basis, to achieve the overall recovery target, Member States have either to increase recycling or to recover energy from the combustible fraction of the packaging waste stream through co-incineration in cement kilns or power plants, which have been recognised by the Court as recovery operations (Law case C-228/00, judgement 13 February 2003).*

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[38] Defra and Welsh Assembly (2003) Consultation Paper on Changes to the Packaging Regulations, July 2003.

The clarity is admirable, but the message does not appear to have hit home in UK Government circles. Possibly, this may reflect the fact that UK concerns related principally to whether or not targets under the Packaging Directive would be met. Since the Packaging Directive targets were revised so as to include, explicitly, incineration, arguably, the UK might have become less concerned as to whether incineration was defined as recovery or disposal. The proposal for revised waste framework directive, notably Art.5(1), gives this distinction in heightened relevance.

For the time being, at least, *incineration is disposal*.

4.3 Will Including Incineration with CHP Under the Renewables Obligation Improve the Climate Change Performance of Incineration?

The review of the Renewables Obligation (RO) led to the inclusion of electricity generated by incineration plants that met the criteria for Good Quality CHP within the list of eligible renewable sources:

> *This will be implemented using a similar approach to the Climate Change Levy, which uses the CHP Quality Assurance scheme. For CHP plants that are fully compliant with the Good Quality benchmark (i.e. they have a high efficiency of electricity generation and heat use), they would receive ROCs on all of their biomass-generated electricity. For those plants that are partially compliant (typically with a lower or intermittent heat use), they would receive ROCs on a lower fraction of their electricity generation. This will be determined by the relationship between their qualifying power output (QPO) and total power output (TPO) in the same manner as for the CCL exemption.*[39]

The RIA of this change did not include any quantitative assessment of any benefit (or cost) associated with the change proposed. Indeed, it merely stated:[40]

> *In relation to extending RO eligibility to mixed waste plants using Combined Heat and Power (CHP), the Government commissioned additional work undertaken by ILEX Energy Consultants which was published alongside the statutory consultation. <u>This suggested that energy from waste projects utilising CHP would offer net environmental advantages over conventional electricity-only plant but also face additional costs which would justify offering such projects the support of the Obligation.</u>*

In fact, the report by ILEX referred to made no attempt to quantify any benefits either. Indeed, the report mentions CHP twice, both occurrences being in the following paragraph:

> *Electricity generated from waste reduces the need to generate power from conventional sources, and Combined Heat and Power (CHP) facilities additionally displace gas or oil space heating, thereby reducing the use of fossil*

[39] Department of Trade & Industry (2006) *Renewables Obligation Order 2006 – Final Decisions January 2006*
[40] *Regulatory Impact Assessment Renewables Obligation Order 2006* http://www.dti.gov.uk/renewables/policy_docs/finalregimpactass.doc

fuels, as well as methane emissions from landfill, a significant greenhouse gas. However, energy recovery is not a perfect solution. It reduces the requirement for landfill by approximately 90% but residual ash from the process may still need to be landfilled. The net electrical energy recovered from these facilities may represent 17% to 21% of the energy contained in the waste stream – compared to 35% recovery for coal-fired power station or up to 50% for gas-fired combined cycle gas turbine (CCGT) power stations. CHP facilities, whether fuelled from waste or conventional sources enjoy considerably greater efficiencies. The operation of all energy-recovery from wastes is governed by the EU Wastes Incineration Directive (WID) which imposes far stricter emission limits than apply to other forms of electricity generation, but emissions are still frequently cited as a barrier to planning consent.[41]

This paragraph does indeed suggest some improvement from using CHP, but there is no demonstrable case made. It is, for example, not true that all the heat from CHP facilities is generated 'additionally' to the electricity generation from facilities generating electricity only. CHP facilities generate lower quantities of electricity, this being a 'penalty' for the generation of heat.[42]

The question then arises as to what level of electricity and heat recovery would ensure environmental improvement. It is not clear that this question has actually been asked.

The analysis in Section 2.0 showed that where energy from waste generates electricity only, it is no better – it is actually worse - than average gas-fired generation in the UK.[43] It is interesting to consider what sorts of figures for GHG emissions per kWh might be applicable to incinerators where they qualify – by virtue of being classed as Good Quality CHP facilities – for support under the Renewables Obligation.

CHPQA Guidance Note 10 states that:

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[41] ILEX Energy and Consulting (2005) Eligibility Of Energy From Waste - Study And Analysis: The Options For, And Implications Of, Amending The Renewables Obligation Eligibility Rules For Energy Recovery From Mixed Wastes, March 2005. Chapter 5 of the same report states that 'In considering the various energy recovery options and technologies we were unable to identify any significant environmental advantage of one approach over another.' This is hardly a ringing endorsement of the amendment to the Renewables Obligation in favour of CHP. It is, on the other hand, simply a statement. There is not one referenced study, still less, any investigation of any sort whatsoever provided to support this 'opinion'. Several studies of relevance to this argument have been conducted, and one of these was for the European Commission (freely available on their website). There have been many other studies of this nature, carried out in Flanders, Austria, Germany and Switzerland. To our knowledge, none of these is 'neutral' on the subject. Rather than commenting that they 'have been unable to identify any significant advantage …', they might have stated that they had not identified anything (which is all one can conclude where no studies are cited, not least where it is known that those studies do conclude something).

[42] The paragraph also makes use of the term 'recovery' when it is not strictly correct to do so for reasons highlighted above.

[43] This does raise some interesting questions as to whether it is really valid to consider energy from waste as eligible for levy exemption certificates (we discussed this in an earlier report for Friends of the Earth – see Eunomia (2003) *Money to Burn: Government Subsidies to Energy from Waste*, Final Report, January 2003. The above analysis showed that gas-fired stations perform better than incinerators generating electricity only even when *all* energy generated from incinerators was included, but only non—biogenic CO_2 emissions were included.

'To be designated Good Quality CHP, CHP Schemes must achieve the following Threshold Criterion:
For Fuel Inputs under Annual and Initial Operation:
Normally, a Scheme that qualifies as Good Quality CHP for its entire annual energy inputs is one where the power efficiency equals or exceeds 20%. However, under transitional arrangements for existing steam turbines and steam engines, the Power Efficiency Threshold is reduced to 15% until 1 April 2005.
For Power Outputs under Annual Operation:
A Scheme that qualifies as Good Quality CHP for its entire annual power output is one where the Quality Index equals or exceeds 100. Normally, the QI Threshold is based on Annual Operation, but can be based on other periods, for example on the Heating Season in the case of Residential Community Heating (RCH) Schemes.
For Power Outputs under Initial Operation:
A Scheme that qualifies as Good Quality CHP for its entire annual power output is one where the Quality Index equals or exceeds 95. Normally, the QI Threshold is based on Annual Operation, but it can be based on other periods, for example on the Heating Season in the case of RCH Schemes.
For Power Capacity under Annual Operation:
An existing Scheme that qualifies as Good Quality CHP for its entire Capacity is one which achieves a QI of at least 100 at its Maximum Heat Output under Normal Operating Conditions.
For Proposed New Power Capacity:
A proposed Scheme that qualifies as Good Quality CHP for its entire Capacity is one which at design, specification, tendering and approvals stages, achieves

- *either QI ≥ 105 and Power Efficiency ≥ 20%, both under Annual Operation.*
- *or QI ≥ 110 at MaxHeat and Power Efficiency ≥ 35% under Annual Operation.*

Responsible Persons may choose which set of criterion is used for Self-assessment.

***GN10.2** The Quality Index (QI) provides a means of assessing the quality of CHP Schemes which takes account of the fact that power supplied is more valuable than heat supplied. It compares CHP to separate power-only and heat-only alternatives. The QI therefore offers scope for a major improvement over conventional methods of assessment, which are based simply on overall efficiency. The Quality Index of a CHP Scheme is calculated using definitions shown in Table GN10-1.'* [44]

The Table referred to in the final sentence states that for facilities run using solid waste, the Quality Index should be calculated as follows:

$$\mathbf{QI = 400 \times \eta_{Power} + 140 \times \eta_{Heat}}$$

Where

[44] *CHPQA Guidance Note 10* (see www.chpqa.com).

η_{Power} (Power Efficiency) = Total Power Output (MWhe) / Total Fuel Input (MWh)

η_{Heat} (Heat Efficiency) = Qualifying Heat Output (MWhth) / Total Fuel Input (MWh)

Total Power Output (CHPTPO) is the total registered annual power generation from a CHP Scheme (MWhe) as measured at the generator terminals.

Qualifying Heat Output (CHPQHO) is the total registered amount of useful heat supplied annually from a CHP Scheme (MWhth). It is the total heat output that is demonstrably utilised to displace heat that would otherwise be supplied from other sources.

Total Fuel Input (CHPTFI) is the total registered annual fuel input to a CHP Scheme (MWh) (measured in Gross Calorific Value terms).[45]

To ensure that the threshold power efficiency (to qualify as Good Quality CHP) of 20% w.r.t. GCV is met, we estimate that the efficiency must therefore be equivalent to around 23% w.r.t. NCV. This is relatively challenging, especially if there is a clear requirement to ensure that heat is also recovered since when operating in combined power *and* heat mode, the power efficiency is inclined to fall. It is not clear, however, that operating in CHP mode is strictly necessary if the QI and power efficiency thresholds can be met by generating electricity alone.

The possibility of this arising is at least hinted at in *Guidance Note 10*, where it is stated that:

> *'For a Scheme that generates power only, Heat Efficiency is zero. For a Scheme which supplies heat only, Power Efficiency is zero.'*

In other words, CHP might be 'just P' or 'just H' as long as the quality index criterion is met. Alternatively, only a minimal amount of heat might need to be recovered or visa versa.[46]

The work by Oakdene Hollins used a figure of 25% efficiency, and this was applied to the GCV of the waste.[47] At such efficiencies, an incinerator generating electricity only would have qualified if it was in existence at the time the Guidance was issued (when the QI threshold was 100). It would fall marginally short of the QI factor for new plant. Similarly, the incinerator modelled by ERM in work for Defra – generating electricity at 28% efficiency relative to the net calorific value of waste, and with extremely low inputs

[45] As above, the source is *CHPQA Guidance Note 10* (see www.chpqa.com).

[46] Presumably, one might, in any case, legitimately claim that any incinerator generates 'space heating'. One of the reasons why the QI threshold can be approached using existing 'power only' incinerators might be the fact that the formula for calculating the QI gives a relative weight to electricity generation of 2.86 relative to heat generation. By comparison, the European Commission's proposed efficiency threshold uses a relative weighting of 2.18.

[47] Oakdene Hollins (2005) *Quantification of the Potential Energy from Residuals (EfR) in the UK*, Report for the Institute of Civil Engineers and the Renewable Power Association, March 2005, http://www.ice.org.uk/downloads//energy_from_waste.pdf.

of electricity and diesel – would come very close to achieving the Good Quality CHP standard without generating any heat at all (the QI would be around 99).[48]

Suppose one posits an incinerator which does meet the QI threshold. This requires, for new plant, that QI

$$\textbf{QI} = \textbf{400} \times \eta_{\textbf{Power}} + \textbf{140} \times \eta_{\textbf{Heat}} \geq \textbf{105}$$

Possible permutations of heat and power generation efficiency required to meet the QI threshold are given in Table 6 below. This converts the efficiencies in terms of NCV to efficiencies in terms of GCVs on the basis of an estimated ratio of NCV:GCV of 0.88.

Table 6: Possible Heat and Power Efficiencies of Incinerators Meeting the QI Threshold and Associated GHG Emissions (g CO2 $_{equ}$ per kWh $_{el\ equ}$)

	Power Efficiency (%)		Heat Efficiency (%)		QI	CO_2 (equ)/kWh (elec equ) (g)	As % electricity only	Value of ROC Sales (@ 3p/kWh)
	GCV	*NCV*	*GCV*	*NCV*				
Heat only	0	0	75.0	85.3	105	321	65%	£0.00
	3.5	4.0	65.0	73.9	105	327	66%	£3.22
	7.0	8.0	55.0	62.5	105	331	67%	£6.44
	10.5	11.9	45.0	51.1	105	337	69%	£9.59
	14.0	15.9	35.0	39.8	105	343	70%	£12.81
	17.5	19.9	25.0	28.4	105	348	71%	
Electricity Only	18.5	21.0	0.0	0.0	74	491	100%	
Gas-fired						382		
Gas-fired (future)						357		

It can be seen that the facilities which meet the QI threshold – which seem more likely to be those which are associated with lower electrical efficiencies – imply a much reduced quantity of CO_2 per kWh electrical equivalent. Indeed, the GHG savings are approximately one-third of what they would otherwise be. They also imply an improvement relative to average UK gas-fired generation, which is not true of existing incinerators generating electricity only.

Recent Guidance from Ofgem states:

> *The number of ROCs issued to a station will depend on the efficiency of that station. This will be determined by the relationship between its qualifying power output (QPO) and total power output (TPO). See Appendix 6 for further information on issuing ROCs to CHP stations burning waste. ….*
>
> *… Generators that are fully compliant with the Good Quality benchmark (that is they have a high efficiency of electricity generation and heat use) will receive ROCs on all of their biomass-generated electricity. Generators that are partially compliant (typically with a lower or intermittent heat use), will receive ROCs on a*

[48] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

lower fraction of their electricity generation. This will be determined by the relationship between their qualifying power output (QPO) and total power output (TPO) in the same manner as for the CCL exemption.

The CHP Standard note defines QPO as follows:

> ***CHP Qualifying Power Output (CHP$_{QPO}$)*** *is the registered annual power generation from a CHP Scheme (MWhe) that qualifies as Good Quality CHP.*
>
> *Most Schemes will meet the relevant Threshold QI Criterion for Good Quality CHP in Annual Operation and therefore CHP$_{QPO}$ is the total power output (CHP$_{TPO}$). For a Scheme that does not achieve the Threshold QI Criterion for Good Quality CHP, CHP$_{QPO}$ is that portion of the annual power output from a Scheme that would have achieved the Threshold QI Criterion, based on the actual annual heat supplied (CHP$_{QHO}$).*

The right-hand column of Table 6 above suggests that the nature of the incentive provided by the RO is highly sensitive to the relative ratio of power:heat generation. Even though all of these configurations generate similar benefits in terms of climate change (and in fact, those producing energy with a higher heat:power ratio seem to perform better, subject to the QI threshold just being met), the nature of the incentive provided by the inclusion in the RO is to favour facilities which generate at the lower heat:power ratios. Interestingly, a facility providing 88% heat recovery relative to GCV (or 100% relative to NCV) would still receive no support under this measure.

The irony in all this is that if Government wishes to see more by way of CHP from incinerators, then the mechanisms already exist for ensuring this (in the form of the Waste Incineration Directive and the Pollution Prevention and Control Regulations). In its position statement on Incineration, the Environment Agency states:[49]

> *The Agency also considers that energy generated by incineration should be recovered as far as practicable, for example using Combined Heat and Power (CHP) schemes, and consistent with the requirements of Best Available Techniques Not Entailing Excessive Cost (BATNEEC) or Best Available Techniques (BAT) as appropriate.*

For some, this might be rather too equivocal. The basis for establishing what is, or is not, an excessive cost needs to be examined closely. Equally, if the intention was that through the RO, CHP would be given a significant boost, it would appear that it does so in a manner which is rather sensitive to the heat:power ratio. The problem, simply stated, is that the ROCs are issued against power generated, and the higher this is, arguably, the lower are the prospects for meeting the QI threshold. Equally, the configurations where high QI values seem likely are those where the heat:power ratio is higher, and where little electricity is generated. This leads to very little by way of ROCs revenue.

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[49] Environment Agency (2003) *Position Statement: Waste Incineration in Waste Management Strategies*, http://www.environment-agency.gov.uk/commondata/105385/wasteincin_319013.pdf

5.0 CONCLUSIONS AND RECOMMENDATIONS

Historically, energy policy and waste policy have been balkanised in the UK. However, events are bringing the two closer together. Straddling these policy debates is the issue of climate change, and how to address the problem of increasing emissions of GHGs into the atmosphere.

A superficial look at the issue of how to bring the issues of waste and energy closer together, whilst contributing to improving the position as regards climate change, has spawned the view that the combustion of waste will have beneficial impacts because energy can be generated, and this can be seen to displace emissions related to fossil fuel generation.

5.1 Energy from Waste Incineration Compared with Fossil Fuel Generation

This paper suggests that yes, incinerating waste does generate energy, and that energy generated can be construed as having displaced a source of energy elsewhere (although this presumes – one might say, unfortunately – continuing demand, not to mention increases therein, for energy). But even if one takes the view that it does, the fact that incinerators – where they are generating electricity only - are relatively inefficient (compared with the average achieved in gas-fired, coal-fired, oil-fired power stations) implies that whether the net effect is positive or negative depends upon:

a) what source of generation one assumes is being 'displaced';

b) whether one takes the view that biogenic carbon should be ignored; and

c) if one takes the view that biogenic carbon *should* be ignored, the proportion of non-biogenic carbon in the waste being incinerated (more specifically, the ratio of this to the net calorific value of the waste – the higher this ratio, the worse is the performance); and

It is clearly possible to improve this relative performance where incinerators are configured to generate energy in combined heat and power mode, or where they are generating heat only, but this assumes that the heat is put to a useful purpose, and that a very high proportion is utilised.

Even so, it is worth pointing out that relatively few UK incinerators operate in anything other than electricity generation mode. This may be a reflection of the nature of incentives which have faced incinerators in the past, but this continues to be the principal mode of operation, despite the fact that the Waste Incineration Directive quite clearly states that heat should be used 'as far as practicable'.

Consequently, depending upon one's view as to the source of energy which is displaced by energy from waste facilities, there may be no net climate-related benefit associated with the generation of electricity from incineration, and indeed, there may be negative consequences for climate change, even when one ignores the contribution from biogenic carbon, if it is assumed (in the same way as was done in the recent ERM report accompanying the Consultation Draft of the Waste Strategy) that the displaced energy source is gas-fired CCGT.

If benefits from energy from waste incineration are to be less equivocal in future, it would seem necessary to ensure that they are operating in such a way as to make better use of the heat generated through operating in CHP, or heat recovery mode. Evidently, in this context, there are likely to be issues associated with the level of demand for heat in the UK on a year-round basis. However, technologies such as absorption chilling (as a means of 'district cooling') might enable the productive use of heat on a more constant basis over the year, though the (changing?) UK climate might itself alter the prospects for this.

5.2 Energy from Waste as a Treatment for Residual Waste

If it can be argued that it is reasonable to ignore biogenic CO_2 when one is comparing energy from waste incineration with fossil fuel generation for the purpose of understanding the emissions of CO_2 per unit of energy generated, it is less easy to do so when one is comparing different waste treatment technologies. Eunomia has consistently adopted this approach to the comparative assessment of waste treatment options for the simple reason that different processes deal with biogenic carbon very differently. The best way to account for climate change impacts, therefore, is to understand how and when the relevant emissions occur and to ignore nothing. This ensures that all technologies are treated equally, and that none are biased by an accounting convention, the logic of which few have really taken the time to question.

When biogenic carbon and time are included in the analysis, energy from waste incineration – where only electricity is generated – looks like a mediocre performer. Indeed, under assumptions widely employed in work for Defra, it is only marginally better than landfilling.

There is a pressing need for investigation as to what really *are* the likely rates of capture of landfill gas over the lifetime of a landfill. Many of the figures quoted remain largely unsubstantiated, with few being based upon quality studies of what *lifetime* captures might be.

The performance of 'energy from waste' may be improved where waste is processed for use as a fuel in industrial facilities. This is the case as long as the fuel is of requisite quality (such that it provides a genuine contribution to the energy input to the plant) and as long as the displacement effect is such that fossil fuels are genuinely displaced by virtue of the refuse derived fuel being used (the performance in this regard being greater where the carbon intensity of the fuel is higher).

5.3 A Revised Landfill Tax?

Because biological treatments sequester carbon, and because some of the biogenic carbon is released only rather slowly, then these also perform well in terms of their impact on climate change, notwithstanding the fact that aerobic treatments are net energy users.

A basic stabilisation process, when looked at in terms of GHG emissions, has a far lower social cost than landfilling untreated waste. The differential social cost is shown in Table 7. This shows that depending upon the assumption made regarding gas capture rates, the differential social cost is between £3.71 and £19.41. We would suggest that the best estimate lies at the higher end of this range, partly on the basis of the assumption that *lifetime* captures of methane are likely to be at the lower, rather than the higher end of the range we have modelled.

There appears, therefore, to be a fairly strong rationale for a lower rate of landfill tax for the landfilling of stabilised waste. This does not imply that the rate for landfilling stabilised biowaste needs to be set at the existing lower rate (£2 per tonne), applicable to inert wastes. However, a rate well below what is envisaged for untreated waste in future (a level of £35 per tonne) would appear justifiable.

Table 7: Differential Social Costs of GHG Emissions from Landfill Relative to Stabilisation

Landfill Scenario	GHG-related Social Costs Relative to Stabilisation
Landfill 75% capture	£3.71
Landfill 50% capture	£11.56
Landfill 25% capture	£19.41

The rationale for this is based upon the differential social costs, regarding GHGs, of stabilisation relative to landfilling untreated waste. But the rationale is just as compelling from a strategic viewpoint.

As UK local authorities seek to respond to the landfill allowances schemes in their different contexts, it is clear that time has become a critical resource. The prospects for procuring, gaining planning consents for, constructing, and commissioning facilities which are complex and controversial in the time which is available to many authorities is looking increasingly unrealistic. Basic stabilisation facilities, or variants upon this, are far more likely to be brought into existence within the desired timeframe. However, the level of landfill tax applied is making such facilities financially less attractive.

He revised level of tax ought to be linked to achievement of a specified stability criterion.[50] We would propose that this be taken as the standard that was proposed in the Second Draft of the Biowaste Directive, which stated:

> *If residual municipal waste undergoes a mechanical/biological treatment prior to landfilling, the achievement of either a Respiration Activity after four days (AT_4) below 10 mg O_2/g dm or a <u>Dynamic Respiration Index below 1,000 mg O_2/kg VS/h</u> shall deem that the treated residual municipal waste is not any more biodegradable waste in the meaning of Article 2 (m) of Directive 1999/31/EC.*

[50] In theory, this could be set at different levels for different levels of stability. In practice, this is likely to lead to additional administrative complexity. The rationale for a standard is to be found in the fact that if a high level of stability is achieved, the landfilled material behaves so differently that zero methane emissions become possible where an active biological layer is used to cover the landfill.

This standard uses the Dynamic Respiration Index, which is also proposed as part of the Environment Agency's approach to measuring the performance of MBT systems in the context of the landfill allowances scheme.

We anticipate that this might reduce the cost, to local authorities, of residual waste treatments based around stabilisation by around £12-14 per tonne of waste treated, in line with the social costs avoided through the pre-treatment process.

5.4 Anaerobic Digestion of Source Separated Organic Materials

There is currently one facility in England which seeks to generate energy from source segregated organic wastes. This facility, based in South Shropshire, has recently started to accept waste. It has been constructed under Defra's New Technologies Demonstrator Programme.

The Consultation Draft of the waste strategy states:

> *21. There are three main techniques for recovering energy from waste (EfW):*
>
> *a. using certain individual waste streams directly in existing energy intensive plant as a fuel;*
>
> *b. separating out any recyclables from general waste streams (either at source, and/or through the use of some sort of mechanical separation process), before incinerating the residue with energy recovery. Electricity is sold to the grid, whilst any heat recovered can be made available to local users through a CHP system;*
>
> *c. using various mechanical and biological treatment (MBT) processes to turn mixed wastes into a refuse-derived fuel (RDF), for combustion in other plant such as industrial boilers, or, potentially, some power stations.*

A footnote in the report notes that this does not include '*energy from landfill gas*'.

We have suggested that under achievable projections, around 1.5TWh of electricity could be generated from a source which is likely to be more acceptable to local communities, and from the separation of part of the waste stream which will help to deliver Landfill Directive targets. This source – anaerobic digestion – is not included in the above list, and receives no mention at all in the Review of the Waste Strategy.

In the work by ERM accompanying the Waste Strategy, it is claimed that anaerobic digestion systems would generate, net, 6.1kWh electricity per tonne of waste input.[51] This quite significant error appears to have been carried through into calculations regarding what appears in the report as Scenario 4. At such calculated levels, those developing the strategy might reasonably have overlooked this as a significant source of 'energy from waste'. We would suggest that net generation is likely to be of the order 30-40 times this figure.

There are good reasons to believe that generating energy in this way may prove more acceptable to communities than the approaches mentioned above. Government should

[51] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006.

consider carefully how to generate more energy from the treatment of source separated organic wastes, which it is urging local authorities to collect. This needs to be considered carefully in tandem with the design of cost-optimised collection systems for collecting kitchen waste.

5.5 Recovery / Disposal / CHP

Both the discussion in Europe regarding the distinction between recovery and disposal, and the discussion in the UK concerning the rules regarding when energy from waste incineration should qualify as Good Quality CHP, and hence, for ROCs, focus on measures of efficiency.

This report shows that the overall efficiency of energy recovery is indeed important in determining the environmental performance of waste incineration. The question is, however, how this should affect key policy debates both here and in Europe.

As regards the disposal / recovery distinction, it is difficult to see how energy efficiency can be used to make this distinction given the wording of the Waste Incineration Directive (concerning the recovery of heat as far as practicable) and the requirement upon those operating incinerators to demonstrate Best Available Techniques (BAT) in order to operate at all. There would appear to be good reasons other than this for retaining the classification of incineration as disposal, not the least of these being the fact that designating such facilities as 'recovery' opens the door for cross-border movements of residual waste to incineration plants in different European Member States.

One already sees considerable variation in costs of incineration in different Member States owing to different approaches to regulation and the application of fiscal instruments. Notwithstanding the attempt, through the Waste Incineration Directive, to harmonise standards across Member States, considerable scope still exists for variation in performance and costs (for example, through differing interpretations of what constitutes BAT, the use of taxes on incineration, the presence of incentives for energy recovery, standards for landfilling of air pollution control residues, etc.). Consequently, price differences still exist, and residual wastes may be transported large distances if incineration is classified as recovery. Cost differentials are already giving rise to concerns regarding the illegal export of German waste to the Czech Republic on the basis of price differentials for waste incineration.

Essentially, we can see no rationale for the European Commission seeking to delineate recovery from disposal on the basis of energy efficiency. Indeed, the debate as it stands is in serious danger of slipping into one which effectively overturns the European Court rulings completely by linking the definition of recovery to a standard which incinerators are meant to achieve in order to operate.

As regards the eligibility for ROCs for incineration operating in CHP mode, the QI threshold appears to provide a useful benchmark. Meeting this benchmark will reduce the emissions of GHGs per kWh equivalent by approximately one-third of the level associated with facilities generating electricity only. However, the incentive provide by ROCs themselves would appear to be rather inappropriate for the purpose of incentivising CHP for the simple reason that the eligibility for ROCs relates to the power generation only, and many of the more effective and more likely CHP configurations which meet the QI threshold generate are likely to generate little or no electrical power. If this was intended as a measure to stimulate the use of CHP, therefore, it is likely to have limited success. Furthermore, to the extent that this leads to the operation of incinerators in CHP mode, as opposed to a mode where they generate electricity only, then these switches might suggest that the incinerators concerned were not, previously, recovering heat as far as practicable, as they are required to do under the Incineration Directive in order to operate at all.

5.6 Climate-friendly Options for Residual Waste Management?

Conventional wisdom has held that climate friendly options for managing residual waste depend upon us generating energy from it. This report challenges that view. It makes clear that if emissions of GHGs are considered as and when they occur, so that impacts on climate changes are understood in the round, then the following attributes are all favourable:

1. The extraction of materials for recycling;
2. Slower release of GHGs (notably those from biogenic sources which have tended to be overlooked in conventional life-cycle approaches); and
3. The generation of energy, especially where the offset effect is high (in other words, high efficiencies if generation or where there is direct displacement of fossil fuel);

From this, it might be stated that a more climate friendly plant might aim to do the following:

1. Extract materials for recycling, the emphasis (tonne for tonne) being on aluminium, plastics; steel, and (possibly) textiles;
2. Stabilise biodegradable fractions prior to landfilling, preferably generating energy in that process through, for example, anaerobic digestion;
3. Generate energy from residual fractions, ensuring that where the materials contain non-biogenic sources of carbon, either the efficiency of generation is very high, or that the material is used in processes where fossil fuels are directly displaced (i.e. what are currently termed recovery processes).

There are other approaches on the horizon. Extraction of gases, or chemicals for synthesis or use in fuel cell technologies are likely to be possible in years to come.

The key point to be made, however, is that the bland, uncritical and undifferentiated statement that ‘energy from waste is good for climate change’ is at best partial, is almost certainly incorrect under some entirely reasonable assumptions, and masks a rather more complex reality than most have been prepared to admit.

5.7 Is Climate Change the Only Issue That Matters?

The brief answer to this question is ‘no’. Other pollutants are clearly of concern, though improvements across technologies in terms of emissions performance make them less so.

The view that 'only climate change matters' appears to have gained credence since the publication of the HM Customs & Excise report mentioned previously.[52] This followed on from a review of emissions and health effects, and the external costs of the relevant air emissions.

The HM Customs & Excise results clearly suggested that climate change externalities were the most important ones. Yet closer inspection shows this to have been more or less implicit in the assumptions:

1. First, the study sought to estimate damages associated with a restricted range of pollutants – SO_2, NOx, VOCs and PM_{10}. Evidently, to the extent that many emissions which may be of significance are effectively attributed a zero damage cost (even though many of the studies reviewed have actually attempted such quantification), then other things being equal, the externalities from both landfill and incineration are likely to be underestimates of the actual damages caused. By way of example, one Norwegian study suggested that pollutants such as chromium, manganese and dioxins account for up to 85-95% of the total socioeconomic costs of waste incineration.[53] NERI also modelled the impact of dioxin emissions from incinerators (modern ones) for the Nordic Ministry.[54] The range of damages referred to equates to a range from £0.93 to £11.85 per tonne of waste incinerated (which hardly supports the view that 'only GHGs matter', still less that the impacts of dioxins can be completely overlooked);
2. Those pollutants to which damages were assigned were assumed to have low unit damage costs. Compared with recent work undertaken in Europe under the Clean Air for Europe programme,[55] the damage costs in the UK study were much lower than what has been suggested as appropriate for the UK.[56] There are a number of reason for this, notably the somewhat conservative, possibly outdated, approach adopted in the UK study, which reflects views which prevailed at the end of the 1990s. What is clear from Table 8 is the considerable gap between the estimates derived *within* the UK for use in the UK context, and *outside* the UK for use in the UK context.

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[52] HM Customs & Excise (2004) *Combining the Government's Two Heath and Environment Studies to Calculate Estimates for the External Costs of Landfill and Incineration*, December 2004

[53] ECON, Senter for økonomisk analyse (Centre for Economic Analysis) (2000) *Miljøkostnader ved avfallsbehandling*, ECON-report 85/00. The study is one of a number which were not considered in the review of external costs of waste management undertaken in the context of the health Effects work, including a number undertaken for the European Commission.

[54] See D. Jensen and N. Dengsoe (2004) *Værdisætning af skadesomkostninger ved affaldsforbrænding - en analyse af dioxiners skadelige effekter og et egneeksempel på disse effekters samfundsøkonomiske omkostninger*, TemaNord 2004:518, Copenhagen, Nordic Ministry.

[55] AEAT Environment (2005) *Damages per tonne Emission of $PM_{2.5}$, NH_3, SO_2, NO_x and VOCs from Each EU25 Member State (excluding Cyprus) and Surrounding Seas*, Report to DG Environment of the European Commission, March 2005

[56] See Enviros and EFTEC (2004) *Valuation Of The External Costs And Benefits To Health And Environment Of Waste Management Options*, Final Report for Defra, December 2004

3. Finally, interrogating the HM Customs & Excise figures, it is difficult to reproduce the published figures (which ought to be straightforward since the process involves a simple multiplication of two figures). The air pollution effects appear to have been miscalculated. In the central high scenario, the effects from SOx, NOx, VOCs and PM, even using the relatively conservative damage costs, are around £3.19 per tonne for incineration (or 319 times what is stated in the report). By way of comparison, if the same emissions data is used, but one uses the high end estimates from the CAFÉ work, the externalities associated with the same pollutants are in excess of £15.00 per tonne for incineration. This is of the same order as the climate change externalities. Of course, the impact of using the CAFÉ work would also be to increase the offsets associated with energy generation. Hence, the *net* effect for some pollutants would, most likely, be positive;

Table 8: Unit Damage Costs Used / Derived in Different Studies

Pollutant	**Enviros and EFTEC (2004)**		**EU-CAFÉ (2005)**	
	Low	High	Low	High
PM (landfill)	161	1,025	24,667	73,333
PM (incineration)	6,119	39,425		
SOx	643	2,941	4,400	12,667
NOx	154	977	2,600	6,667
VOCs	263	665	759	2207

Sources: Enviros and EFTEC (2004) Valuation Of The External Costs And Benefits To Health And Environment Of Waste Management Options Final Report for Defra, December 2004: AEAT Environment (2005) Damages per tonne Emission of $PM_{2.5}$, NH_3, SO_2, NO_x and VOCs from Each EU25 Member State (excluding Cyprus) and Surrounding Seas, Report to DG Environment of the European Commission, March 2005.

Evidently, climate change is still not the only thing that matters (or at least, it might not be). This is no less important for power plants than it is for incinerators. It is well known that power plants are regulated less stringently than incinerators. An interesting side effect of this is that the market for refuse derived fuels (RDF) is much thinner than it might otherwise be.

If the intention is to improve the market prospects for RDF, it might be tempting – and from the environmental perspective, there would be good reasons for doing so – to seek to tighten emissions standards at major combustion facilities. Whilst the implications of IPCC and the Large Combustion Plant Directive may assist in this regard, they may not do so soon enough if the intention is that more installations should become – as a matter of course – compliant with the terms of the Waste Incineration Directive in respect of co-incineration. From this point of view, there may be good reasons to seek to speed up the transition, possibly through targeted subsidies, to improve emissions standards. As with waste treatment plants, for power plants, climate change is not all that matters. The implications might be that the majority of power installations became, subject to the quality of the outputs from pre-treatment processes, viable outlets for this material. The net effect would be to improve overall environmental performance (for some specific pollutants, emissions would probably be worse at these facilities than at incinerators) since emissions associated with non-waste fuels would also be improved.

A general point of this report has been to highlight the complexity of some of the issues involved in debates at the waste/climate change/energy interface. This is a crucial time for the UK, and indeed other countries, to ensure that policies and incentives that are put in place are not working in contradictory ways. Failure to do this at a time when, in waste, many local authorities are seeking to make major investments which will be in place for decades to come raises the likelihood of heightened levels of regret in the coming years.

The Review of the Waste Strategy makes many encouraging noises concerning the move to more sustainable resource management. What is not so clear is the evidence base for what is proposed, given that the quality of some of the evidence reviewed by this report is clearly questionable in some areas.

A.1.0 GHG EMISSIONS PER UNIT OF ENERGY GENERATION

This section reviews the performance of the following technologies

- UK coal fired power station;
- UK Oil fired power station;
- UK gas-fired power station;
- Gas-fired CHP;
- Waste-to-energy incineration, electricity only;
- Waste to energy incineration, CHP;
- Waste to energy, heat only.

This type of analysis is not as clear-cut as many would like to believe. Some important methodological issues are outlined in Appendix 2.

A.1.1 Approach Taken

The approach taken in this study is to report emissions of GHGs in two ways:

- Ignoring biogenic CO_2;
- Including biogenic CO_2;

In addition, some of the schemes below generate electricity only, some generate heat only, and some generate both electricity and heat. Where heat is generated, we have quoted emissions with and without a factor converting the heat generated into an 'electricity equivalent'. Where heat is generated, in order to convert heat generation into an 'electricity equivalent', the generation of heat is multiplied by a factor of 0.40, representing a broad estimate of the efficiency of conversion of heat to electricity in UK generation.

The following sections describe the data sources used.

A.1.2 UK Coal-fired Power Station;

For UK coal–fired power stations, we have used:

- ➢ For the efficiency of generation, we have used the UK average (2004 figure from DTI Energy Statistics Table 5.10). This figure is expressed relative to the Gross Calorific Value of the coal input (36.2%);
- ➢ For the GCV of coal, we have used the 2004 figure from DTI Energy Statistics (Table A.1);
- ➢ For the carbon content of coal, we have reviewed a range of sources. The carbon content, like the GCV, varies with the type of coal used (both are lowest for brown coal, higher for subbituminous coal, higher still for bituminous coal, and highest

for anthracite). Coal used in the UK has been taken to have a carbon content of 60% (as received, or 80% dry and ash free)[57];

Using these figures, and assuming 99% conversion of carbon to CO2, gives a figure of 835g/kWh. A recent DTI publication gave a figure of 891g/kWh generated.[58] AEAT cite a figure from the CEGB from 1988 giving a figure of 848g/kWh.[59]

Note that this figure is for generation only. Other studies indicate additional emissions of CO_2, CH_4 and N_2O associated with other aspects of the mining, transport and generation processes.

The discounted and undiscounted values are the same, as are the figures with and without biogenic CO2.

A.1.2.1 The Future

The above assumes that energy efficiencies are as for the UK on the average. Evidently, not all power plants are 'average' performers. DTI quotes current efficiencies of between 36-40% for pulverised fuel plants. However, it notes that even today, state of the art supercritical pulverised fuel plants are estimated to achieve efficiencies of 45% (net) depending upon the coal type and plant location. The same report notes that:[60]

> *'It is also expected that by 2020, efficiencies of 50-55% can be achieved. This is likely to be achieved through a combination of enhanced steam conditions (650-700°C) from reduced plant losses and improved operating methods. Enhanced steam conditions put considerable demands on boiler and steam turbine materials and currently work is under way to develop materials that have the required strength and ductility.*

A Table from the report is included below with a row emboldened to show the potential for efficiency improvements through use of new technologies.

One might argue that state of the art facilities could be capable of emitting rather less CO_2 per unit of energy output than is the case today. In 2020, the efficiencies are around 150% of the average figures used here, so CO_2 emissions might drop to two-thirds of their current levels in state-of-the-art plants at that time. However, we have used a figure of 50% efficiency for the future scenario.

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[57] Often in the literature, it is not clear what measurements of the carbon content of coal are being reported. Frequently, very high values are reported, and one assumes these are reported on a 'dry and ash free' basis (though this is not always clear). Moisture measurements appear to vary between 8-11% on typical UK coals, whilst ash constitutes 7-15% by weight on an as received basis. The figure of 60% for carbon is the same as was proposed by ETSU in 1991. Evidently, the structure of supply, including imports, will have changed over the period, but relatively recent measurements suggest 80% content measured on a dry and ash-free basis.

[58] DTI (2005) *Energy Trends*, March 2005, http://www.dti.gov.uk/energy/inform/energy_trends/mar_05.pdf

[59] AEAT (1998) *Power Generation and the Environment - a UK Perspective Volume 1*, Report for European Commission DGXII, AEAT 3776.

[60] DTI (2001) UK Capability, Research And Development In Cleaner Coal Technologies, March 2001.

Table 9:

	Conventional	Advanced		Gasification	Hybrid
	Subcritical	**Supercritical**	**Pressurised Fluidised Bed Combustion (PBFC)**	**Integrated Gasification Combined Cycle (IGCC)**	**Air Blown Gasification Cycle (ABGC)**
Maturity	Completely proven. Commercially available with guarantees	Substantially proven. Commercial plant available with guarantees	Substantially proven. Commercial plant available with guarantees	Mainly demonstration plant operational where coal is the fuel source	At R&D stage
Range of units	All commercial sizes available (common unit sizes in the 300-1000MWe range)	All commercial sizes available	Three sizes available	250-300MWe. Currently limited by the size of the large gas turbine units available	~90MWe demonstration plant proposed
Fuel flexibility	Burns a wide range of internationally traded coals	Burns a wide range of internationally traded coals	Will burn a wide range of internationally traded and low-grade coals. Best suited to low-ash coals	Should burn a wide range of internationally traded coals, though not proven. Not really designed for low-grade, high-ash coals	Should use a wide range of internationally traded coals. Designed to use low-grade, high-ash coals efficiently
Thermal efficiency	**Limited by steam conditions. Modern designs achieve 41%**	**>45% now possible and >50% subject to successful materials development, ie further R&D**	**~44% now possible. Improvement likely with further R&D and/or supercritical steam cycle**	**~43% currently possible, but >50% possible with advanced gas turbines and further R&D**	**~43% should be obtainable. >50% possible with advanced gas turbines and further R&D**
Operation flexibility	Can operate at low load, but performance would be limited	Can operate at low load, but performance would be limited	Can operate at low load, but performance would be limited	Realistically could only operate at base load	Design suggests would have reasonable performance at low load
Environmental performance	Good SOx and NOx reduction with FGD and low-NOx systems fitted. Low efficiency, therefore high CO2 emissions	Higher efficiency will reduce SOx and NOx as well as CO2 emissions	Good for SOx and NOx. CO2 reasonable due to high efficiency. Solid waste may be difficult to dispose of	Excellent. Inert slag, sulphur capture and low NOx. High efficiency results in lower CO2 emissions	Not proven, but should be as good as PFBC
Availability	Proven to be excellent	Proven to be good	Limited experience	Not yet proven	Not yet demonstrated
Build time	~3 years	~3 years	~3 years	~4-5 years	~3-4 years?

Source: DTI (2001) UK Capability, Research And Development In Cleaner Coal Technologies, March 2001.

A.1.3 UK Oil-fired Power Station;

For UK oil–fired power stations, we have used:

- For the generation of energy per tonne of oil, we have calculated this from the fuel used in generation, and the electricity supplied, both for 2004 (2004 figure from DTI Energy Statistics Table 5.1). We have used figures from both major power producers and others;
- For the carbon content of fuel oil, we have reviewed a range of sources. The most recent UK quoted source is from work undertaken in the context of reporting of greenhouse gases. This gives a figure of 0.879 tonnes carbon per tonne of oil.[61] Other sources lie within the range 0.86 to 0.87, so this figure seems to be one which is known with some confidence;

Using these figures, and assuming 99% conversion of carbon to CO_2, gives a figure of 770g/kWh. A recent DTI publication gave a figure of 700g/kWh generated.[62] It is difficult to understand how this figure could be so different to the one we have calculated given that it comes from DTI statistics regarding energy generation, and from the use of one other parameter – the carbon content of fuel oil – which appears to be known with a high level of confidence.

Note that this figure is for generation only. Other studies indicate additional emissions of CO_2, CH_4 and N_2O associated with other aspects of the mining, transport and generation processes.

The discounted and undiscounted values are the same, as are the figures with and without biogenic CO2.

A.1.3.1 The Future

In the analysis, oil-fired power stations are assumed to achieve an efficiency of 45%. In the study, the rationale for future efficiency levels was somewhat weaker. It is not expected, however, that oil will play a major role in electricity generation in the UK in future. In 2004, less than 0.5% of electricity generation from major suppliers was derived from oil.

[61] Baggott SL, Brown L, Milne R, Murrells TP, Passant N, Thistlethwaite G, Watterson JD (2005) *UK Greenhouse Gas Inventory, 1990 to 2003: Annual Report for submission under the Framework Convention on Climate Change*, AEAT/ENV/R/1971, 29/04/2005

[62] DTI (2005) *Energy Trends*, March 2005, http://www.dti.gov.uk/energy/inform/energy_trends/mar_05.pdf

A.1.4 UK Gas-fired Power Station;

For UK gas–fired power stations, we have looked at UK average gas-fired generation. We have used:

- For the efficiency of generation, the UK average (2004 figure from DTI Energy Statistics Table 5.10). This figure is expressed relative to the Gross Calorific Value of the input energy in the gas;
- For the GCV of gas, we have used the 2004 figure from DTI Energy Statistics (Table A.1);
- For the carbon content of one tonne of gas, we have made the simplifying assumption that all natural gas is methane, and the as a result, (12/16)=75% of the mass of natural gas is carbon.

Using these figures, and assuming 99% conversion of carbon to CO_2, gives a figure of 382g/kWh. A recent DTI publication gave a figure of 97 tonnes carbon per TWh generated, equivalent to 356 g/kWh.[63] A USEPA study gave a figure of 372g/kWh at 48.8% efficiency.[64] AEAT gave a figure of 393g/kWh for the power production phase.[65]

It is worth stating that the CIWM's report on energy from waste – which offered no source for the data used – assumed figures of 525 g/kWh for gas fired electricity generation and 400g/kWh for CCGT.[66] The DTI figures are averages, so the CIWM figures appear to be significant overestimates of the actual emissions.

Note that this figure is for generation only. Other studies indicate additional emissions of CO_2, CH_4 and N_2O associated with other aspects of the mining, transport and generation processes.

The discounted and undiscounted values are the same, as are the figures with and without biogenic CO_2.

A.1.4.1 The Future

For the future scenario, we have assumed that efficiencies improve to those being achieved by the most efficient stations today (55%).

A.1.5 Combined Heat and Power

For CHP, we have used:

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[63] DTI (2005) *Energy Trends*, March 2005, http://www.dti.gov.uk/energy/inform/energy_trends/mar_05.pdf

[64] Pamela L. Spath and Margaret K. Mann (2000) *Life Cycle Assessment of a Natural Gas Combined-cycle Power Generation System*, Report NREL/TP-570-27715, National Renewable Energy Laboratory, September 2000.

[65] AEAT (1998) Power Generation and the Environment - a UK Perspective Volume 1, Report for European Commission DGXII, AEAT 3776

[66] CIWM (2003) *Energy from Waste: A Good Practice Guide*, Northampton: IWM Business Services Group, November 2003 – see Annex 4

- For the efficiency of generation of energy, figures from DTI (2004 figure from DTI Energy Statistics Table 6D).
- These efficiencies are given for different CHP schemes:
    - Backpressure steam turbines;
    - Pass out condensing steam turbines;
    - Gas turbines;
    - Combined cycle gas turbines; and
    - Reciprocating engines.

  These different designs tend to use different types of fuel though the majority of the CHP operations are fuelled by natural gas. The DTI gives a figure suggesting that natural gas accounts for 64.5% of all fuels used in CHP schemes.

  The basis for the calculation, therefore, is the most popular type of CHP facility run on natural gas, i.e. combined cycle gas turbine. This is not the most efficient type according to current UK performance statistics, but it performs above average for UK schemes (on a comparison based on simple summation of electricity and heat generation). Back pressure steam turbines – which have higher efficiencies – are often run on coal. This would reduce performance considerably in terms of carbon generation per unit of energy. Here, the emissions have been calculated on the basis that gas is the input source, and that electrical efficiency is 26% with heat efficiency of 48% (in line with DTI figures);

Using these figures, and assuming 99% conversion of carbon to CO_2, gives a figure of 241g/kWh where all energy is given equal weighting, or 395 g/kWh using the heat to electricity conversion factor of 0.40.

Note that this figure is for generation only. Other studies indicate additional emissions of CO_2, CH_4 and N_2O associated with other aspects of the mining, transport and generation processes.

The discounted and undiscounted values are the same, as are the figures with and without biogenic CO_2.

A.1.6 Waste-to-energy Incineration (electricity only);

For waste to energy incineration, there is likely to be rather more variation in terms of calorific value of the feedstock, and in respect of the carbon content of the feedstock, both the non-biogenic content and the biogenic content. Equally, there is clearly some debate – and one which has policy significance – regarding the potential efficiency of energy from waste incineration in respect of *net* generation of electricity. These issues are explored in more detail below.

A.1.6.1 Input Feedstocks

Each of the components of the waste stream has its own ‘energy content’ and carbon content (biogenic and non-biogenic). Care must be taken when linking the ‘calorific value’ of waste to the potential to generate energy from incinerators. The reason for this is that calorific values may be quoted either as ‘gross calorific values’ (GCVs) or ‘net calorific values' (NCVs). The difference between the two is explained in Box 2. The difference between NCVs and GCVs is usually significant for waste materials partly because of the moisture content of municipal waste.

Surprisingly, the quoted calorific values and carbon contents of components of municipal waste vary quite considerably, even once one accounts for the fact that some of the figures are quoted on an 'as received' basis, and others are quoted on a dry matter basis, and others are quoted on the basis of matter which is dry and ash free. Consequently, there are bound to be ranges quoted for the calorific value, gross or net, of residual waste destined for incineration.

The Incineration BRef Note proposes values that the NCV of municipal waste typically varies from 6-10.5 MJ/kg, with an average value of 9 MJ/kg. After recycling, the suggested range is 6.3-11.5 MJ/kg with an average value of 10 MJ/kg.[67] It also cites a study where, across 50 plants treating municipal waste, the NCV ranged from 8-12.6 MJ/kg, with an average value of 10.4 MJ/kg.[68]

In the UK, a study by Atkinson et al (1996) looked at GCVs of waste from a number of different local authorities with and without hypothetical recycling systems. Without the systems in place, vales ranged from 9.75-10.21 MJ/kg, and carbon content from 22.4-24.1%. The largest percentage changes estimated when the hypothetical – rather low-performance (the maximum rate was 22%) - recycling systems were introduced was an increase in 8% in GCV (when organics were included) and an increase in 9% in carbon content (also, where organics were included).

IPPC default values seem very high for C content of waste at between 33-50% with a default value of 40%. What we have done is to take the composition of 'bin waste' as identified by Parfitt, and we have made estimates as to what might be removed under a 'typical' recycling scenario a) today and b) in order to meet the Government's 2020 recycling target of 50% of household waste. In seeking to do this, we have assumed that bin waste would not have to be recycled at a rate of 50%. If HWRCs around the country reach a level of 75% recycling in that year, and if HWRCS account for 20% of municipal waste at the same time, then the required recycling rate from the 'bin waste' stream would be 44%.

In our estimation, the NCV of the waste stream is initially 9.7MJ/kg and has a carbon content of 25%, of which 7.6% is fossil carbon. After recycling, the NCV increases to 10.3MJ/kg and the carbon content increases to 27.7% of which 11.3% is fossil carbon.

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[67] European Commission (2005) Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration, July 2005.

[68] Energysub-group (2002) Energy Recovery from Waste Incineration Plants, cited in European Commission (2005) Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration, July 2005.

> ### Box 2: Net and Gross Calorific Values
>
> The gross calorific value (GCV) is the amount of heat released when all of the combustible material is burnt, converting all of the carbon to CO_2 and all of the hydrogen to H_2O. (It also includes the energy released by the oxidation of other elements such as sulphur and nitrogen, but the contribution of these may usually be ignored for practical purposes since their concentration in wastes is usually very low). Water is assumed to be recovered as liquid and, along with any ash residue, is assumed to have a final temperature the same as the starting material. The GCV may therefore be considered to represent the theoretical maximum amount of energy available through combustion.
>
> In practice, incinerators cannot recover all of the heat implied by the GCV of the waste. This is because the water produced by the oxidation of hydrogen in the fuel is not condensed, but escapes from the system in the stack gas as steam (at about 200-250 deg C) and other residues and products leave the incinerator at a higher temperature than they enter, so removing heat. The energy that would therefore have been recovered by condensing the steam to liquid water is therefore lost to the system. Furthermore, non-combustible residues (ash etc) also remove heat from the incinerator, proportional to their specific heat and the temperature difference between the incoming waste and the discharged hot ash as it leaves the incinerator. Finally water present in the waste will consume energy through evaporation and so reduce the overall amount of useful heat that can be recovered. Thus the wetter the fuel and the more ash it produces, the lower will be the heat recovered. Some waste may therefore remove more heat from an incinerator than they provide through combustion. The more useful parameter for estimating the energy input to incinerators is therefore the net calorific value, which takes account of these potential losses.
>
> The values for calorific value shown in Table A3.36 are average Net calorific values, based on analysis of extensive samples of waste received during the National Household Waste Analysis Programme. Some variation is seen in NCV within categories of waste, reflecting its natural variability. For example, food and garden wastes will contain tree prunings and dry stale bread with relatively high NCV values (ca 10 MJ/kg), to wet grass cutting negative value for NCV may occur for very wet wastes where more heat is removed in evaporating the water in the incinerator than is provided by combustion of the residue. Some variation is therefore to be expected, but overall averages are in good agreement with data reported elsewhere (eg US data reported in [54]) and the overall gross CV of waste based on this composition is within the range of 9 to 11 MJ/kg reported for European MSW.
>
> *Source: Smith et al (2001) Waste Management Options and Climate Change, Report to the European Commission, July 2001.*

A.1.6.2 Efficiencies of Electricity Generation from Incineration

The efficiency of generation of electricity by an incinerator ought to be calculated net of any energy used in the plant itself. The energy use in the plant depends partly upon the nature of the flue gas cleaning system used, but also upon a range of other factors. The relationship to flue gas cleaning is important since it seems likely that as standards for abatement have improved, so the energy used in achieving those levels of abatement has increased also.

A review of some recent figures regarding efficiencies, and their calculation relative to gross or net CVs, highlights the following. A number of studies report what are – by the standards of those studies attempting to measure ‘actual’ efficiencies, rather high. Amongst these, one can cite the following:

- The work by ERM supporting the Consultation on the Waste Strategy. This study uses an implied efficiency of 28% relative to reported NCVs. This is a gross figure and the energy use was 0.118kg of diesel plus 3.91kWh of electricity. No justification for these figures is provided in the report;

- Work for the Institute of Civil Engineers by Oakdene Hollins used a figure of 25.4%. This was based upon a somewhat theoretical discussion of possible energy efficiencies by C-tech.[69] The C-Tech work clearly reports this efficiency relative to NCVs. The study for the ICE appears to have applied the efficiency figure to GCVs, consequently overstating the potential for electricity recovery significantly. This led to an unheard of level of generation for conventional incinerators of 714kWh/tonne (and since all other technologies are scaled relative to this figure, it is worth adding that the potential for energy recovery from all the other technologies are also overstated). This is all the more remarkable since the presumption is that this is net of any internal use;
- Fichtner, in a report for ESTET, was critical of the basis for favouring advanced thermal treatments relative to conventional incineration, supposedly on grounds of superior efficiencies to be gained from the latter.[70] Fichtner quoted net electrical efficiencies for steam cycle combustion of 19-27% based upon NCV. The upper end of this range is not especially common;
- CIWM reports efficiency of generation of 22%-25%, but this does not make reference to any measure of the CV used.[71]

In the context of the development of the BAT standard for incineration, measurements were made at 8 German plants and efficiencies ranged from 12.9% - 22%, with an average of 18%. However, this did not account for the plant's own use of electricity, which reduced net efficiencies to 8.7% - 18%, with an average of 13%,[72] The Bref note also noted that for new French facilities, efficiency of production was 16.4%, with net efficiencies at 13.4%.[73]

A recent report for the German Umweltbudesamt stated:

> *If the steam produced is used to generate electricity only, the best German waste incineration plants from an energy production point of view achieve an efficiency of approx. 21 %.... The internal energy requirements of waste incineration plants, measured in terms of the energy introduced in the*

[69] Oakdene Hollins (2005) *Quantification of the Potential Energy from Residuals (EfR) in the UK*, Report for the Institute of Civil Engineers and the Renewable Power Association, March 2005, http://www.ice.org.uk/downloads//energy_from_waste.pdf.

[70] Fichtner Consulting Engineers Limited (2004) *The Viability Of Advanced Thermal Treatment Of MSW In The UK*, ESTET, March 2004

[71] CIWM (2003) *Energy from Waste: A Good Practice Guide*, Northampton: IWM Business Services Group, November 2003.

[72] Energysub-group (2002) Energy Recovery from Waste Incineration Plants, cited in European Commission (2005) Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration, July 2005.

[73] European Commission (2005) Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration, July 2005.

> *waste, are currently put at an average of about 4 % electricity, 6.5 % heat and 3.5 % external energy.*[74]

The study also noted a Netherlands case where targeted subsidies pushed efficiencies up to 29%.

On the basis of the above discussion, we take the view that some of the reported values are, especially where they are not linked to actual reported performance, rather high. Some are especially high given that they are reported as net (of internal use) efficiencies. It would appear that internal use of energy accounts for around one sixth of electricity actually generated. However, current average net generation efficiencies are likely to be of the order 21% (higher than what is reported under the IPPC Bref noted above). For a 2020 scenario, where national recycling rates reach 50% (and bin waste recycling reaches 44%) we have assumed that efficiencies reach 25%.

A.1.6.3 Results

If waste with its current constitution is combusted 'whole', then at 21% efficiency, CO_2 emissions are:

- 1,627 g/kWh including all carbon sources; or
- 491 g / kWh if biogenic CO_2 is ignored.

In addition to CO_2, incinerators emit nitrous oxide. Nitrous oxide is a GHG which is 310 times as potent in terms of radiative forcing (though actually, this depends upon the time horizon adopted). It is believed to be more of an issue where combustion temperatures fall below 850C and where the control of NOx is through use of SNCR, especially with urea as the reagent.

Authoritative data on N_2O emissions is difficult to come by. The Bref note for Incineration suggests a range for municipal waste incinerators of 1-12 mg/Nm3, which would translate to (roughly) 5g – 60g per tonne of waste. It is suggested that N_2O emissions may be more problematic in fluidised bed facilities (of which, the UK will soon have two for municipal waste, one in Dundee, the other at Allington in Kent). IPPC data was used by AEAT as the basis for their estimate of 50g/tonne MSW. Converted to CO_2 equivalents, this figure amounts to some 18g/kWh in the lower efficiency scenario, or 15 g/kWh in the higher efficiency scenario.

A.1.6.4 Looking to the Future

In future, with higher rates of recycling, but higher efficiencies of generation, these figures are estimated to become

- 1,390 g/kWh including all carbon sources; or
- 565 g / kWh if biogenic CO_2 is ignored.

[74] Dehoust et al (2005) *Status Report on the Waste Sector's Contribution to Climate Protection and Possible Potentials*, Research Report 2005 33 314, UBA-FB III, German Federal Environmental Agency, August 2005

Interestingly, because it is anticipated that (in line with experience elsewhere and current UK trends) captures of recyclables will be greater for paper, card and biowaste than for plastics, the higher fossil carbon content of waste pushes this figure up, counteracting the effect of higher efficiencies of generation. On the other hand, total carbon does not increase to the same degree, so the dominant factor is the improvement in efficiencies where total CO_2 is concerned.

A.1.7 Waste to Energy, CHP

In calculating emissions from CHP processes, essentially, the same methodology has been used as for incineration with electricity generation only. All that changes is the efficiency of generation. European experience suggests that the efficiency of energy *utilised* is determined as much by the potential market for heat utilisation as by the underlying efficiency of the plant. Critical in this context is whether the incinerator is essentially a provider of base load energy as opposed to being a provider of additional energy at times of peak demand. This is captured well by a recent German report, which notes:

> *With electrical efficiency levels of 5 to 15 %, overall efficiency levels of up to 70 % are possible using combined heat-and-power generation (CHP). For example, the five German plants with the highest energy efficiency figures not only output an average of 7.6 % of the fuel energy as electricity, but also some 60 % heat from waste in the form of district heating or process steam. Other plants achieve overall efficiency levels of only about 18 %, of which an average of 46 % is due to electricity output (Öko-Institut 2002). This indicates that a considerable proportion of the steam generated in such plants cannot be used.*

The report cites, amongst other things, competition with municipal-owned power plants and whether or not the facility provides base load energy, and the seasonal nature of demand, as key issues.

The Bref note for Incineration reported figures from RVF (The Swedish Waste Management Association) at between 70-85% for CHP installations.[75] It also reported averages from a survey of CHP plants of 49.3% efficiency, which includes a weighting factor of 2.6316 for electricity generation. There is clearly an enormous amount of variation in actual performance (in energy utilisation as much as in generation) where CHP incineration is concerned.

However, for the purposes of this report, we are interested in the prospects for CHP where the demand exists. We have used efficiencies of 10% for electricity and 55% for heat generation.

The figures for CO_2 emissions are:

- If heat and electricity are given equal weighting:
  - 525 g/kWh including all carbon sources; or
  - 159 g / kWh if biogenic CO_2 is ignored.
- If heat is multiplied by a factor of 0.40:

[75] RVF (2002) Energy Recovery by Condensation and Heat Pumps at WTE Plants in Sweden

- 1,068 g/kWh including all carbon sources; or
- 322 g / kWh if biogenic CO_2 is ignored.

A.1.7.1 Looking to the Future

For future performance, we have used efficiencies of 15% for electricity and 60% for heat generation.

The figures for CO_2 emissions are:

- If heat and electricity are given equal weighting:
  - 463 g/kWh including all carbon sources; or
  - 188 g / kWh if biogenic CO_2 is ignored.
- If heat is multiplied by a factor of 0.40:
  - 891 g/kWh including all carbon sources; or
  - 362 g / kWh if biogenic CO_2 is ignored.

A.1.8 Waste to Energy, Heat Only

In calculating emissions from processes where only heat is generated, essentially, the same methodology has been used as for incineration with electricity generation only. All that changes is the efficiency of generation.

It may sound odd to state this, but quoted figures for incinerators generating heat only sometimes exceed 100%. This is because of the fact that most incinerators report efficiency performance against the NCV of waste as opposed to the GCV. Where heat generation employs condensing of the flue gas (to extract additional energy), then effectively, part of the energy in the moisture evaporated in the process is being utilised as heat in the energy generation process.

Condensing the flue gas is not common in Germany. It is more common in Sweden and other Scandinavian countries. This reflects the fact that district heating is far more common, and the climatic situation, which is such that heat has a much higher value relative to electricity. Fossil fuels are heavily taxed when used for heating and natural gas is not so readily available.

The Incineration Bref reported figures from RVF (The Swedish Waste Management Association) for different incinerators as shown in Table 10 below.

Table 10: Thermal Efficiencies for Incinerators in Different Operating Modes

Plant Type	Reported Potential Thermal Efficiency (%) ((heat + electricity)/energy output from the boiler)
Heating stations with sales of steam and / or hot water	80-90
Steam sales to large chemical plants	90-100
CHP and heating plants with condensation of humidity in flue-gas	85-95
CHP and heating plants with condensation and heat pumps	90-100

RVF (2002) Energy Recovery by Condensation and Heat Pumps at WTE Plants in Sweden

These efficiencies are the highest observed across the different configurations for energy generation.

For the purposes of this study, we have used a figure of 90% efficiency for plants generating heat only.

The figures for CO_2 emissions are:

- If heat and electricity are given equal weighting:
  - 379 g/kWh including all carbon sources; or
  - 114 g / kWh if biogenic CO_2 is ignored.
- If heat is multiplied by a factor of 0.40:
  - 949 g/kWh including all carbon sources; or
  - 287 g / kWh if biogenic CO_2 is ignored.

A.1.8.1 Looking to the Future

For future performance, we have used the figure of 100%, re-iterating that this figure is quoted relative to NHV of the waste rather than the GHV.

The figures for CO_2 emissions are:

- If heat and electricity are given equal weighting:
  - 348 g/kWh including all carbon sources; or
  - 141 g / kWh if biogenic CO_2 is ignored.
- If heat is multiplied by a factor of 0.40:
  - 868 g/kWh including all carbon sources; or
  - 353 g / kWh if biogenic CO_2 is ignored.

A.2.0 METHODOLOGICAL ISSUES

A.2.1 Should We Include Biogenic Emissions of CO_2?

One question– particularly relevant where waste is concerned – is which emissions to consider, and which not to consider. This sounds like a question that ought to have an obvious answer, but it does not. Despite that, few studies even bother to raise it as a question, let alone, as an important one. For example, the recent study by ERM does not even mention this as an issue.

The key issue is biogenic carbon. Should it be included in the analysis, or should it not?

Currently, convention appears to be shaped by decisions made by the Intergovernmental Panel on Climate Change (IPCC) regarding the reporting of Greenhouse Gas Inventories by different countries. It is argued, in most reports comparing waste treatment options, that this effectively allows carbon dioxide emissions from biogenic sources to be ignored in the reporting of inventories.

As regards waste, the Guidelines from IPCC state that the following should be reported:

> *Total emissions from solid waste disposal on land, wastewater, waste incineration and any other waste management activity.* ***Any CO_2 emissions from fossil-based products (incineration or decomposition) should be accounted for here*** *but see note on double counting under Section 2 "Reporting the National Inventory." CO_2 from organic waste handling and decay should not be included (see below).*[76]

Specifically regarding waste incineration, the same guidelines state that reporting should include:

> *Incineration of waste, not including waste-to-energy facilities. Emissions from waste burnt for energy are reported under the Energy Module, 1 A. Emissions from burning of agricultural wastes should be reported under Section 4. All non-CO_2 greenhouse gases from incineration should be reported here as well as CO_2 from non-biological waste.*

Given the above, then it worth reporting what is set out regarding energy. The following are too be reported:

> *Total emissions of all greenhouse gases from all fuel combustion activities as described further below.* ***CO_2 emissions from combustion of biomass fuels are not included in totals for the energy sector****. They may not be net emissions if the biomass is sustainably produced.* ***If biomass is harvested at an unsustainable rate (that is, faster than annual regrowth), net CO_2 emissions will appear as a loss of biomass stocks in the Land-Use Change and Forestry module. Other greenhouse gases from biomass fuel combustion are considered net emissions and are reported under Energy. (Sum of I A 1 to I A 5). Incineration of waste***

[76] Understanding the Common Reporting Framework, in IPCC (u.d.) *Revised 1996 IPCC Reporting Guidelines for National Greenhouse Gas Inventories, Reporting Instructions (Volume 1)*, Hadley Centre, Bracknell, http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/contri.pdf.

> ***for waste-to-energy facilities should be reported here and not under Section 6C***. *Emissions based upon fuel for use on ships or aircraft engaged in international transport (1 A 3 a i and 1 A 3 d i) should, as far as possible, not be included in national totals but reported separately.*

The crucial point here is that for the purposes of IPCC reporting, biogenic CO_2 is effectively not reported.

Brief discussions with IPCC suggest that they believe that the issue of biogenic carbon is effectively dealt with through the reporting under the Land Use, Land-Use Change and Forestry (LULUCF) sector. The approach used here is to use stock changes to estimate emissions. In theory, IPCC has suggested (in a private communication) that this is meant to include not just uptake of CO_2 by crops and forests etc but also, the release of CO_2 after use as food, fuel or from waste disposal. Perhaps unsurprisingly – neither incinerators nor landfills obviously look like something which registers under 'Land-use Change and Forestry' – these do not seem to be reported. We believe this is a potentially significant omission.

Whatever the merits or otherwise of not reporting biogenic CO_2 for the purpose of national inventories, in comparative assessments between processes, it cannot be valid to ignore biogenic CO_2 if the different processes deal with biogenic CO_2 in different ways. The atmosphere does not, after all, distinguish between molecules of GHGs depending on their origin.

A.2.2 How Should One Account for Biogenic CO_2?

The need to include biogenic CO_2 is well recognized by some of those involved in life-cycle assessments:

> *The practise to disregard biotic CO_2-emissions can lead to erroneous results (Dobson 1998). Let us consider an example to illustrate this. Let us compare incineration and landfilling of a hypothetical product consisting of only cellulose. When incinerated, nearly 100 % of the carbon is emitted as CO_2. However, in the inventory, this emission is often disregarded as noted above. If the product is landfilled, approximately 70 % of the material is expected to be degraded and emitted during a short time period, mainly as CO_2 and CH_4 (Finnveden et al. 1995) (The short time period is here defined as the surveyable time period, which will be explained in 2.3.6). Again the emitted CO_2 is normally disregarded, although the CH_4-emissions are noted. During the surveyable time period, 30 % of the carbon is expected to be trapped in the landfill. There is thus a difference between the landfilling and the incineration alternatives in this respect, in the incineration case all carbon is emitted, whereas in the landfilling case some of the carbon is trapped.* ***This difference is however not noted, since the CO_2-emissions are disregarded and this is in principle a mistake.*** *Additionally, the biological carbon emitted as CH_4 in the landfilling case is noted and will discredit this option. It could be argued that a part of the global warming potential, corresponding to the potential of the*

same amount of biological carbon in CO_2, should be subtracted from the landfilling inventory.[77]

Few, however, acknowledge the implications of the inclusion of biogenic carbon alongside consideration of time in the analysis.

Once one accepts the point that biogenic CO_2 should be included in the analysis, an equally important question is how the emissions should be accounted for. The vast majority of life-cycle studies simply define a moment in time and aggregate all emissions occurring until that point in time. For processes whose profile of emissions varies in time, this raises the following questions:

- Is there no equivalent of discounting to be applied in such analyses (do emissions in all years count equally)? and
- What is the justification for drawing the cut off in time in one year as opposed to another?

These are really flip-sides of the same question, which can be succinctly put as 'doesn't time matter?' In life-cycle studies, the implied answer is that up to the stated cut-off point, time does not matter at all. What matters, however, is where that cut off point is drawn. If time was taken to be infinite, presumably, all carbon could be assumed to be mineralized by all processes. Perhaps reflecting on the fact that any life-cycle comparison might be rendered rather meaningless by taking an infinite time horizon (even though, one might reasonably argue, this is what would need to be done in accounting for fates from cradle to grave), life-cycle studies tend to draw cut off points around 100 years. Finnvenden et al distinguish between 'surveyable time' and 'remaining time'.[78] Whilst this might be a reasonable way of trying to understand differences between different time-horizons, there is still no apparent logic – apart from understanding the differences – for choosing either of these time horizons, which in terms of the analysis are chosen arbitrarily.[79]

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[77] G. Finvenden, J. Johansson, P. Lind and A. Moberg (2000) *Life Cycle Assessments of Energy from Solid Waste*, FMS: Stockholm.

[78] G. Finvenden, J. Johansson, P. Lind and A. Moberg (2000) *Life Cycle Assessments of Energy from Solid Waste*, FMS: Stockholm.

[79] Some of those who – like Finnvenden – have recognised the significance of time do so in the sense that they seek to make study of the emissions beyond 100 years more relevant:

There are essentially two different approaches to handle the long term emissions from landfills. One is to try to model the emissions also for longer time periods while acknowledging the difficulties […]. The other approach is to say that it is impossible to model the long term emissions from landfills in a meaningful manner and future studies should address how residues remaining in landfills after 100 years shall be treated in the LCA impact assessment step. Only future research can reveal which approach is most useful. For the moment however, our message is clear: Long-term emissions from landfills should not be disregarded *(G. Finvenden, J. Johansson, P. Lind and A. Moberg (2000) Life Cycle Assessments of Energy from Solid Waste, FMS: Stockholm).*

From an economist's point of view, as long as discounting occurs at a non-zero rate, what is far more important for assessing impacts is the time-distribution of emissions in the early years, not the decades after the hundredth year. This is not to trivialise the issue of, for example, the long-term fate of toxic materials contained within landfills. Rather, the point is to highlight the complete disjuncture in the perspectives being adopted by life-cycle modellers and economists, even though on occasion, the economists choose to use the work of life-cycle modellers in what is effectively an insecure marriage of mixed methodologies.

Yet from an economist's perspective, the sorts of time horizon being considered by LCA practitioners are already rather long. Economists, who tend to apply discounting to take into account the effects of time, are much more interested in the influence of discounting applied over the whole time horizon. Time is not arbitrarily truncated, but it begins to influence the analysis.

Consequently, applying discounting to the emissions which occur, allocated to each time period, is likely to provide an indicator of climate change effects which is of more relevance to the policy discussions underway. In such an analysis, time matters, and it matters in ways which are not arbitrarily defined.

It is worth reporting that the study accompanying Defra's Draft Waste Strategy effectively combined a life-cycle approach to understanding emissions with a cost-benefit approach, using discounting, to quantify costs and benefits. This is methodologically flawed. It cannot be right to employ a discounting approach to emissions of GHGs which are aggregated for a period projected forward one hundred years. This merely adds to the confusion regarding the methodological approach being taken.

A.3.0 WASTE MANAGEMENT OPTIONS

This Annex describes the assumptions made concerning the different waste treatments modelled. In cases where GHG emissions are reported, results are given in terms of kg CO_2 equivalent per tonne (kg CO_2 equ/t). Elsewhere, we show the social costs per tonne in different years.

The GHGs included were CO_2, N_2O and CH_4. The weightings used, relative to CO_2, ought to vary with the time horizon used and the discount rate deployed. This is discussed in (amongst others) work by Clarkson and Deyes.[80] We have used weightings which were 21 for CH_4 and 310 for N_2O.

The approach has been based upon the following:

- Unit damage costs, and escalation in these, given by Table 2. These have been taken from the recent review of the social costs of carbon. These were, in turn, devised to assist in policy-making. Only the 'Central Guidance' figures which appear in the Table have been used for ease of presentation of results. This would be appropriate for project-type appraisals where a basis for a decision would be sought (as, for example, in real-world local authority decisions being taken today);
- A time profile for the discount rate as recommended in the Treasury's Green Book which shows a decreasing discount rate over time;
- Electricity use was modelled as UK average mix. Electricity generation was assumed to displace gas-fired generation (this is broadly the same approach as used in the ERM report).[81] Where heat is generated, it was deemed to displace gas-fired heat generation;
- Biogenic and non-biogenic emissions are treated equally.

It should be noted that the rate of escalation in the unit damage costs (which depends upon the scenario used from Table 11) relative to the effects of the discount rate will have a bearing upon the relative performance of processes for which emissions occur over an extended period of time, against those processes where emissions occur on day one.[82]

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[80] R. Clarkson and K. Deyes (2002) *Estimating the Social Costs of Carbon*, Government Economic Service Working Paper, January 2002.

[81] ERM (2006) *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions*, Final Report for Defra, January 2006.

[82] There is an interesting discussion to be had concerning whether methane emissions – because of their short residence time – are better emitted earlier rather than later. In modelling using PAGE, a recent report suggested:

> the SC [of methane] discounted to 2000 actually rises over time. This is because of the short atmospheric lifetime of methane; any methane emitted today will have disappeared from the atmosphere before the most severe climate change impacts start. This implies that given a choice today between emitting 1 tonne of methane now, or at some time up to 60 years in the future, we should opt to emit it now. The best fit to the mean values in the year of emission is **a 3.6%**

All electricity generation is assumed to displace gas-fired generation at current average performance. All heat generation is assumed to displace gas-fired heating. All electricity use is assumed to lead to emissions based upon UK average electricity generation. These are the same assumptions as were made in the ERM study.[83]

Table 11: Example Shadow Price Values from the Study, consistent with Recommendations (£/tonne carbon)

Year of emission	Central guidance	Lower central estimate	Upper central estimate	Lower bound	Upper bound
2000	55	35	130	10	220
2010	65	40	160	12	260
2020	80	50	205	15	310
2030	100	65	260	20	370
2040	140	90	330	25	450
2050	210	130	420	30	550

Source: Paul Watkiss, David Anthoff, Tom Downing, Cameron Hepburn, Chris Hope, Alistair Hunt, and Richard Tol (2005) The Social Costs of Carbon (SCC) Review: Methodological Approaches for Using SCC Estimates in Policy Assessment, Final Report, November 2005.

A.3.1 Incineration

Four options were modelled:

1. generating electricity only
2. generating electricity only with recovery of steel;
3. generating electricity only with recovery of steel and aluminium;
4. generating heat with recovery of steel and aluminium;

The incinerator was modelled as in Annex 1. The recovery of steel was modelled using a capture rate of 60% of the ferrous metal in the input waste. The recovery of aluminium

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increase in SC of methane each year. (Paul Watkiss, David Anthoff, Tom Downing, Cameron Hepburn, Chris Hope, Alistair Hunt, and Richard Tol (2005) The Social Costs of Carbon (SCC) Review: Methodological Approaches for Using SCC Estimates in Policy Assessment, Final Report, November 2005.)

In this report, we have simply used a weighting factor to convert the social costs of carbon to the social costs of methane. It is clear that this is not strictly correct, and in future, it ought to be common for analysis of impacts from the different GHGs to be carried out independently to highlight the fact that the evolution in social costs over time is quite different for the different GHGs. The implications of the above cited paragraph would be that the performance of landfills, where waste is untreated, would appear far worse from a social cost perspective.

[83] ERM (2006) *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions*, Final Report for Defra, January 2006.

was modelled using a recovery rate of 40% of the non-ferrous metal in the input waste. The figures for the benefits from recycling are as they were put forward in the ERM report.[84]

Table 12: Emissions from Incineration Process and Sub-processes

Sub-processes	Emissions (kg CO_2 equ/t)
Incineration (1)	936
Generation of Electricity (electricity only) (2)	-222
Generation of Heat (heat only) (3)	-508
Ferrous (Fe) Extraction (4)	-15
Aluminium (Al) Extraction (5)	-33
Incineration, Electricity Only, Fe and Al (1+2+4+5)	**666**
Incineration, Heat Only, Fe and Al (1+3+4+5)	**381**

A.3.2 Landfill

Three options are modelled:

1. Landfill with a life-time rate of gas capture of 75%;
2. Landfill with a life-time rate of gas capture of 50%;
3. Landfill with a life-time rate of gas capture of 25%;

The approach follows that suggested in work by Gregory for Defra, based, in turn, upon previous work by IPCC (currently being revised) and Brown. The reader is referred to that work for details of the full approach.[85]

In the approach, the carbon in the different biodegradable fractions of the waste stream is split into rapidly, moderately and slowly degrading fractions. First order decay functions are then used to model the emissions over time from each of the fractions. For each fraction a factor is used to delineate the proportion of the carbon which decays into methane, and the proportion which is generated as CO_2. These emissions are then aggregated to give the total figure.

For simplicity, the landfill scenarios were all deemed to have the same performance parameters with one exception. This was the lifetime capture rate of the gas emitted. An important simplification employed in the study was to use the same rate of capture in all years. A more complete analysis would assign different gas capture rates to different years. This could be done, quite trivially, in the modelling, but for reasons of time, this was not carried out in this study. This simplification will probably affect the lower gas

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[84] ERM (2006) *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions*, Final Report for Defra, January 2006. The figures are shown in Annex 4 below.

[85] LQM (2003) *Methane Emissions from Landfill Sites in the UK*, Report for Defra, January 2003.

capture scenarios more than the higher ones since the lower gas capture scenarios will be derived from relatively high gas captures in ‘good’ years, and lower gas captures over the remaining life of the landfill.

It is our view that this remains - surprisingly – an under-explored area of research. An important question would appear to be whether or not – even where landfill gas captures are assumed to be low over the landfill’s lifetime – the uncaptured gas is emitted to the atmosphere as methane or CO_2. As the rate of flux of uncaptured gas declines, then depending upon the nature of the cover, it could be assumed that any uncaptured methane would be converted to CO_2 through oxidation in the cap. However, a less sanguine view might be that it is in these later years where the cap itself is less likely to be in a condition which makes this likely.

The baseline parameters are the following:

1. Proportion of collected gas which is flared 50%
2. Proportion of collected gas used for energy recovery 50%
3. Efficiency of generation of electricity from collected methane 37.5%
4. Rate of oxidation of methane at the cap 10%

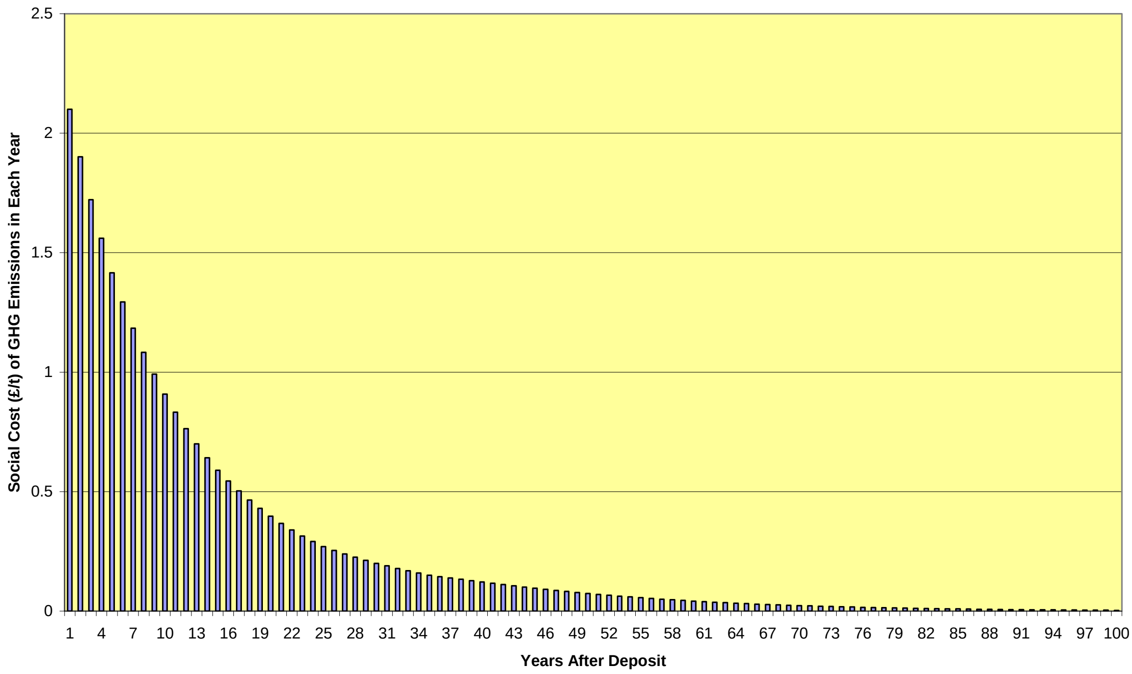
The first two of these are the means of figures from the Defra health effects report.[86] The third is typical of figures used in the literature for landfill gas engines (typically, 35-40%). The fourth is, again, a widely used figure and is likely to be used as the IPCC default. All these figures are, of course, subject to some variability. The social costs per tonne in each year are shown in Figure 8 for the 25% capture scenario.

The net social costs are:

- Landfill 75% capture £10.68 per tonne
- Landfill 50% capture £18.54 per tonne
- Landfill 25% capture £26.39 per tonne

[86] Enviros, University of Birmingham, RPA Ltd., Open University and Maggie Thurgood (2004) *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*, Final Report to Defra, March 2004.

Figure 8: Social Costs Related to GHG Emissions (£ per Tonne) of Landfilled Waste v Year of Deposit (25% capture of landfill gas over lifetime)



A.3.3 Aerobic MBT

Three options are modelled:

1. With:
    a. Extraction of steel and aluminium; and
    b. Stabilisation of material prior to landfilling;
2. With:
    a. Extraction of steel and aluminium; and
    b. Drying of material to prepare a refuse-derived fuel (RDF) for subsequent use in a dedicated (i.e. to treating waste) fluidised bed incinerator;
3. With:
    a. Extraction of steel and aluminium; and
    b. Drying of material to prepare a RDF for subsequent combustion in a cement kiln, with the assumption being that coal is displaced;

In the former case, input electricity is estimated at 65kWh per tonne with diesel use at 0.2l/tonne. Energy use is estimated from a number of facilities operated in this fashion across Austria, Germany and Italy. The greater the complexity of any separation processes, generally, the higher is the energy use.

The pre-treatment process is deemed to generate 410kg CO_2 per tonne of waste. In addition, 0.62kg CH_4 is produced and 0.017kg N_2O. This is based upon modelling by Hellweg et al, these being derived in turn from work by Wahlmann et al.[87]. The CO_2 figures are probably on the high side, given that these are similar to those derived from compost plants where a somewhat greater proportion of the input waste is biodegradable carbon. However, since the landfilled waste is deemed to have a carbon content calculated from the carbon loss in the pre-treatment process, this may be less important.

The remaining biogenic carbon (calculated from a mass balance) is deemed to be composed of moderately and slowly degrading carbon. The emissions of this are treated in the same way as the landfilling of untreated waste. However, in this case, no landfill gas is captured, but the oxidation rate is set much higher at 90%. This may seem extreme. However, it may be a reasonable reflection of reality. Probably, the model overstates the proportion of moderately quickly degrading fractions in the waste. However, when combined with a relatively high rate of oxidation, the assumptions might be considered a reasonable reflection of best practice.[88] Total process emissions are broadly similar in this approach to those we have modelled previously following the work of GUA et al, with short- and long-term transfer factors for landfilled material being used to estimate emissions.[89] The advantage of the approach used here is that the time profile for the emissions is captured more readily.

Extraction of steel and aluminium are as with the incinerator with captures at the same rate.

For the second case, the energy input to the pre-treatment process is somewhat lower, but there is also energy used at the fluidised bed incinerator. In the (much shorter) drying process, 185kg CO_2 are emitted as well as 0.15kg CH_4. This is estimated on the basis of estimates for the carbon loss by component of the waste stream. This is somewhat lower than some others have estimated.[90] In the FBI combustion phase, 732kg CO_2 is liberated

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[87] Stefanie Hellweg, Gabor Doka, Goran Finnvenden and Konrad Hungerbuhler (2003) Ecology: Which Technologies Perform Best?, in Christian Ludwig, Stefanie Hellweg and Samuel Stucki (eds) (2003) *Municipal Solid Waste Management: Strategies and Technologies for Sustainable Solutions*, London: Springer.

[88] See K. Fricke and H. Santen (2001) Bioremediation of Abandoned Landfills, microbiological Oxidation in Landfill Capping, European Remediation Conference, Crete. K. Hoering, I. Kruempelbeck, H-J. Ehrig, (1999) Long-term emission behaviour of mechanical-biological pre-treated municipal solid waste. In: Proceedings Sardinia 99. *Seventh International Waste Management and Landfill Symposium*. S Margherita di Pula, Caligari, Italy, 4-8 October 1999. pp 409-418. Recent work in the US has also highlighted the potential of active landfill layers to reduce methane emissions from landfills – see M. A. Barlaz, R. B. Green, J. P. Chanton C. D. Goldsmith and G. R. Hater (2004) Evaluation of Biologically Active Cover for Mitigation of Landfill Gas Emissions, Environmental Science and Technology, 2004, Vol.38, pp.4891-4899.

[89] For full details, see GUA, AWS and IFIP (2000) *Bewertung Abfallwirtschaftlicher Maßnahmen mit dem Ziel der Nachsorgefreien Deponie (BEWEND)*, Final Report, Vienna, November 2000. An English summary is available – G. Doberl, R. Huber, P. Brunner, M. Eder, R. Pierrard, W. Schonback, W. Fruhwirth, H. Hutterer (2000) *Long-term Assessment of Waste Management Options – a New, Integrated and Goal-Oriented Approach*.

[90] For example, see Lahl, Uwe, Barbara Zeschmar-Lahl and Thomas Angerer (2000) *Entwicklungspotentiale der Mechanisch-biologischen Abfallbehandlung: Eine Ökologische Analyse*, Vienna: Umweltbundesamt, June 2000.

(calculated on the basis of a mass balance). In addition, FBIs are believed to be heavier emitters of N_2O than conventional incinerators. However, the ranges quoted in the literature are very large. The Incineration BRef reports a very wide range, whilst work for the Austrian Umweltbundesamt used a zero value. We have assumed the same rate of emission as at conventional incinerators. The efficiency of the FBI is assumed to be slightly higher than for the conventional facility partly because of the likelihood of more complete combustion and partly owing to the fact that, being measured relative to net calorific value, the fact that the moisture content of the pre-treated waste is lower than that of raw waste improves performance relative to this measure.

For the third case, the modelling is similar to the above, but with the displacement effect associated with the use of RDF being related to the calorific value of coal with the equivalent energy content.

A.3.4 AD-based MBT

The AD-based MBT process is assumed to use 80kWh per tonne of electricity. The heat to operate the plant is anticipated to be provided from the biogas generated. Approximately 70m^3 biogas per tonne of waste input to the plant is assumed to be collected from the digester of which 55% is assumed to be methane. This is converted at 40% efficiency to electricity, giving generation of 154kWh per tonne of waste input to the plant.

The stabilisation analysis and the materials recovery analysis are as described above and in the main text.

A.4.0 BRIEF REVIEW OF PREVIOUS LITERATURE

A.4.1 ERM Study

The study lists some of its objectives:

> *Further, specific objectives were to:*
>
> *• review recent research on the effects of waste management policies on greenhouse gas emissions and from these studies and data sources to produce a best estimate of greenhouse gas emissions;*
>
> *• estimate the financial costs and benefits associated with waste management scenarios; and*
>
> *• identify the key sensitivities and risks that will affect these assessments.*

Neither the first nor the last of these can be said to have been carried out in the study. Only the second has been undertaken, but without any review of the literature or any understanding of the sensitivities of the analysis to key assumptions and variables, it is not possible to know whether the one specific objective which was carried out – estimating the financial costs and benefits - has been carried out with any precision. It is not possible from the report to understand what costs have been used for, for example, incineration, or gasification, etc.

The study's approach is set out as follows:

> *A life cycle approach has been used to assess the greenhouse gas emissions associated with waste management operations in the UK.*

Though it is not explicitly stated in the study, biogenic emissions of CO_2 seem to have been ignored in the study, and there appears to be no allowance for any sequestration effects (though this is not clear either).

The study produces some data concerning emissions of GHGs in CO_2 equivalents from some energy generation processes. It gives these for the average and CCGT (marginal (offset)) sources. The CCGT figure is rather higher than that derived in this study and is much higher than the DTI figure reported above. It is unlikely, on the basis of a review of other literature, that the losses from extraction and gas distribution account for 100g CO_2 equ /kWh of energy generated, which is (approximately) the difference between the figure calculated in this study and that in the ERM report. The USEPA and AEAT studies cited earlier both looked into the whole lifecycle and found emissions related to pre-combustion phases to be much lower than this figure.

GHG savings associated with recycling of different materials are also highlighted. The figures for compost and for paper and card are likely to be the most hotly contested, though the literature – unsurprisingly – gives a range of values here. The paper and card benefits are almost certainly low if the dynamics of the forest sector are taken into account.[91] The compost benefits are clearly affected by the assumption concerning biogenic carbon, and the way in which sequestration effects are treated (and hence, the time horizon for the emissions).[92]

Table 13: GHG Emissions Associated with Electricity Generation in the UK

Process	Release	2005	2010	2015	2020	Long term
Electricity production and distribution	Direct UK	0.54	0.50	0.53	0.53	0.53
(kg CO_2-equivalents/kWh)	Non-UK	0.047	0.039	0.035	0.026	0.026
Marginal (offset) electricity production	Direct UK	0.46	0.46	0.46	0.46	0.46
(kg CO_2-equivalents/kWh)	Non-UK	0.001	0.001	0.001	0.001	0.001

Source: ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final report for Defra, January 2006

Table 14: GHG Emissions Associated with Recycling

Material	Release	Emission Factor (kg CO_2 equivalents/ tonne)
Paper and card	Non-UK	-496
Textiles	Non-UK	-7869
Ferrous metals	Non-UK	-434
Non-ferrous metals	Non-UK	-11634
Glass	Non-UK	-762
Plastic, dense	Non-UK	-2324
Plastic, film	Non-UK	-1586
Gravel	Non-UK	-2.74
Compost	Non-UK	-16.2

Source: ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final report for Defra, January 2006

For incineration, the report assumes an efficiency of electricity generation (implied) of 28%. This is very high, and virtually unreported in any document. Set against this is an extremely low level of energy use. For each tonne of waste, the energy use is reported as

[91] For a discussion of this, see USEPA (2002) Solid Waste Management and Greenhouse Gases: A Life-cycle Assessment of Emissions and Sinks, 2nd Edition, EPA530-R-02-006, May 2002.

[92] See See D. Hogg et al (2002) *Economic Assessment of Options for Dealing with Biodegradable Waste*, Report to DG Environment, European Commission, by Eunomia, Scuola Agraria del Parco di Monza, HDRA Consultants, ZREU and LDK; D. Hogg (2003) External Costs and Benefits of Composting and Anaerobic Digestion, in L. Marmo and H. Langenkamp (eds) *Biological Treatment of Biodegradable Waste: Technical Aspects*, European Commission Joint Research Centre; D. Hogg (2004) Costs and Benefits of Bioprocesses in Waste Management, in P. Lens, B. Hamelers, H. Hoitink and W. Bidlingmaier (eds.) (2004) *Resource Recovery and Reuse in Organic Solid Waste Management*, pp.95-121.

0.118kg of diesel and 3.91kWh of electricity. These are very generous assumptions regarding energy efficiency and energy use.

Interestingly, higher efficiencies are reported for gasification. However, much higher energy use is also reported (2.41kg diesel and 97.5kWh). Certainly, for electricity use, these are the sorts of figure one might expect to see for incineration. It might be recalled from the main report that the BREF note on incineration suggested a target:

> *to reduce average installation electrical demand (excluding pretreatment or residue treatment) to be generally below more 0.15 MWh per tonne of MSW processed and based on an average NCV of 2.9 MWh per tonne of MSW*

In other words, below 150kWh per tonne would be considered acceptable. 3.91 kWh per tonne would be wonderful, but it probably does not happen.

Equally problematic figures are those used for anaerobic digestion, and these probably explain the rather small difference between scenarios where biowaste is composted and those where it is digested. If – as the technical annex notes – the digestion process generates only 241 kg of compost, then one would expect a very high rate of destruction of volatile solids and a correspondingly high generation of biogas. This would be expected to generate *more than* ten times the quantity of energy suggested for anaerobic digestion (quoted in the study at 26.7kWh per tonne of waste). Net generation is less than 10kWh per tonne, a figure already highlighted in the report as being ridiculously low.

Another interesting aspect of the report is its characterization of stabilization processes as being '75% stabilised'. This is perhaps an artifice of the UK's approach to assessing the performance of MBT systems. However, most foreign readers would find it strange to see stabilization processes being credited with energy generation from the landfilled waste. The justification for this given in the report is that the

> *'recent report by Juniper (Mechanical-Biological-Treatment: A Guide for Decision Makers. Processes, Policies and Markets. Juniper Consultancy Services, March 2005) reports an estimated performance range of 24 % to approx 90% BMW diversion for MBT plant configured to stabilise waste for landfill. An upper estimate within this range was taken.'*[93]

It is debatable that this is the right context in which to consider a '24-90% range'. To the extent that the report was seeking to understand the potential for different technologies to contribute to delivery of the UK's waste strategy, then it is perhaps slightly unreasonable to compare a sub-optimal example of one technology with another technology (incineration) whose specification far exceeds what is usually reported in the literature.

This – allied to the fact that the report ignores the inter-related issues of biogenic sources of CO_2, the effects of time, and the time-limited sequestration associated with biological treatments – implies that the study strongly favours thermal processes for the treatment of (residual) waste.

[93] ERM (2006) *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions*, Final report for Defra, January 2006

Would be users of the successor to WISARD, WRATE, may wish to be aware of some of the shortcomings in the datasets highlighted above, and some of the assumptions being made. The report notes for each treatment that:[94]

> *Data for the inputs and outputs associated with the treatment of waste via [* [for example, anaerobic digestion] *were generated using data the Environment Agency have collected (2003-2005) for waste management processes in support of the development of WRATE.*

Unless considerable revision of the data has occurred subsequent to the report being written (which might be considered unlikely given its recent vintage), then decisions made on the basis of WRATE are likely to be no more robust to challenge than those based upon its predecessor.

A.4.2 CIWM

In a previous report on Energy from Waste, the CIWM assumed that CO_2 emissions from incinerators were 0.881 kg per kg waste.[95] This is at the lower end of what could generally be expected. It assumed that 85% of this – a rather low proportion - was 'bioderived' and therefore, assumed that this could be ignored (see Annex 2 for a discussion as to why this assumption is not necessarily appropriate). It also assumed that 500kWh per tonne of waste would be generated. On this basis, it argued that energy from waste was responsible for 264g CO_2 per kWh generated. It further assumed that coal-fired generation was responsible for 950g/kWh, gas fired generation was responsible for 525 g/kWh electricity and CCGT would emit 400g/kWh electricity. These assumptions enabled the report to suggest a 'CO_2 saving achieved by EfW electrical power generation' depending upon the source.

It went further by assuming that :

> *As residual MSW consigned to EfW does not end up in landfill disposal, there is an avoided methane credit equivalent to 1.2 tonnes CO_2 avoided from landfilling per tonne of input waste. This gives an additional avoided greenhouse gas credit / kWhe* [kWh electricity].

According to this study, therefore, energy from waste does not simply displace other sources of energy, but it also displaces emissions which might otherwise have occurred if the same material had been landfilled. None of the figures quoted – for energy generation, or landfilling – were substantiated through reference to other sources.

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[94] ERM (2006) *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions*, Final report for Defra, January 2006

[95] CIWM (2003) *Energy from Waste: A Good Practice Guide*, Northampton: IWM Business Services Group, November 2003.

A.4.3 CIWM Position Statement

In its position statement on energy from waste, CIWM made a number of points.[96] For example, it stated:

> *Energy recovery from residual waste will have less climate change impact than landfill. Even if we meet Landfill Directive targets, 50% of biodegradable municipal waste could still go to landfill in 2013 and 35% in 2020. The carbon in landfilled residual waste is turned into equal amounts of methane and carbon dioxide over a protracted period. Only a proportion of this gas can be collected and used as a fuel, and the fugitive methane has 23 times more greenhouse effect than carbon dioxide.*

The term 'energy recovery' is used, which under current European law, would mean mechanisms for generating energy from waste other than dedicated facilities. Like UK Government, CIWM still perceives incineration as 'recovery', even though one of the recommendations flowing from the Position Statement is the confusingly worded:

> *prioritise the re-definition of energy recovery from waste as a "recovery" rather than "disposal" operation under the Waste Framework Directive, (based on energy efficiency criteria) to remove unnecessary barriers to transfrontier shipment of waste derived fuels while they are still classed as "waste"*

Energy recovery *is* defined as energy recovery. What is excluded from the definition is conventional incineration, which is currently defined as disposal.

Existing definitions *do* allow transfrontier shipments of fuels derived from waste where they are used in facilities whose principle purpose is not the disposal of waste (i.e. where the waste is being recovered). Hence, the recommendation itself is confused. No change in definition would be required to allow RDFs to be moved across borders where they are used in industrial facilities. Since UK incinerators do not usually combust waste imported from elsewhere, the change to the definition of recovery would seem to have none of the relevance being accorded to it (unless some form of sea transport of waste to foreign incinerators is being envisaged).

CIWM goes on to say:

> *Energy recovery from waste, compared to landfill, offers more carbon dioxide saving by displacing fossil fuels that would otherwise be burnt to generate that energy.*
>
> *Good quality CHP techniques will also reduce overall climate change impacts by generating more energy per tonne of fuel burnt.*

The statements seems reasonable, set in the context (as CIWM took care to do) of ensuring recycling would not be crowded out. What CIWM does not say, however, is the biological treatments, where residues are landfilled, may perform better than energy from waste. It is not possible to tell, from the analysis, how the view has been arrived at. However, the unusual release of such a Position Statement, and the incorrect

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[96] CIWM (2006) *CIWM Position Statement Energy Recovery From Waste*, February 2006, http://www.ciwm.co.uk/mediastore/FILES/12321.pdf

interpretation of the existing legislation within it, once again highlights the need for more by way of clear and transparent analysis.

A.4.4 Oakdene Hollins

Oakdene Hollins carried out a study for the Institute of Civil Engineers and the Renewable Power Association in 2005 entitled Quantification of the Potential Energy from Residuals (EfR) in the UK.[97] The study makes a range of assumptions to seek to derive the quantity of electricity which could be expected to be generated from treating residual waste under various strategy outcomes (based upon the work of the Strategy Unit, *Waste Not, Want Not*).

In seeking to estimate the calorific value of waste, the study uses figures for '*gross* thermal value' from a study by C-tech. It then applies conversion efficiencies for incinerators to these gross thermal values.

The study claims to have examined 'historic values' of yield and reports these to be of the order 25.4% electrical efficiency. It also gives a value reported in work by Enviros et al of 581kWh/tonne waste. It goes on to state:

> *In review we have found the CTech figure of 25.4% to be a fair representation of the current efficiency of a high performing mass burn incinerator. We believe it is justified to use this figure in subsequent analysis on the expectation that, with advances in technology, this performance will come to represent a mid-range, or typical, plant efficiency.*

It is not clear what the 'review' is that was carried out to arrive at this view. C-tech's 25.4% figure is based upon a quite theoretical discussion in their report. It is a high figure. It is made all the more so by the fact that Oakdene Hollins apply it to the *gross* calorific value whereas C-tech clearly intended it to be applied to the *net* calorific value of waste.

Consequently, the net generation figure from the report - 714kWh/t – is well above most quoted figures. Figures for other technologies are scaled on the basis of this figure, so all figures for electricity generation in the report appear to be on the very high side.

[97] Oakdene Hollins (2005) *Quantification of the Potential Energy from Residuals (EfR) in the UK*, Report for the Institute of Civil Engineers and the Renewable Power Association, March 2005, http://www.ice.org.uk/downloads//energy_from_waste.pdf.