WASTE MANAGEMENT TECHNOLOGY OPTIONS AND THE RENEWABLE OBLIGATION ORDER: FRIENDS OR FOES?

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ABSTRACT

Legislative reform of the Renewable Energy Obligation has resulted in a new statutory instrument, the Renewables Obligation Order (ROO),in which electricity generating technologies are “banded” to encourage emerging processes into the market. Many of the the technologies identified in the ROO feature in integrated waste management systems throughout the EU and other developed nations. Therefore, the waste management sector offers opportunities to reduce the size of its own carbon footprint whilst simultaneously mitigating the environmental burden from generating electricity in the UK. However, renewable electricity can only be attributed to energy generated from the biogenic carbon compounds that comprise the fuel used. Different waste management technologies produce energy in a variety of ways using a diverse range of fuels that vary in biogenic carbon content. Furthermore, each type of technology will generate different levels of revenue depending upon the outputs utilised from the process (e.g. heat, electricity, stabilite, oils, char, etc.). With the electricity revenue linked to biogenic carbon content, the choice of technology to invest in is not an obvious one. This paper discusses the ROO with specific relevance to waste management technologies to identify potential opportunities and difficulties arising from generating electricity in the waste management sector. As with achieving Landfill Directive compliance, a counterintuitive ramification of technology “banding” may indeed jeopardise renewable energy targets, despite being introduced to support this aim.

KEYWORDS

Renewable energy; energy from waste; thermal treatment; greenhouse gas emissions; residual waste

INTRODUCTION

Recent research findings indicate that the sustainable development of urban regions is more influenced by behaviour and form-dependent technologies, rather than urban form itself (Solutions, 2009). As part of the EPSRC ReVISIONS project, technology options specific to the waste management sector are being appraised to identify if any cross-sector, form-dependent synergies and conflicts exist. An example of this is the contribution that waste management technologies could make to the electricity generation sector, in particular from generating renewable energy.

In 2005, 1.3% of UK energy was from renewable sources, but this figure must be increased to at least 15% by 2020 to ensure that mandatory EC renewable energy targets are met (RED, 2009). Historically, waste management has made a healthy contribution to the UK’s renewable energy portfolio. In 2007, 30% of renewable energy was generated from landfill gas and a further 10% from waste combustion (HMSO, 2008); the potential of landfill gas is likely to be jeopardised as compliance with the Landfill Directive is achieved.

Recent amendments to the renewable energy obligation have resulted in a variety of incentives for different waste management technologies that are capable of generating renewable energy. Risky, unproven technologies receive more incentives than those with a proven track record. But are the most sustainable technologies being encouraged?

To answer this, the impact of energy legislation on two different technology scenarios is explored. The first considers mass burn incineration with and without combined heat and power and the second considers pyrolysis with fuel prepared by refuse derived fuel, bio-mechanical, and autoclave processes. In each case it is assumed that the 2020 waste targets outlined in the Waste Strategy 2007 are realised. As the energy legislation is restricted to UK based greenhouse gas emissions and offsets, the analysis is focused on the net emissions arising from treating residual household waste.

The analysis suggests that thermal options for residual waste are not going to be major contributors to reducing fossil-carbon emissions in the UK but their use has the potential to conserve valuable abiotic resources. Without considering the requisite pre-treatment systems, the environmental performance of thermal treatment plant cannot be realistically compared. As a result, the subsidies available could encourage investment in inappropriate technology packages and / or use of the outputs.

PROMOTING RENEWABLE ENERGY GENERATION ACROSS EUROPE

The EC Renewable Energy Directive (RED) was introduced as a mechanism to mitigate emissions of greenhouse gases by reducing the amount of energy generated from fossil fuels. By 2020, 20% of energy and 10% of transport fuels consumed with the EC must be of renewable origin. National mandatory targets have been issued to each member state to ensure that the EC achieves these targets but also provides certainty for investors whilst encouraging the continuous development of technology. Each member state is required to report its progress on promotion and use of renewable energy by end of 2011 and every two years thereafter until 2021. Reports must identify how much renewable energy is used in electricity, heat/cooling, and transport sectors and include details of support schemes and other measures used to promote renewable energy.

A member state's share of renewable energy comprises the renewable energy consumed from generating electricity, heat, and cooling and by transport. To prove the share or quantity of renewable energy in a suppliers energy mix, guarantees of origin are issued per MWh and must be issued in response to request from electricity customers and may be issued for heat/cooling.

Transition to UK Policy

The Renewable Energy Obligation (REO) was introduced in the UK in 2002 to comply with the RED. It replaced the Non-Fossil Fuel Obligation and aimed to reduce the environmental impact of electricity generation by increasing the proportion of electricity derived from non-fossil fuels. Consequently, the amount of fossil fuels consumed per unit of electricity generated is reduced, thus complementing the objectives of the Kyoto protocol. In 2005, 1.3% of the energy consumed in the UK was from renewable sources but this must be increased by 2020 to at least 15% (RED, 2009). The UK renewables strategy seeks to extend and expand the renewables obligation to ensure that over 30% of electricity is produced from renewable sources by 2020.

The Renewables Obligation Order (ROO) replaced the REO in 2009. The revised legislation introduced technology "bands" that will be receive different varying awards of ROCs per MWh of electricity generated. The award is based on the track record of the technology so, for example, investment in emerging waste treatment technologies such as gasification, pyrolysis, and anaerobic digestion is being encouraged by awarding double ROCs whilst the support for established technologies like landfill gas utilisation is being reduced (see Table 1).

Table 1: Waste Management Technology eligible for ROCs

Banding	Technologies	ROCs per MWh
Established	Landfill Gas	0.25
Reference	Energy from Waste with CHP	1.0
Post-Demonstration	None (e.g. off-shore wind)	1.5
Emerging	Gasification, Pyrolysis, Anaerobic Digestion	2.0

However, prior to the REO the UK government had introduced the climate change levy (CCL), which increased the cost of energy as a means to encourage non-domestic energy users to reduce greenhouse gas emissions (Carbon Trust, 2009). One way in which firms can reduce these costs is to consume renewable energy, which is exempt from the levy. Renewable sources include landfill gas and municipal and industrial waste providing that the strict definition of renewable fuel in the ROO is met (HMSO, 2000).

Green Energy Certificates

Renewable Obligation Certificates (ROCs) are issued for each MWh of renewable electricity generated and, therefore, are only awarded on the proportion of electricity generated from sources of biogenic carbon (e.g. paper, card, etc.). As biogenic carbon compounds tend to be more oxygenated than fossil carbon compounds, they tend to release less energy per unit mass and hence have a lower calorific value (CV). Thus the ROC-able content of a waste stream is not necessarily the same as the biogenic carbon content.

Levy Exemption Certificates (LECs) are also issued for each MWh of renewable electricity generated but are used to demonstrate the level of renewable electricity that qualifies for reducing the CCL. Utility companies are required to source LECs so that business customers can become exempt from paying the CCL.

Renewable energy guarantee of origin certificates (REGOs) are issued per MWh of electricity generated and are used to prove compliance with fuel mix disclosure regulations. Unlike ROCs and LECs, REGOs have no monetary value and consequently there is no way to formally trade them (DTI, 2005).

ROCs and LECs can be traded independently or as a package including the electricity price, which is determined by the market (Biffa, 2006).The ROC price was fixed until April 2007 at £33.24 per mega-watt hour but inflated annually in line with the retail price index. A premium for the ROCs can be obtained within the trading market if there is a shortfall in electricity generated relative to the REO targets. The LEC price is a negotiated proportion of the climate change levy that the electricity suppliers would have paid if the electricity had come from a non-renewable source.

The Investment Dilemma

As noted, waste management technologies and landfill gas in particular, have made significant contribution to the renewable energy portfolio in the UK. As Landfill Directive compliance is achieved, the future contribution of landfill gas is likely to diminish. But with compliance comes the need to treat the waste that has been diverted from landfill and this means investing in suitable technology.

Waste management technologies qualify for the financial benefits of green energy certificates providing that not more than 90% of the energy content in the waste can be derived from fossil fuels – for MSW, this value is deemed as 50% (HMSO, 2009a). Providing these criteria are met any energy generated is classed as renewable so contributes towards CCL exemption and national RED targets, but further conditions are necessary for the technologies to receive the more lucrative ROCs. For example, MBI without CHP can claim that 50% of electricity generated is renewable, which will contribute to RED targets and electricity suppliers will be able to use electricity to reduce CCL paid by their customers. However, if MBI with CHP is used, the electricity generated also qualifies for ROCs.

Because of the double ROCs available for emerging technologies, the choice may be to maximise the biogenic content in the feedstock so as to increase the renewable energy generated and the revenue received. But the waste management sector needs to determine what to recycle and what to recover energy from to achieve the targets set out in the Waste Strategy 2007. This decision is further compounded by how benefits from recovering and recycling are realised. Most of the materials recycled in the UK offset greenhouse gas emissions in other countries (Fisher, 2006) and hence won't contribute to UK greenhouse gas reduction targets, but energy generation will.

Therefore, incentivising energy recovery may lead to a conflict of interest in recycling combustible materials such as paper products and textiles. Reduction in fossil CO_2 will feature on UK Plc's carbon balance sheet if these biogenic materials are combusted, whereas from recycling, larger offsets are achieved but realised off shore.

APPROACH TO ANALYSIS

The analysis in this paper is focused on the energy use and production associated with managing residual waste assuming that 2020 waste diversion targets are achieved. No attempt is made to assess the fate or greenhouse gas impact of dry recyclables or organic waste, it is assumed the same for all residual waste treatment options. The basic greenhouse gas parameters selected for the scenarios and used in this analysis are presented in Appendix A. Hence the boundary for our analysis encompasses the residual waste treatment solution only.

An established and an emerging technology have been compared: mass burn incineration with and without combined heat and power (CHP) and pyrolysis. As fuel for pyrolysis plant can be provided by a number of pre-treatment options, the pyrolysis scenario considers fuel preparation by conventional refuse derived fuel (RDF), bio-mechanical treatment (BMT), and autoclave technologies. Pyrolysis rather than gasification has been selected as the syngas quality (typically > $15MJ/m^3$) easily meets the threshold value of $4MJ/m^3$ for qualifying for double ROCs (many gasification plants operate on untreated residual waste and burn the gas for steam-turbine electricity generation, these qualify for single ROC provided the syngas is > $2MJ/m^3$).

Anaerobic digestion (AD) has deliberately been avoided. Although it qualifies for double ROC, it is also a well established technology and its future in the renewable energy debate is worthy of its own discussion. For example, reducing paper recycling would improve biogas yield but impact recycling offsets, but what is the best output for the gas? Under ROO it is eligible for double ROCs but the gas is also likely to be injected into the national grid system (HMSO, 2009b).

Technology Scenarios

Two thermal treatment options are considered with and without CHP[1] in this paper, the traditional boiler-steam-turbine combination mass-burn incineration (MBI) process and the fledging pyrolysis process. A flash pyrolysis unit that recycles condensable hydrocarbons back to the reactor to maximise syngas production (e.g. Scarborough Power; one of the DEFRA demonstrator projects (DEFRA, 2008)) is assumed and the syngas produced is used to power a spark ignition engine-turbine system. Three pre-treatment methods are considered to provide the fuel input for the pyrolysis process:

- Traditional mechanical Refuse Derived Fuel (RDF) plant to maximise Calorific values and minimise ash and moisture content.
- Autoclaved Solid Recovered Fuel (AC-SRF) to maximise the biogenic content of the fuel (high calorific value fossil categories largely rejected).
- Bio-drying/Biological Mechanical Treatment (BMT) where heat from partial composting of the waste is used to dry the waste before mechanical recovery of a BMT-SRF, targeted at recovering a high biogenic content rather than maximising recovery.

Data and Assumptions

Residual waste composition is based on typical UK household waste (Parfitt, 2002) assuming 50% diversion of source separated dry materials for recycling and putrescible waste for composting or anaerobic digestion. This is the UK's national recycling target for 2020, and the capture rates assumed for each fraction are consistent with values reported by Barton et al. (2001) and Friends of the Earth (2007). As both dry

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[1] In the context of this paper this serves as a proxy for whether or not a market exists for the heat produced.

recyclables and putrescibles need to be targeted for separate collection to achieve this level of recycling, it has been assumed the as-received moisture content of categories found in the “total collected dustbin waste” reported by the National Household Waste Analysis Program (NHWAP) are still valid (this would not be a reasonable assumption if only dry recyclable or wet organic collections occur)

NHWAP chemical data set (EA, 1994) (i.e. CV, moisture, ash, carbon content etc.) measured for categories and sub-categories of household waste is used. Sub-categories are combined to give a simplified category list that is consistent with DEFRA guidelines (DEFRA, 2006) and then the chemical analysis data is apportioned accordingly. For example; kitchen and garden waste comprise the category of putrescibles. An estimate of biogenic carbon content was made on the basis of reported LATS definitions but amended to reflect actual category descriptions, measured ash and moisture contents and ratios of carbon to hydrogen[2]. Energy contribution of fossil and biogenic content is based on measured calorific values and results in the ratio of fossil to biogenic carbon being less than the ratio of fossil energy to biogenic energy. The as-received composition of residual waste based on these assumptions is reported in Table 2.

Table 2: Assumed composition of residual waste (as received)

Category	Assay wt %	Moisture wt%	Ash wt%	GCV MJ/Kg	Bio-C wt%	Fossil C wt%	Hydrogen wt%
Paper	21.4	25.1	8.7	13.1	31.6	0.5	4.7
Putrescibles	21.4	61.3	10.0	6.1	15.7	0.0	2.2
Misc. Combustibles	14.3	34.1	8.4	12.8	25.0	6.3	4.7
Plastics	14.3	21.3	7.6	24.7	0.0	50.4	6.8
Inert	14.3	5.0	94.1	0.2	0.3	0.1	0.0
Fines	14.3	41.0	36.8	4.8	12.3	1.4	1.6
Total	100.0	33.0	25.0	10.2	15.5	8.4	3.4

Plant capacity to handle the residual waste flow is assumed to be 56,000 tpa, equivalent to 7tph operating for 8000 hours per year and represents 50% of a total collected domestic waste arising of 112,000 tpa – an amount typical of many small to medium sized LA’s in the UK (as a comparison Burnley, a relatively small Borough, generated approximately 30,000 tpa from a population of around 90,000 in 2001/02 (Martin et al., 2006)). This flow is considered sufficient to apply all technology packages at a reasonably commercial scale (e.g. two plants of similar size are currently in operation in Britain; Newlincs’ MBI facility in Grimsby and SITA’s MBI plant on Isle of Man).

Process models

Mass Burn Incineration (MBI)

Without CHP, i.e. electricity only mode, steam turbine efficiency is assumed to be 30% and reflects the not uncommon situation where heat cannot be sensibly recuperated from the system as typically, most plants have no local user or distribution infrastructure in place to provide a market. With CHP, it is assumed that the steam turbine efficiencies will be reduced to 20% for electricity in order to provide high quality steam flow suited for both process and district heating (DH) use. Unlike some of our continental neighbours such as Denmark and Sweden where DH systems in cities and towns are commonplace, achieving a secure and steady demand for heat in the UK for MBI plant has not been easy. Sheffield and Nottingham are successful examples but SELCHP in London, built in 1994 is still to implement its original plan to supply heat. Furthermore, industrial process heat demand can also be problematic (e.g. Coventry MBI plant supplied Peugeot /Talbot car plant until it closed and now produces electricity alone). Therefore a relatively low heat utilisation of 70% is assumed for MBI with CHP even though higher values would be achieved if the plant provides the base load to large district heating system or large process heat user.

RDF/SRF production

Assumptions regarding energy use and category recovery to the fuel fraction (Appendix A) are based on typical plant operations for RDF (Barton et al., 1985). For autoclave and bio-mechanical treatment (BMT) plant, reported energy use, fuel yields and compositions are consistent with assumptions made by previous authors (GLA, 2008). Steam at 3-6 bar pressure is needed for the autoclave. Although it could be provided by syngas from the pyrolysis stage, possibly supplemented by waste heat, this would require reducing exported electricity and heat output from the pyrolysis stage. Hence, for simplicity, it has been assumed to be provided separately using natural gas. This would be essential if the autoclave wasn’t co-located with the pyrolysis plant and even if it was, probably a more reliable and robust solution given the developmental nature of the both the autoclave and pyrolysis stages. For the autoclave, it is assumed that no heat can be reasonably recuperated from the steam energy utilised by this process. This is because heat losses are significant as residence times of the process are typically 1 hour and part of the steam generated is absorbed into the waste; in addition, the waste steam release from the autoclave is not steady but occurs in short bursts during

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[2] This is necessary as the DEFRA definition is crude (e.g. 50% of fines category assumed biogenic) and relates to the as-received weight of a category, irrespective of moisture, ash or carbon content.

depressurisation. Due to high odour / VOC content, this polluted steam requires rapid condensation prior to gas cleaning (e.g. bio-filtration); thus on process continuity grounds and environmental imperatives, heat recovery would be expensive and inefficient.

Pyrolysis

All systems require a fuel preparation plant and the fuel must undergo moisture reduction to at least 15% or below prior to pyrolysis. This ensures satisfactory calorific values are reached from both ROC and gas engine performance perspectives (e.g. avoiding excessive de-rating and knock associated with low CV syngas). To achieve this, it is assumed that the waste heat from the pyrolysis unit and gas engines is used to dry the feedstock with an efficiency of 50%. However, there is a lack of validated data for these plant in CHP mode, but an optimistic assumption is to retain gas engine efficiency at 35% and that any residual waste heat that is not used to dry fuel can be recuperated via a heat exchange system to provide low grade heat. It has been assumed that only 50% utilisation is achieved as the continuity of demand or efficiency of use for low grade hot air or hot water would normally be less than high grade steam. If high grade steam were to be an option, de-rating of the electricity generation would be needed because commercial CHP gas engines producing high grade heat require a heat recovery steam generator unit and electricity efficiencies are reported to drop from up to 42% to below 34%. (DTI, 2006) With or without CHP, the electricity consumed by the plant is assumed to be part of the parasitic load and hence reduces the exported power.

Materials Recovery

Residues and additional product recovery following pre-treatment or thermal processing can also occur and normally would be included in an assessment of options. BMT, Autoclave and RDF plant can be operated to recover additional metals and materials. MBI plant recovers metals and the bottom ash can be used as a low grade construction material (Bruder-Hubscher et al., 2001) and it is also feasible that the organic rich residues from traditional RDF plants could be used to generate methane in an anaerobic digestion (AD) plant. These additional resource recovery operations could contribute to reduced greenhouse gas emissions but it was decided to ignore these processes for a number of reasons:

1. The overall metal recycling efficiencies are similar for all plants and hence inclusion would not make a significant change to the relative differences between options.
2. ash recycling for MBI plant to low grade aggregate is beneficial but does not contribute major reductions in emissions (Grant Thornton, 2006) and aggregate like materials can also be recovered in fuel pre-treatment plant and from pyrolysis residues, again minimising significance in relative terms.
3. Plastics recycling from BMT and autoclaved MSW have the potential to provide a reduction in greenhouse gas emissions but in practice, no market has been successfully established for such materials. Furthermore quality issues can also significantly reduce potential GHG savings (WRAP, 2006).
4. AD for RDF fines may be worth considering in more detail but markets for the digestate are very uncertain and landfill restoration would appear the only likely outlet.
5. Any residues landfilled from fuel pre-treatment systems will tend to contain biodegradable material with potential to generate landfill gas and hence contribute to greenhouse gas emissions.
6. Finally in terms of UK inventory, material recycling emissions offsets identified by a full LCA approach are generally not realised within the UK system boundary (Fisher, 2006) within which this analysis is focussed, whereas the process emissions and the displaced emissions for electricity and heat recovered are.

The assumptions made for the various pre-treatment and pyrolysis options considered in this analysis are more speculative than those for the established MBI options, which are considered conservative but realistic. Moreover, they are also likely to be optimistic in terms of expecting first generation plant to achieve the efficiencies and reliabilities presumed in the process evaluation.

RESULTS AND DISCUSSION

The first part of the analysis considers the emissions and electricity generated from each scenario. The resultant energy generated and CO2 emissions per kWh exported are shown in Figure 1. The difference between the MBI options is from the loss of electricity output when operating in CHP mode, which results in a significant drop in overall electricity export and consequent increase in specific emission factors. For the MBI_e, the emission factor for total CO2 is approximately 1600 gCO2/kWh and approximately 1/3 of the CO2 emission is from fossil carbon. RDF production with pyrolysis generates the highest electricity yield per tonne of "fuel" entering the thermal process, as might be expected for a system designed to significantly upgrade the calorific value. Comparison of MBI_e performance with the pyrolysis options illustrates lower total export of electricity from these systems but the RDF and BMT-pyrolysis systems show a reduction in total and fossil carbon emissions per kWh. For the autoclave and pyrolysis system, the emission performance of both total and fossil carbon emissions is poor compared to MBI_e because of the pre-treatment demand for electricity and gas fuel.

The rationale for including the effect of pre-treatment on system performance can be illustrated by considering only the emissions from the thermal plant, i.e. RDF, BMT and AC-SRF delivered with 15% moisture content, ready for use. In this case, the energy consumption and emissions profiles of the pre-treatment processes are ignored, shown in Figure 2. Although each process has similar electrical power demands, neither the RDF nor BMT processes require additional steam, which is assumed to be raised by a conventional gas boiler. With the “system boundary” focused on the thermal plant, a different set of conclusions can be reached.

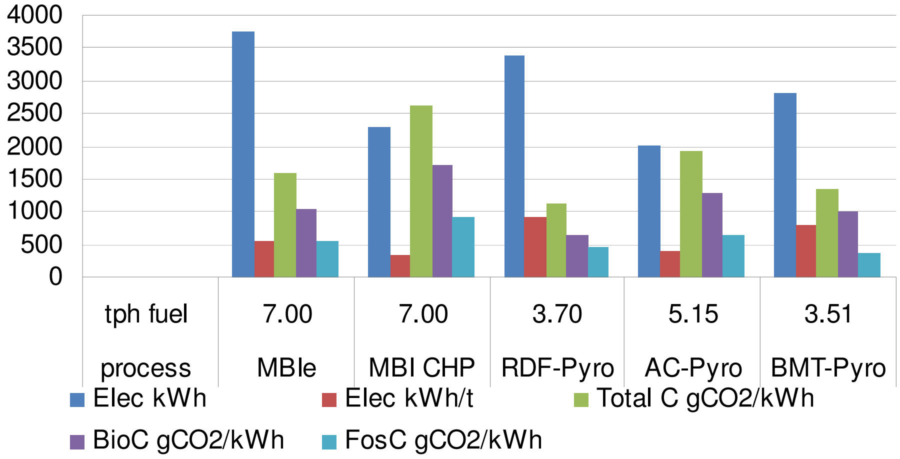

Figure 1: Energy and Emissions Output from Process Options exporting only Electricity

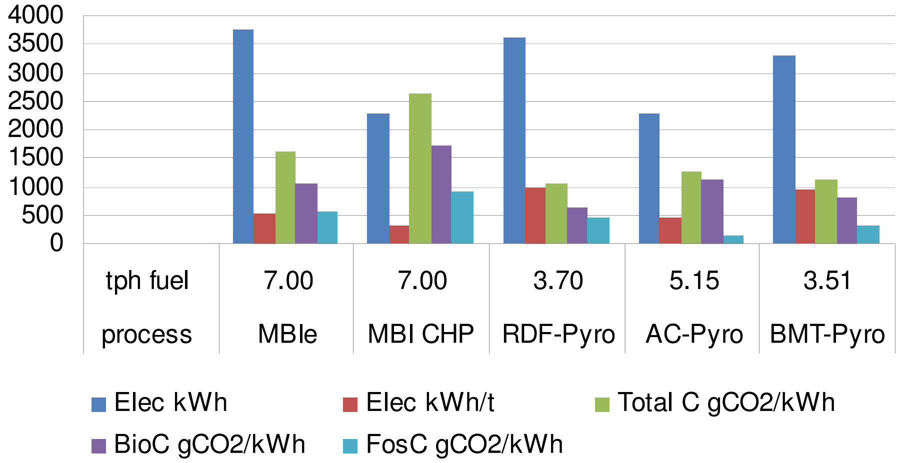

Figure 2: Energy and Emissions Output from Thermal Plant

Figure 2 illustrates that whilst the MBI$_e$, with no pre-treatment energy demands to be offset, does export the most power from the residual MSW originally available, it has worse specific emission factors than all the other options apart from the MBI with CHP option. The autoclave option, targeting the biodegradable fractions in MSW for the fuel, now has at similar overall CO$_2$ emissions profile per tonne to the RDF and BMT options, yet for fossil CO$_2$ it yields the lowest carbon footprint per kWh electricity exported. The impact of the system boundary change has a major effect on performance and illustrates why thermal options cannot be equitably compared as stand-alone processes when differing pre-treatment systems are employed – quite possibly off-site. Hence all subsequent comparisons are based on the overall package including pre-treatment.

Figure 3 illustrates the overall energy recovered and the specific energy per tonne of waste entering the thermal process. Figure 4 provides the emissions data based on total energy exported. MBI with CHP performs significantly better than MBI$_e$ and autoclave with pyrolysis options. Operating RDF or BMT with pyrolysis options in CHP mode are similar in performance to MBI with CHP. The BMT option reports the lowest fossil CO$_2$ emissions because the process is designed to concentrate the biogenic content in the fuel. This result is not surprising when the pre-treatment demands and fuel requirements are considered; pyrolysis processes require the fuel to be dried to around 15% moisture content. For RDF, the drying demand is significant but the waste heat from pyrolysis and the gas engines still permits significant export. For BMT, the bulk of the drying is achieved via composting and does not reduce the potential to export excess heat from the pyrolysis stage. However, for the autoclave, energy demand to raise the required steam pressure is considerable and steam absorption into the waste means the fuel output has a moisture content typically around 50%, which significantly increases the drying demand compared to RDF and MBT options in particular[3]. Thus, in addition to non recoverable heat from the autoclave process, the exported heat from the autoclave-pyrolysis system is also reduced compared to RDF or BMT pyrolysis options.

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[3] As produced, RDF moisture content is typically 30% and for BMT-SRF moisture content is typically 18%.

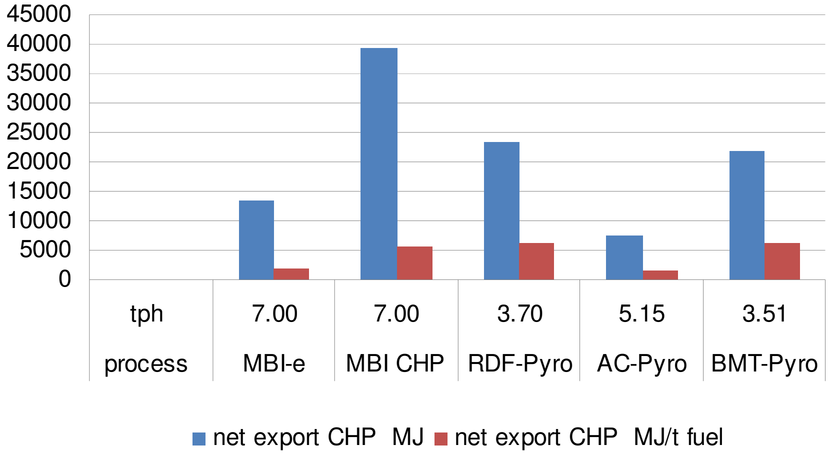

Figure 3: Net Energy Output including CHP

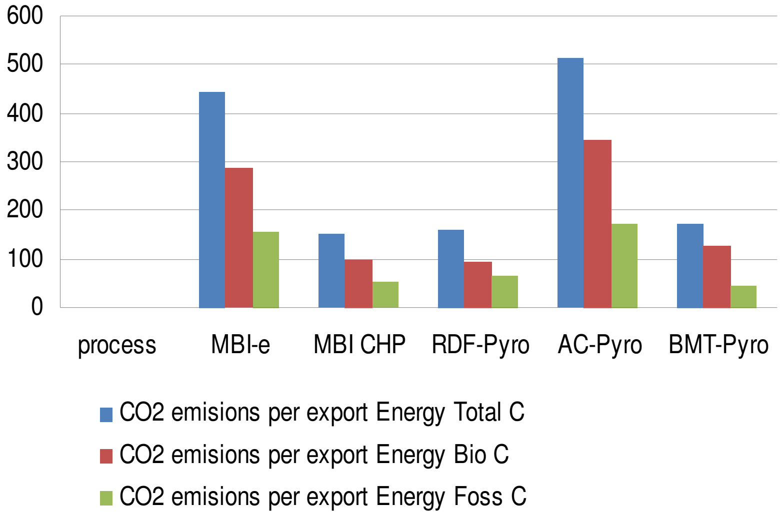

Figure 4: Carbon Dioxide Emissions per MJ Output

An Alternative Perspective: Abiotic Resource Conservation

Another way of interpreting the output data from this analysis is to consider the issue from a resource supply perspective. The EC member states have demanding mandatory renewable energy targets to meet and residual waste is one resource that can contribute whilst simultaneously diverting waste from landfill. It can be noted from Figure 1 and Figure 3 that MBI_e maximises electricity generated and MBI with CHP maximises total energy recovered.

If each process option is assumed to be required to provide this quantity of electricity and heat as a normalised energy output it is possible to compare the waste technologies with conventional means – this is analogous to supplying a town with approximately 3,750 kWh of electricity and 11,500 kWh of heat. Each of the process options would require additional energy to meet the shortfall, e.g. MBI_e, would require only heat from conventional supply but in CHP mode would only require additional electricity, but for the pyrolysis systems a mix of electricity and heat would be required. Shortfalls in electricity have been assumed to be made up from efficient CCGT power stations and shortfalls in heat from efficient natural gas fired boiler systems[4]; efficiencies have been assumed as 50% and 90% respectively. The CO_2 emissions from supplying this quantity of energy from each process option are presented in Figure 5.

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[4] In this comparison, CO_2 emissions and plant efficiencies used for conventional supply only relate to the thermal plant.

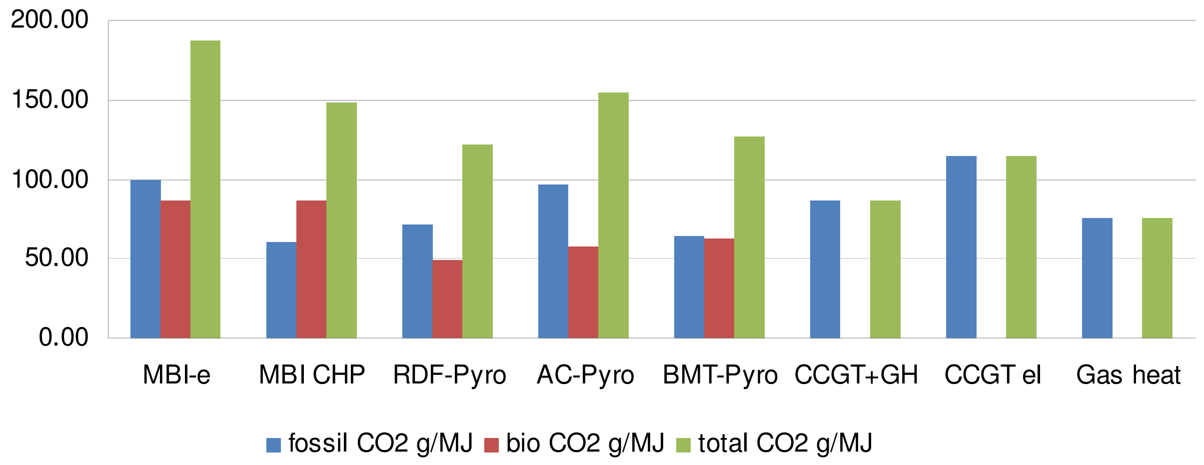

Figure 5: CO_2 Emissions per MJ for Meeting Specific Energy Demand

Figure 5 illustrates that competing with highly efficient conventional CCGT for electricity and gas boiler systems for heat is a major task for these waste treatment options. In terms of total CO_2 emissions a combination of CCGT electric and gas heating delivering the same mix of total energy as the treatment systems gives the lowest specific emission at approximately 87gCO_2/MJ; RDF or BMT with pyrolysis systems offer the lowest emissions from the waste options at approximately 123 gCO_2/MJ. However, if only fossil-carbon emissions factors are considered then MBI with CHP and BMT with pyrolysis at approximately 60gCO_2/MJ are the best options. Autoclave with pyrolysis appears to release as much fossil CO_2 as MBI_e and both contribute more fossil CO_2 than if the mix of energy had been delivered by conventional CCGT and gas boilers. Some interim conclusions can be drawn from these results:

- The conversion efficiency of available calories is paramount to reducing total CO_2 emissions from energy consumption. Conventional methods of energy generation are highly efficient and release less total CO_2/MJ than the WTE options considered. However, MBI with CHP and BMT with pyrolysis reduce fossil-carbon emissions by approximately 25%, whereas autoclave with pyrolysis and MBI_e release more fossil-carbon emissions than the conventional methods.
- If producing a high biogenic content fuel requires high input energy or results in excessive moisture content then total CO_2 emission factors and even fossil CO_2 emissions may well exceed that generated by conventional methods.
- Thermal options for residual waste are not going to be major contributors to reducing UK emissions of fossil-carbon if the energy produced is offsetting CCGT or gas boilers. However, use of thermal options will reduce demand of fossil fuels.

A Very Real Prospect

Probably the most realistic situation for the majority of WTE plants that will be delivered over the next decade will be to provide electricity to the grid, given the lack of district heating infrastructure in the UK. Furthermore, although some studies (e.g. GLA (2008)) consider all CO_2 for waste processing to be anthropogenic, energy policy and GHG reduction targets ignore the biogenic CO_2 emissions. Therefore, if the treatment options are considered as a source of electricity and the focus is shifted to the fossil emission profile alone then “UK” decision makers will look at the electricity generated compared to conventional sources, i.e. coal or CCGT power stations. The emissions profile from this comparison is presented in Figure 6.

From this perspective (taking MBI as the bench mark for maximum electricity generation and CCGT providing the shortfall for other systems), BMT with pyrolysis has a lower specific emissions factor than the other options, which have similar emission profiles. The comparison with coal fired plant illustrates the magnitude of the reduction in fossil carbon emissions if these waste options were used to replace coal power stations in the future. The difference between MBI_e and BMT with pyrolysis diminishes and MBIe outperforms the autoclave with pyrolysis option by some margin. These data also show that utilising waste by all systems is preferable to conventional coal fired power generation.

Based on total CO_2 emissions (fossil and biogenic) the greenhouse gas benefits are questionable, but from a political perspective, the use of WTE technologies for power generation can be justified in other ways. In terms of energy policy, these options facilitate the security of energy supply whilst simultaneously achieving compliance with renewable energy targets. Furthermore on an environmental basis, these options will reduce the future need for and reliance upon landfill as a disposal route (avoiding methane emissions) and perhaps more importantly, they will preserve abiotic resources, in particular coal.

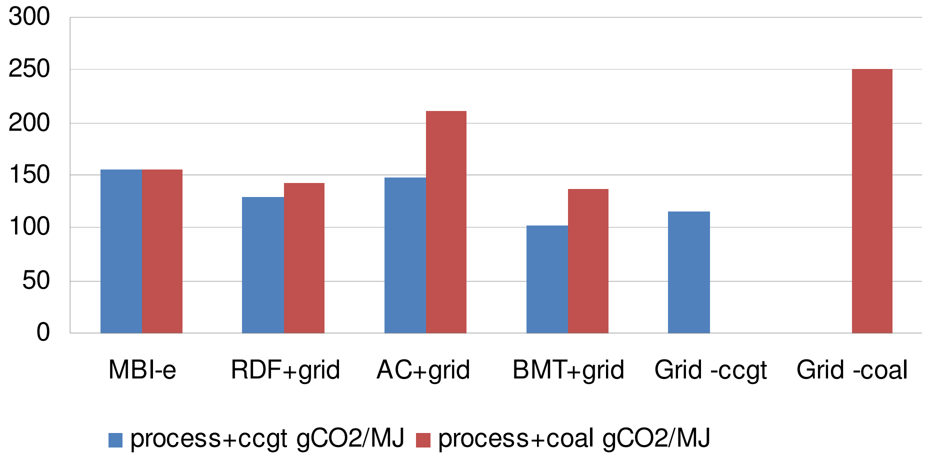

Figure 6: Fossil CO_2 Emissions from Meeting Specific Electricity Demand

Subsidy vs. Sustainability: A Conflict of Interest

Figure 7 shows the renewable and fossil electricity output based on the proportion of biogenic energy content of the input fuels to the thermal processes (using the gross calorific values; proportions would be slightly less on a net basis) The maximum total and maximum renewable electricity is generated from the MBI_e option, whereas the autoclave option, using a process dedicated to concentrating the biogenic content in a fuel, generates less renewable energy. Overall, the autoclave option generates less energy than the other processes. Furthermore, each option generates more than 50% of electricity from biogenic sources and suggests that it would be in the interest of plant developers and investors to determine the renewable energy content in the feedstock as the default value of 50% in the ROO appears conservative and demonstrating higher contributions may have considerable impact of the economic feasibility of these technology options.

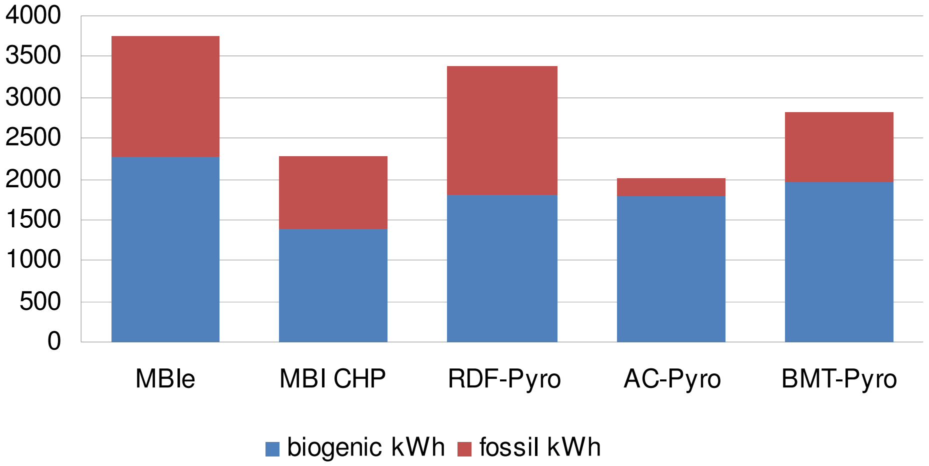

Figure 7: Renewable and Non-renewable Electricity Generated

Critically, it is these data, rather than the emissions related to the delivery of the renewable electricity that determine the revenue streams. In terms of export electricity value and traded benefits from green energy certificates, each system can expect to get similar export prices averaging approximately £45 per MWh over a year for both the fossil and biogenic generated power. Each technology option also qualifies for LECs as not less than 10% of the energy is biogenic, the price of a LEC has been assumed to be £3.50 per MWh. The renewable electricity from MBI with CHP qualifies for a single ROC value assumed to be £40 per MWh and the pyrolysis options qualify for double ROCs at £80 per MWh. The impact of these prices on revenues is reported in Figure 8.

Compared to MBI_e, the ROC rules enable higher revenues to be earned for the lower electricity generation rates achieved by the pyrolysis options but similar revenues for MBI with CHP. The Impact of the electricity revenues generated on “gate fee” for residual waste range from approximately £20/t for the MBI options to almost £35/t for the RDF pyrolysis option. This might appear a significant commercial incentive for industry to offer the advanced treatment systems but this revenue has to be viewed in the context of the avoided cost of land-filling the residual waste at approximately £65 per tonne currently (including circa. £40/t tax) and increasing to around £100 per tonne (£72/t tax) by 2013. It is the avoided costs that set the benchmark fee for treatment systems in the current high demand for solutions that meet landfill directive diversion targets and avoid the potential costs of punitive fines.

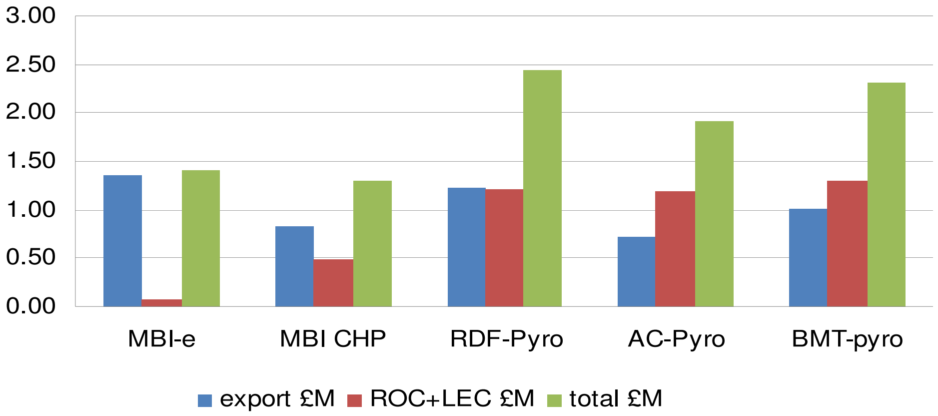

Figure 8: Annual Electricity Revenue Streams

In terms of abiotic resource conservation (fossil fuels) and greenhouse gas mitigation, the subsidies could risk encouraging technology solutions that will generate sub-optimal quantities of electricity (total and renewable) and in the process emit more carbon dioxide than a conventional fossil fuel power station would have that provided the same quantity of electricity. But the key message is to choose technologies appropriately. Autoclave preparation of residuals for combustible fuel is not an environmentally sound option. Not because the chemicals involved or released are toxic, but because the output from the process is higher in moisture content than when it entered the process. Energy is required to autoclave waste and additional energy is then needed to drive off this moisture to produce a fuel that can then be pyrolysed to release energy. The organic rich, high in moisture output is likely to be more suited to anaerobic digestion, which also attracts double ROCs or used as a material substitute in board products. Unfortunately the latter option is not subsidised, requires market development and may well not yield the revenues energy production attracts due to ROCs.

CONCLUSIONS

1. Pre-treatment requirements prior to applying the thermal conversion technology have a major effect on option performance and illustrates why thermal plants cannot be equitably compared as stand-alone processes.
2. Thermal options for residual waste are not going to be major contributors to reducing UK emissions of fossil-carbon if the energy produced is offsetting CCGT or gas boilers. However, use of thermal options can make a significant contribution to renewable energy supplies and reduce demand for fossil fuels and thus conserve valuable abiotic resources.
3. Progress in environmental performance can be compromised by subsidising “technologies” to encourage their development and entry into the marketplace rather than basing support against achieving the environmental goals directly.
4. The Waste Hierarchy and supporting life-cycle assessment studies that consider global impacts have been the basis for DEFRA waste policies, hence high targets to promote recycling and composting in preference to energy recovery, which should be reserved for residual waste unsuited to recycling. However the mechanisms to support greenhouse gas reductions and renewable energy supplies have historically been developed by industry-focused policy departments (DTI, BERR and now Energy and Climate). They are more UK-centric as the “performance measures” used to meet our international commitments are geographically constrained to UK activities. It is the latter measures that are setting the economic decision framework for residual waste and hence it is perhaps not surprising that there is some confusion and conflict.

Our overall conclusion on energy recovery from residual waste by thermal systems is that the case for technology selection should be primarily based on resource conservation and/or (renewable) energy supply and not based on reducing greenhouse gas emissions. Focus should be on the overall energy conversion efficiency from the available energy content within the waste, not on the technology adopted. Advanced thermal treatment technology can deliver good performance but there is not a significant gap between the best options and traditional, proven mass-burn solutions. Consequently, there appears little justification for differential electricity subsidies if based on promoting renewable supplies alone. The analysis indicates it is possible to achieve much poorer results than mass burn incineration and still qualify for subsidies. Finally, it appears that decision criteria and environmental assessment methods differ as the tiers of the hierarchy are traversed – global criteria to justify recycling activities, but UK-centric criteria for supporting energy recovery from residual waste.

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APPENDIX A

Parameters Selected for Calculating GHG Emissions and Energy Recovery

System	MBI (e and chp)	RDF-Pyro	AC SRF -pyro	MBT SRF -pyro
Pre-treatment	none	to fuel* paper 0.9 putres 0.3 mc 0.8 pl 0.9 inert 0.1 fines 0.1 * wt recovery	to fuel* paper 0.9 putres 0.9 mc 0.4 pl 0.1 inert 0.3 fines 0.7 water added To 50% moist.	to fuel* paper 0.9 putres 0.6 mc 0.8 pl 0.5 inert 0.2 fines 0.7 Water loss 50%
Tonnes of “fuel” to thermal plant	7.00 tph @ 33.0 % moist.	3.70 tph @ 30.4% moisture	5.15 tph @ 50% moisture	3.35 tph @ 17.9% moisture
Chemical energy input MJ/kg of fuel (as produced)	GCV = 10.19 NCV = 8.69	GCV = 14.43 NCV = 12.74	GCV = 7.19 NCV = 5.48	GCV = 14.02 NCV = 11.97
Fossil -energy content (GVC and NCV basis)	GVC; 39.4% NCV; 42.1%	GVC; 46.2% NCV; 47.9%	GVC; 11.3% NCV; 13.1%	GVC; 22.9% NCV; 24.4%
Chem conversion to heat	98%	na	na	na
Chem conversion of Carbon to syngas		85%	85%	85%
Chemical energy conversion to syngas (GCV)		75%	75%	75%
Heat to steam	90% (of NCV)			
Engine/Turbine efficiency (GVC)	30% MBIe 20% MBIchp	35%	35%	35%
Waste Heat utilisation	0.7 (high quality steam chp)	a) Fuel Drying to 15%. b) 0.5 for any residual (low grade)	a) Fuel Drying to 15%. b) 0.5 for any residual (low grade)	a) Fuel Drying to 15%. b) 0.5 for any residual (low grade)
Process Electrical Energy demand	90 kWh/t residual waste input	RDF- 30 kWh/t residual waste Pyrolysis - 80 kWh/t fuel input	AC - 45 kWh/t residual waste Pyrolysis – 80 kWh/t fuel input	MBT- 70 kWh/t residual waste Pyrolysis – 80 kWh/t fuel input
Process thermal energy demand (natural gas)	Start up flow / low feed supplement Ignored as energy recovered also not accounted for	Start up and Balancing flow Ignored as any energy recovered from NG used to supplement engine not accounted for	144kWh/t for Autoclave steam (Natural Gas @90% efficiency) Start up / balancing flow of NG for engine ignored	Start up / balancing flow of NG for engine ignored
Grid electricity Emissions/MJ fossil C	Ccgt; 115 gCO2/MJ @ ~ 50% efficiency Coal – steam tubine 250 gCO2/MJ @ ~ 36% efficiency			
Heat supply Emissions/MJ fossil C	Natural gas, 75 gCO2/MJ @ ~ 90% efficiency			

Notes:

In this case study, the waste loses 50% of the moisture content during bio-drying which results in the BMT-SRF reporting approximately 18% moisture levels. Bio-carbon breakdown to CO$_2$ due to composting is included in the emissions inventory (approximately 10% of input biogenic carbon). Typical weight proportion of kitchen to garden waste putrescibles found in collected domestic waste is assumed to be 70:30 – the chemical properties of the combined putrescible category are calculated based on this weight contribution.

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