Risk assessment for the use of mixed waste composts on previously developed land in the UK

Antony Chapman*, Paul Bardos & Graham Merrington***

*WCA environment, **r[3] Environmental Technology Ltd, Dept. Soil Science, The University of Reading,

Abstract

One possible output from a Mechanical Biologiocal Treatment (MBT) process is an organic fraction referred to as MBT compost, which is distinctive from source segregated green waste compost and may either be landfilled as a biostabilised material or potentially used in a number of applications on land. Within the current regulatory framework in the UK the most significant land-based outlet for MBT compost in the UK is likely to be previously developed land (PDL). If MBT compost is to be successfully and sustainably applied to PDL over time, there is a need to assess the potential environmental and human health risks of such an activity in a proportionate and robust manner. Such an assessment would provide a clear framework through which informed decisions could be made by both environmental regulators and the regulated community alike. This paper will describe the potential scale of future MBT compost production in the UK and potential applications for the material on PDL, as well as approaches to the assessment of the degree of risk involved in doing so.

Keywords

MBT, compost, Previously Developed Land (PDL), risk assessment, market opportunities

1 Introduction

Mechanical Biological Treatment is an umbrella term that applies to many processes for the treatment of residual waste that use some form of mechanical separation to refine the feedstock either before or after some form of biological treatment, such as composting or anaerobic digestion. There are several possible biological outputs from such processes, one of which is an organic fraction referred to within this paper as MBT compost. This is predominantly organic material derived from mixed waste feedstock and subjected to biological treatment (composting, in-vessel composting, anaerobic digestion, or possibly a combination of these) as part of an MBT process. The resulting organic fraction may either be landfilled as a biostabilised material or used in a number of potential applications, such as landfill engineering (daily cover or capping for example) or the management of previously developed land (PDL). The use of MBT compost (or any other organic material) on PDL could be for two principal end goals. First, it could be used to reduce the risk of any physical loss of contaminants present within a site migrating beyond its boundaries by improving soil quality, making it more stable and potentially improving the short to medium term sorption capacity of the soil. Alternatively, in cases where PDL is less contaminated and/or is situated in a suitable location, MBT compost could be used to restore the land to a beneficial end use, which might include a recreational facility such as a country park, or a commercial activity such as non-food crop production, or a combined site with commercial and recreational areas.

While other recreational land uses, such as parks and golf courses, or new infrastructure such as earthworks for roads, railway lines and airports, agricultural and horticultural applications, or biological applications such as plant pathogen control *may* provide an outlet for MBT compost in the future, previously developed land remains the most significant and most realistic outlet for MBT compost. While MBT compost would provide a cheap and plentiful source of organic carbon for soil of generally poor quality (in most potential applications), concerns exist over its quality and consistency, particularly in relation to physical and chemical contaminants in the material.

If MBT compost is to be successfully and sustainably applied to PDL over an extended period of time, thereby providing a reliable alternative to landfill for this material and a source of organic matter for the land, there is a need to assess the potential environmental and human health risks of such an activity. Such an assessment would provide a clear framework through which informed decisions could be made by both environmental regulators and the regulated community alike.

This paper will describe the potential scale of future MBT compost production in the UK and potential applications for the material on previously developed land, as well as approaches to the assessment of the degree of risk involved in doing so. It will collate information on potential hazards in MBT composts, along with possible pathways and receptors and suggest how these might be applied in deriving generic risk based criteria for the use of MBT composts on PDL. A practical and proportionate screening risk assessment methodology for the identification of potential risk for several exposure scenarios and receptors will be discussed. This methodology moves beyond the limited historic view in the UK that only considers a few trace metals detailed in sewage sludge regulations. Uncertainties, assumptions and information gaps will be highlighted.

2 What is MBT compost and how much of it is there?

The term MBT compost describes organic materials that have been derived from mixed municipal solid waste (MSW) feedstock and processed by some form of Mechanical Biological Treatment (MBT) to produce an organic-rich fraction. MBT is a term that can be used to describe numerous processes, or combinations of processes. The only common factors between all of them are:

- They treat mixed waste.
- They contain some form of mechanical separation of unwanted inorganic elements, like fragments of metal, glass and plastic, such as screening, ballistic separation and magnets, for example
- Mechanical separation takes place either before and/or after treating the organic-rich fraction using a biological treatment such as composting or digestion.

The feedstock used in these processes is largely household waste, with a small proportion coming from commercial and industrial units; due to urban and rural locations, different seasons and the efficiency of recycling schemes within the area this feedstock can be widely variable throughout the year. As a result of the variation in the initial feedstock and the range of processes classed as MBT, there is considerable variation in quality both within and between the organic amendments collectively known as MBT compost.

MBT composts should not be confused with green waste composts produced from source segregated material. Green waste composts that comply with PAS100 or the compost Quality Protocol (WRAP 2006) can be used as garden-based growing media and soil improvers, and for commercial horticulture and agriculture (WRAP, 2007a,b). Such opportunities are not realistically open to MBT composts but finding alternative end uses for these materials, that are genuinely sustainable in the long term and do not compromise environmental quality would allow for the diversion of significant quanities of material from landfill, aiding compliance with the Landfill Directive (EU, 1999).

In order to place MBT compost into a wider context of land and waste management solutions, it is necessary to have an estimate of the likely quantity of material that will be produced in the future. Two estimates have been derived; one based on the capacity of operational and planned MBT plant in the UK, the other based on national data on municipal waste arisings and waste management.

In the last five years MBT has gone from being a potential waste management solution to an actual solution in the UK. Several plants are now operational, others have been commissioned and yet more are in the earlier stages of development such as PFI negotiations (references). The total estimated input capacity of MBT plants either in operation or under construction by local authorities at the end of 2008 was in excess of 3.1 million tonnes per year by 2010, assuming all projects come to fruition. This may be a conservative estimate, as further plants are now under consideration. However it may also overestimate MBT compost production, as there is increasing production of Solid Recovered Fuel (SRF) rather than MBT-compost due to greater market security for the otput and uncertainty over the development of future markets (Bardos & Chapman, 2008; Environment Agency, 2008).

Previous research has suggested that around 35% of a typical input waste stream for a MBT plant would be processed by composting, if most of the paper content were treated by energy from waste (Bardos 2005). The composting process typically reduces the volume of material to 60% of the input weight, which leads to an estimated MBT-compost yield of 21% of the input volume. On this basis an input of 3.1million tpa of residual waste to the MBT process would result in MBT-compost production of 650,000 tonnes per year by 2010 (Bardos & Chapman, 2009). However, the highly variable configurations of MBT plant, the principal outputs produced (i.e the plant could be configured for Solid Recovered Fuel or stabilised biowaste production, rather than MBT compost), and natural variation in feedstock mean that the figure of 650,000 tonnes per year is probably an overestimate.

In comparison, WRAP (2006b) suggested in a recent meeting report that 3.6 million tpa of compost from source segregated sources could be being produced by 2010. In fact the 2006/7 survey of composting in the UK (Afor, 2008) reported that this figure had been reached. In the same year approximately 87,000 tonnes of anaerobic digestate was produced from source segregated feedstock, while the amount of mixed waste composted by MBT was estimated at 140,000 tonnes for 2006/7 (Afor, 2008). This material was either distributed at no cost, used on site or on sites owned by the producer, or disposed of to landfill. Thus although MBT-compost will be produced in significant quantities in the near future, the scale of production will be comparable to or less than the production of other forms of waste-derived organic matter.

3 The extent of Previously Developed Land in the UK

The term Previously Developed Land (PDL) has been defined as ‘land that was developed but is now vacant or derelict, or land currently in use with known potential for redevelopment (DCLG, 2007). Previously Developed Land encompasses sites that have been affected by former uses of the site or surrounding land and are derelict or underused. Generally they are urban or semi-urban areas and would require intervention to bring them back to beneficial use; in addition they *may* have real or perceived contamination problems. Some sites may have remained unused for long periods because they occupy a very large area or they are relatively inaccessible by road or are inappropriate for a hard development or otherwise unsuitable. There may be little economic incentive to regenerate the areas affected. In the UK a proportion of this marginal land has been managed with “soft” restoration, for example for amenity use such as “country parks” (recreational areas in rural or semi-rural locations). The amount of land that remains degraded over the long term is a matter of concern as the degradation continues to blight local populations, and there are strong quality-of-life, social and political arguments for some form of action.

Redevelopment of PDL is usually categorised as “hard” or “soft”. Hard end-use refers to built redevelopment. Soft end-use describes non-built end-use. Soft end uses can either non-commercial (e.g. in the amenity, landscaping and habitat sectors) or commercial (e.g. non-food crops). The Department of Communities and Local Government produced a survey of previously developed land in 2006 (DCLG, 2007). The main conclusion was that there were 62,700ha of previously developed land, of which 34,900ha (55%) were vacant or derelict (as opposed to in use with scope for rehabilitation). Note that this figure includes more than just long-term derelict land: a survey by English Partnerships (2003) estimated the scale of long-term (i.e. longer than ten years) derelict sites greater than 2ha in size at 16,523 hectares. There is no dataset to estimate the total area of long-term derelict sites that are less than two hectares. However, anecdotal evidence from Local Authorities suggests that the unrecorded land area occupied by such sites could be up to ten percent of that occupied by those above two hectares. This would indicate approximately 1,700 hectares in this category, making an estimated total of 18-20,000ha of long-term derelict land in England. In a European context it is forecast that the number of brownfield and potentially contaminated sites across Europe is expected to grow, making brownfield land a significant and ongoing land management issue for the foreseeable future. This represents a significant financial burden that will largely be the responsibility of Local Authorities in which these areas exist.

4 Existing guidance on the application of MBT compost in the UK

Existing guidance supports a risk based use of MBT composts on PDL. There are two environmental frameworks to be considered: the application of MBT compost to land under the Environmental Permitting regime and the management of land affected by contamination:

1. The Environmental Permitting (EP) programme, introduced in 2008, streamlines and combines Waste Management Licensing (WML) and Pollution Prevention and Control (PPC) legislation under a single environmental permit (Defra, 2008). A waste management operation (including recovery operations, such as use on land) may take place under a standard permit, with an exemption or with a bespoke permit depending on the degree of risk in each case. A standard permit has standard rules, with which the permit holder must comply. Bespoke permits have conditions that are set specifically for an individual facility or activity. The use of MBT composts on land would require either a standard or bespoke permit.
2. PDL may also be land affected by contamination, in which case the suspected quality of the land itself will trigger a risk assessment. Typically the initial risk assessment

is generic, with site investigation and quantitative risk assessment being carried out if the initial appraisal indicates a need. Good practice is described in the Model Procedures for the Management of Land Contamination Contaminated Land (Defra & Environment Agency, 2004).

Hence for previously developed land, MBT compost applications need to be considered in a risk assessment framework. In this context it would seem appropriate that criteria used for generic risk assessment for organic waste applications are linked to risk assessment tools developed for land affected by contamination, such as the Soil Guideline Values (SGVs), rather than the current approach which is related to guidelines for the use of sewage sludge on agricultural land. A significant step forward in deciding how to tackle risks to the environment from compost addition might be to reach a consensus on what constitutes "harm" or "damage", along with guidance on how sources, pathways and receptors can be appraised. It is possible that such a consensus might enable a broader range of applications of MBT composts than is currently available.

5 The potential hazards in MBT compost

In common with other waste derived organic materials, the use of MBT-compost may cause undesirable impacts which *may* affect human health, the intended application and/or the wider environment. Principal concerns relate to risks from chemical and visual contaminants, plant nutrients, impacts on soil (pH, conductivity and redox conditions), partially degraded (immature) composts and the effects caused to plants growing in them. The severity of any impact is related to the composition of the organic matter added, the requirements of the soil and its application and the sensitivity of the land, for example its proximity to water resources and its capacity to buffer inputs such as nitrogen and phosphorous.

5.1 Potential biological hazards

Many plant pathogens are destroyed during the composting process although some parasitic organisms may persist (Noble & Roberts 2003). Human and animal pathogens are likely to be rare or absent in properly made and matured composts derived from MSW, produced in accordance with the Animal By-product Regulations (Defra 2006a). Work by Dimambro *et al* (2007) showed that levels of fecal coliforms and *E. coli* in two types of MBT-OM were comparable with those in composts made from source segregated organic materials and better than many. In both cases the level of E. coli was lower than the PAS 100 criterion (there is no PAS100 criterion for fecal coliforms and salmonellae were absent from all samples tested).

5.2 Potential chemical hazards

Levels of many trace elements, in particular arsenic, cadmium, copper, lead, and especially zinc, tend to be elevated in MBT-compost compared with soils. There are several reports that regular application of MBT-compost to land leads to accumulation of trace elements in the topsoil (e.g. Jobbágy & Jackson, 2004, Zhang *et al.,* 2006), although findings about the potential effects of these trace elements to plants, soil and animal health are not consistent. Due to the source mateial MBT composts may also have elevated concentrations of a range of pthalates, PFOS and biocides such as triclosan (unpublished data).

Some authors believe that such pollutants do not pose a significant risk, while others suggest that MBT-compost should not be used as a precautionary measure (Groenveld & Hébert, 2003). Amlinger *et al* (2004) recommend restricting the use of mixed waste compost to limited non-food areas such as land reclamation of brownfields and surface layers on landfill sites or on noise protecting walls beside roads or railways. Conversely, Smith (2009) argues that the application of source segregated and MBT composts to soil does not necesarily increase the availability of heavy metals or lead to phytotoxic effects.

The content of plant nutrients in MBT-OM, as well as the effect it has on pH, redox and soil conductivity from the content of cations such as potassium, sodium and calcium and anions such as nitrate and chloride, can have negative as well as beneficial impacts. Its content of nitrogen and phosphorous may migrate to surface and groundwater depending on their environmental availability. This is a particular issue in sensitive areas such as Nitrate Vulnerable Zones (NVZs) and Groundwater Protection Zones (GWPZs). The significance of the discharge will depend on the river ecology, its capacity to withstand discharges and the scale of the discharge. Organic matter addition is seen as the overriding benefit of MBT-compost and compost addition for soil improvement. However, the organic matter addition itself may carry a risk of undesirable impacts, including the generation of gas from MBT-compost used as fill material, reduction in soil oxygen by decomposition processes (Inbar *et al.,* 1990), phytotoxic effects from immature composts (Ozores-Hampton *et al,* 1998) and the removal of plant available nitrogen during the decomposition of high C:N ratio MBT-compost in soil (Janssen, 1996)

As well as the concept of risk to the environment from the potential contamination in all composts and sludges, closer consideration will also have to be given in the future to a broad range of potential impacts on soil, groundwater and water as a result of:

- The expanded scope of the Nitrate Directive
- The implementation in the UK of the Water Framework Directive and the Groundwater Daughter Directive

- Developments in soil protection policy
- Concerns over potential impacts from organic pollutants (e.g. endocrine disrupting substances)

5.3 Potential physical hazards

Depending on the substance in question, inert materials such as stones, glass, metal and plastic pose a variety of problems in compost; in particular the visual appearance of treated soils may be affected (Mamo *et al*., 1998) and the potential for harm to wildlife or domestic animals (via the ingestion of plastics for example (Mays *et al.,* 1973). Other issues include the presence of sharp items, including shards of metal, glass and ceramics, splinters of wood and plastic, needles, pins and blades. These pose a risk of cuts and grazes during handling (Kendle, 1990) and may also pose a risk to humans and animals once applied. The elimination of sharps is often a major goal of MBT refining and processing.

6 Risk assessment

Risk is distinct from hazard. A hazard is an inherent property of a material, such as the level of contamination it contains: risks relate to the possible impact of those properties on a receptor such as human health or the environment and is a function of both the scale of any such potential impact and the likelihood of the impact happening. It may be possible for risk to be minimised by appropriate management and use.

Risk assessment provides an objective, technical evaluation of the likelihood of unacceptable impacts to human health and the environment. Considerations of risk can also be used to how best to minimise risk. This process of decision making and its consequent actions are called risk management. Risk management is a process of deciding how pollutant linkages might be most effectively and efficiently broken, and then undertaking the actions which have been agreed as necessary. There are three basic ways in which pollutant linkages can be broken for CLO applications:

- Source reduction, (minimising the content of hazardous materials in CLOs)
- Pathway management (for example using a barrier to restrict the migration of contaminants from an applied CLO, say in an engineered highway embankment), and
- Modifying exposure (for example by choosing a future land use where opportunities for exposure are reduced).

Should a risk be demonstrated the next question is whether it has a significant impact or not. What constitutes harm to receptors like human health, soil ecology, ground and surface water is controlled in large part by political considerations about what it is reasonable to expect to achieve, balancing environmental considerations against social and economic constraints. What is acceptable depends on whether the regulator takes a multi-functional approach to how soil is used (i.e. that any soil can be used for any purpose) or a view related to its use. For example, fear of damage to soil function may be a greater concern for agricultural land than for the restoration and remediation of a brownfield site. If a site already carries a heavy burden of trace elements, the possible harm from incremental increases due to CLO addition may not be high compared to the potential benefits of the CLO use for restoration and remediation (Defra 2006c).

6.1 Risk to Humans

Humans potentially exposed to harmful constituents of CLO include those employed in production and individuals using, visiting or living on CLO treated land. It is also conceivable that pathways such as wind-blown dust might affect humans on surrounding sites. The principal human health impacts that need to be considered for any soil improver have already been elaborated in some detail by CEN TC 223 (BSI, 1999) and include toxic substances, pathogens, dust, odour and bioaerosols and/or allergens (particularly during processing and application) and sharps. These hazards can potentially apply to any organic materials whatever the feedstock.

Human exposure to soil contaminants can occur via many pathways (Defra & Environment Agency 2002a, 2002b, 2002c). Direct human exposure pathways of importance include dermal absorption, inhalation of soil/dust, inhalation of volatilized compounds and inadvertent soil ingestion (or, in the case of some children, deliberate soil ingestion). Indirect pathways include plant uptake of contaminants followed by ingestion, contaminant presence in groundwater/surface water followed by ingestion, and pathways involving transfers through the food chain. A similar set of pathways can be envisaged for contaminants in CLOs, and also for exposures to pathogens, and some pathways could also apply for exposure to allergens. Exposure pathways for sharps are likely to be those related to direct contact.

6.2 Risks to the Environment

Inappropriate use of organic material on land may have detrimental effects ono soil and water, to ecosystems and to plants and animals. These risks may be posed by one or more hazards, such as chemical contamination, plant and/or animal pathogens, inerts, changes in pH or redox conditions, nutrient loadings (particularly nitrogen and phosphorous) and conductivity and the effects of organic matter addition (including immature composts).

Transport and migration of certain chemicals including nitrates, phosphates and heavy metals to water bodies have been widely reviewed (Defra, 2004d; Foster & Charlesworth, 1996). The pathways are related to the movement of air, water (including entrained sediment) or dust. These pathways also spread contaminants through soil, and to plants and soil dwelling organisms. The effects of burrowing animals (Smallwood *et al.,* 1998) and also of plant accumulation followed by leaf litter fall also can spread contamination (Jobbágy, & Jackson, 2004). Animal exposure pathways are likely to be similar to pathways of exposure for humans, described above, but are not generally well accounted for in exiosting regulatory frameworks for sewage sludge. In particular it is important to account for the environmental risks of secondary poisoning from metals and organic contaminants.

6.3 Approaches to risk assessment

Modern risk assessment needs to consider the sources, pathways and receptors descirbed, but also has to reflect developments in knowledge and understanding related to contaminants and contaminant behaviour. Traditional approaches to risk assessment, focused on heavy metals, do not reflect modern understanding of the range and complexity of contamination that can be found in waste-derived organic materials, nor do they consider the wider impacts of organic contaminants such as PAHs, PFOS, triclosan and some flame retardants. Modern risk assessment must reflect modern knowledge and provide a practical, precautionary approach to the application of organic material to land that reflects the correct balance between the benefits of added organic matter and the hazards of introducing potential contaminants into the environment.

From a wider management perspective, such risk assessments must fit into broader considerations of how brownfield land is to be managed in the most practical, sustainable manner. In part this reflects the environmental risk discussed, but should also take into account the suitability of the proposed land use, the land to be used, the wider added value of undertaking the project and the long term environmental and financial sustainability of doing so. This is the approach proposed within the Rejuvenate project[1], applied to the assessment of the suitability of brownfield land to the cultivation of biomass. While this is a specific end goal, it illustrates one apprach to investigating the sustainability of land management practices, which incorporates environmental risk assessment as a key stage in the process.

---

[1] Rejuvenate includes partners from Germany, the UK, the Netherlands and Sweden and began in October 2008. It is funded, under the umbrella of an ERA-Net (SNOWMAN), by the Department for Environment Food and Rural Affaires and the Environment Agency (England), FORMAS (Sweden) and Bioclear BV (Netherlands). The EU ERA-Net SNOWMAN is a network of national funding organisations and administrations providing research funding for soil and groundwater bridging the gap between knowledge demand and supply (http://www.snowman-era.net). It is one of more than 70 ERA-Nets (European Research Area-Networks) funded by the EC's 6th Framework Programme for Research and Technological Development.

7 Conclusions

MBT is now an established method if waste treatment in the UK and the number of plants is expanding. Many of these plants produce MBT compost as an output and this is likely to become a significant source of organic matter in the near future. The application of CLO to land is a realistic outlet for this material and is increasingly likely given the Environmental Permitting regime and the pressure to divert biostabilised material from landfill. In this context it is important that the material applied to land is fit for purpose and an appropriate form of risk assessment is required to ensure regulators and users that it is so.

A particular consideration for all forms of waste-derived organic material will be to move toward a risk assessment approach that reflects improvements in the understanding of both the range of contaminants present in waste-derived organic materials and the behaviour of chemicals. This increased understanding, including knowledge realating to chemicals that have not been routinely monitored in the past, suggests that a practical, precautionary approach to the use of organic wastes to land is required. A secure, honest, yet flexible form of risk assessment will be a valuable tool for the future. Risk assessment is iterative and provides a powerful methodology to target resources and deliver commercially and environmentally beneficial solutions. Such risk assessments should fit into a wider planning and management process that considers the suitability of the proposed land use and the proposed site for the end purpose, as well as the value added by the change in use and the financial stability of the project as a whole. Land management and risk assessment starategies have to evolve and historical approaches to risk assessment

8 References

Amlinger, F., Favoino, E. and Pollak, M.	2004	Heavy metals and organic compounds from wastes used as organic fertilizers. On behalf of the EU Commission DG ENV.
Association for Organics recycling, Afor	2008	The state of composting and biological waste treatment in the UK, 2006/7, ISBN 0-95477797-9-7
Bardos, R.P.	2005	Composting of Mechanically Segregated Fractions of Municipal Solid Waste – A Review. SITA Environmental Trust Ltd. www.compost info.info
Bardos, R. P. & Chapman, A. S.	2008	Towards certainty in the use of MBT organic outputs: a workshop report, May 19th 2008. Available at www.r3environmental.co.uk

Bardos, R. P. & Chapman, A.S.	2009	The market potential for organic matter derived from MBT processes. Available at www.r3environmental.co.uk
British Standards Institution, BSI	1999	PD CR 13455:1999: Soil improvers and growing media. Guidelines for the safety of users, the environment and plants, British Standards Institute, London, UK
Department for Communities and Local Government, DCLG	2007	Previously-Developed land that may be available for Development: England 2006 - Results from the National Land Use Database of Previously-Developed Land (NLUD) June 2007 Product Code 07HC04713
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2002a	Potential contaminants for the assessment of land. R&D Publication CLR8 ISBN 1 857 05733
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2002b	Contaminants in soil: Collation of toxicological data and intake values for humans. R&D Publication CLR9 ISBN 1 857 05734 1.
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2002c	The Contaminated Land Exposure Assessment (CLEA) model: Technical basis and algorithms. R&D Publication CLR10 ISBN 1 857 05749 X.
Department for the Environment, Food and Rural Affairs, Defra and the Environment Agency	2004	Model Procedures for the Management of Land Contamination Contaminated Land Report . 11 ISBN: 1844322955
Department for Environment, Food and Rural Affairs - Defra	2006a	Animal by-products: Treatment in approved composting or biogas plants of animal by-products and catering waste - Q&A.
Department for Environment Food and Rural Affairs, Defra	2007a	Waste Strategy for England 2007 PB12596 CM 7086.

Department for the Environment, Food and Rural Affairs, Defra	2007b	Municipal waste management statistics 2006/7. Statistical release 404/07,
Department for Environment Food and Rural Affairs, Defra.	2008	Environmental Permitting: core guidance for the Environmental Permitting Regulations (2007).
Dimambro, M.E. Lillywhite, R.D. and Rahn, C.R.	2007	The physical, chemical and microbial characteristics of Biodegradable Municipal Waste derived composts. *Compost Science and Utilisation,* 15; 243-252
English Partnerships	2003	Towards a National Brownfields Strategy; Research findings for the Deputy Prime Minister.
European Union	1999	Council Directive EC/31/1999 on the landfill of waste
Foster, I.D.L. & Charlesworth, S.M.	1996	Heavy metals in the hydrological cycle, trends and explanation. *Hydrological Processes*, 10 pp227-261
Groeneveld, E. and Hébert, M.	2003	Dioxins, furans, PCBs and PAHs in eastern Canada compost. Prepared on behalf of Ministère de l'environnement de Québec
House of Commons Environment, Food and Rural Affairs Committee	2005	Waste Policy and the Landfill Directive: Fourth Report of Session, 2004-2005. Report HC 102 (incorporating HC 1256-i & -ii, Session 03/04)
Inbar, Y., Chen, Y., Hadar, Y. and Hoitink,	1990	H.A.J. (1990) New approaches to compost maturity. BioCycle, December 1990.
Janssen, B. H.	1996	Nitrogen mineralization in relation to C:N ratio and decomposability of organic materials. Plant and Soil, 181 (1) 39-45
Jobbágy, E. G. and Jackson, R. B.	2004	The uplift of soil nutrients by plants: biogeochemical consequences across scales. Ecology, 85: 2380–2389.
Kendle, A.	1990	Soil ameliorants for landscape planting, Plant user specification No 3, Part 1, July 1990, pp 3-7
Mamo, M. Halbach, T. R. and Rosen, C. J.	1998	Utilization of Municipal Solid Waste Compost for Crop Production. Online factsheet, University of Minnesota, US.

Mays, D.A., Terman, G.L. and Duggan, J.C.	1973	Municipal Compost: Effects on Crop Yields and Soil Properties. Journal of Environmental Quality. 2 (1), pp. 89-92.
National Audit Office, NAO	2006	Reducing the reliance on landfill in England REPORT BY THE COMPTROLLER AND AUDITOR GENERAL, HC 1177 Session 2005-2006 | 26 July 2006
Noble R. and Roberts S.J.	2003	A review of the literature on eradication of plant pathogens and nematodes during composting, disease suppression and detection of plant pathogens in compost. WRAP, Banbury, Oxon, UK
Ozores-Hampton, M.P., and T.A. Obreza.	1998	Use of composts in Florida's vegetable crops. pp. 39-42. In: Florida Department Environmental Protection (ed.). Compost use in Florida.
Smallwood, S.K., Morrison, M.L. & Beyea, J.	1998	Animal Burrowing Attributes Affecting Hazardous Waste Management *Environmental Management* 22 (6) pp831-847
Smith, S. R.	2009	A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge, Environment International, 35 142-156, ISSN: 0160-4120
The Waste and Resources Action Programme, WRAP	2002	Research Analysis of the market potential for CLOed materials in the UK. ISBN 1 84405 034 3
Waste and Resources Action Programme, WRAP	2007a	Quality Protocol Compost. The quality protocol for the production and use of quality compost from source-segregated biodegradable waste.
Waste Resources Action Programme, WRAP	2007b	Quality compost opens up new uses for brownfield land on Teesside: The case for greener brownfield regeneration
Waste Resources Action Programme, WRAP	2007c	The Lambton Cokeworks reclamation scheme: The case for greener brownfield regeneration
Zhang, M. Heaney, D. Henriquez, B. Solberg, E. and Bittner, E.	2006	A four-year study on influence of biosolids/MSW compost application in less productive soils in Alberta: Nutrient dynamics. Compost Science and Utilisation, 14 68-80

Author's addresses

Dr. Antony S. Chapman; Dr. Graham Merrington
WCA environment Ltd
Brunel House

Volunteer Way

Faringdon

Oxfordshire

Sn7 7YR, UK
Tel +44 (0)1367 246022

Email Tony.Chapman@wca-environment.com
Website: www.wca-environment.com

Prof. Paul Bardos

r3 Environmental Technology Ltd.

Room 120, Department of Soil Science

The University of Reading

Whiteknights

PO Box 233

Reading

RG6 6DW, UK

Tel +44 (0)118 3788164

Email paul@r3environmental.co.uk

Website: www.r3environmental.co.uk