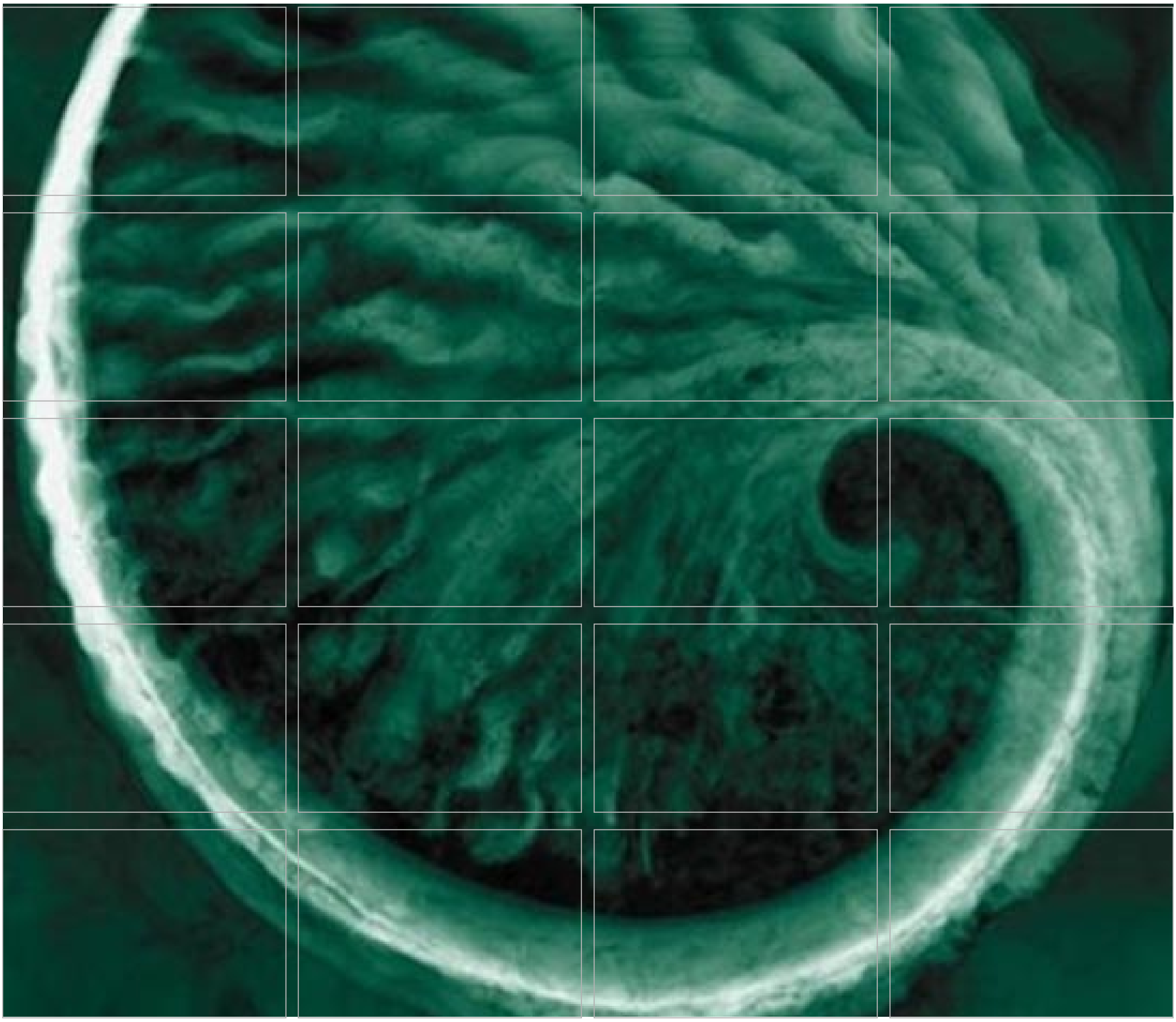

Carbon Balances and Energy Impacts of the Management of UK Wastes

Defra R&D Project WRT 237

Executive Summary

December 2006

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Final Report

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For and on behalf of
Environmental Resources Management

Approved by: Simon Aumônier ___________

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Date: 18th December 2006 _____________________

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1 EXECUTIVE SUMMARY

This project undertook a macro-level investigation of the carbon flows, energy and greenhouse gas benefits and impacts associated with alternative management routes for the predominant waste materials arising in the UK. The research examines the scale of benefits and impacts resulting from different process and recovery routes, traces carbon flows through alternative systems and identifies the most significant wastes and management methods.

Findings illustrate that some materials and management routes show significant potential for greenhouse gas emission and fossil energy demand savings. Although there are a number of uncertainties (see below), the largest potential, over and above current recovery efforts, is with regard to:

- **energy recovery via anaerobic digestion of agricultural manures/slurries**;
- **energy recovery via combustion of waste wood**;
- **recovery of both resources (through recycling) and energy (through combustion) from waste paper and card**; and
- **recycling of non-ferrous metals.**

The energy benefits estimated for these materials and management routes equate to a combined saving in the region of 88 to 202 PJ-equivalents per year over the period assessed. This is equivalent to approximately 1-3% of UK energy consumption in 2003 (1).

Discounting the influence of relative material arisings, on a tonne-for-tonne basis the **recycling of textiles and plastics** and **energy recovery via anaerobic digestion of kitchen and green wastes** and **combustion of crop and other organic wastes** (2) also show significant potential for benefit.

It was our objective to assess the broad alternatives for managing waste materials and identify where potential benefits might lie. Four core scenarios were developed to assess the management of waste arisings over the period 2005 to 2031:

1. *baseline scenario* – reflecting best current estimates of waste material arisings and management, and assuming that this will not change;
2. *high resource recovery scenario* – reflecting increased rates of recycling and composting over the period;
3. *high energy recovery* – reflecting increased rates of energy recovery via thermal processing technologies (with energy recovery) or anaerobic digestion; and
4. *combined recovery* – reflecting a combination of both resource and energy recovery.

(1) DTI Energy Statistics. http://www.dti.gov.uk/energy/statistics/regional/index.html
(2) Predominantly sewage sludge.

Each scenario was designed to assess the maximum performance theoretically achievable for each waste material, in the absence of current policy or infrastructural barriers. The maximum limit was set based on best performance demonstrated across Europe – under the proviso that if it has been achieved elsewhere, it is 'theoretically achievable' in the UK.

The major flows of both carbon/greenhouse gases and energy through waste management systems result from:

- ancillary requirements for fuel and energy in processing and transporting materials;
- direct releases from waste fractions on processing (eg biological processing or combustion) or disposal in landfill;
- avoidance of greenhouse gas emissions or energy use elsewhere in the economy; and
- sequestration of carbon in soils.

For each material and scenario these flows were quantified in each year from 2005 to 2031 and were combined with estimates of time-lagged landfill gas release and capture over 100 years. Carbon and greenhouse gas balances were drawn up, outlining the flow and fate of all carbon over this period. Both direct and indirect greenhouse gas releases were accounted for.

The work further explored the range of potential performance for alternative materials by assessing a set of 'maximum' and 'minimum' avoided burdens.

For energy recovery processes, these maxima and minima were based on the range of conversion efficiencies reported in literature:

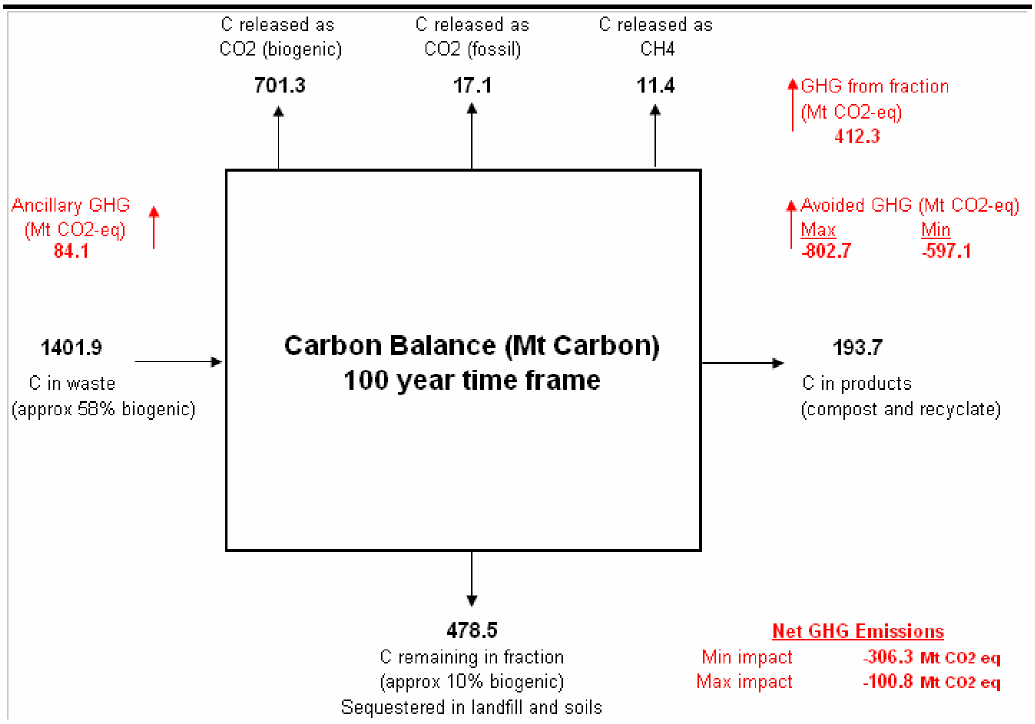
- *Combustion*: minimum – 20% electricity only; maximum – combined power at 70% total efficiency (40% electricity, 30% heat); and
- *Anaerobic Digestion*: minimum – 30% electricity only; maximum – combined power at 85% total efficiency (40% electricity, 45% heat).

For resource recovery, maxima and minima were based on the range of potential fates for recovered materials. As a general rule, the potential savings are higher where recovered materials are of higher quality, material integrity can be maintained and virgin material production is avoided. The relationship is not a straightforward one for all materials, however, and so maxima and minima were developed on a material-by-material basis.

Figure 1.1 shows a carbon and greenhouse gas balance for all UK wastes, according to best estimates of current arisings and management for the materials assessed [(1)].

(1) Those listed in *Table 1.1* and *Table 1.2.*

Figure 1.1 Carbon and Greenhouse Gas Balance over Study Period – Baseline Scenario



Maximum and minimum net greenhouse gas emissions and fossil energy demand per tonne of material and by scenario are shown in *Table 1.1* and *Table 1.2*. These are expressed in terms of net impact over the baseline [(1)] to highlight opportunities for improvement on a unit basis.

Table 1.1 Net Greenhouse Gas Emissions (kg CO_2-eq) per Tonne of Waste Material – Net Impacts over Baseline

Material	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**
	High Resource	*High Energy*	*Combined*
Paper/Card	-104.1 to -143.0	-181.7 to -311.7	-123.3 to -170.9
Kitchen/ Food Waste	-27.0 to -51.5	-85.7 to -168.0	-40.8 to -75.4
Green Waste	-11.2 to -16.4	-87.7 to -158.7	n/a
Agricultural Crop Waste	9.6 to 16.9	-69.5 to -205.0	n/a
Manure/ Slurry	4.7 to 5.5	-28.9 to -70.3	n/a
Other Organics	17.6 to 38.0	-65.8 to -193.7	-29.7 to -72.3
Wood	-23.2 to -26.2	-255.8 to -558.0	-149.1 to -295.3
Dense Plastic	127.5 to -455.0	163.8 to 561.1	-404.0 to 342.3
Plastic Film	132.1 to -324.1	192.1 to 482.6	-274.9 to 319.3
Textiles	-178.2 to -276.6	-61.2 to 143.6	-138.3 to -361.7
Ferrous Metals	-64.7 to -93.5	n/a	n/a
Non-ferrous Metals	-798.9 to -852.9	n/a	n/a
Silt/Soil	0.6 to 2.3	n/a	n/a
Minerals/Aggregate	0.1 to 0.1	n/a	n/a

(1) A range, showing the maximum estimate for scenario minus maximum estimate for baseline; and minimum estimate for scenario minus minimum estimate for baseline

Table 1.2 *Net Fossil Energy Demand (MJ-eq) per Tonne of Waste Material – Net Impacts over Baseline*

Material	Net Energy Demand over Baseline (MJ-eq/ tonne)	Net Energy Demand over Baseline (MJ-eq/ tonne)	Net Energy Demand over Baseline (MJ-eq/ tonne)
	High Resource	*High Energy*	*Combined*
Paper/Card	-206.8 to -755.8	-764.7 to -3172.3	-245.1 to -943.1
Kitchen/ Food Waste	318.9 to 389.5	-349.0 to -1357.1	65.6 to 330.9
Green Waste	203.0 to 286.4	-764.1 to -2104.3	n/a
Agricultural Crop Waste	101.7 to 401.8	-1199.7 to -3236.5	n/a
Manure/ Slurry	57.7 to 176.5	-502.0 to -994.5	n/a
Other Organics	227.3 to 651.3	-1231.4 to -2939.5	-243.3 to -691.0
Wood	194.9 to 205.1	-2513.8 to -7732.2	-927.5 to -3393.2
Dense Plastic	2977.4 to -12693.7	-4215.1 to -10,623.2	1493.0 to -16,997.0
Plastic Film	2561.7 to -11654.2	-3906.4 to -7671.6	1321.0 to -15,262.6
Textiles	-1535.2 to -5208.3	-1373.7 to -4086.1	-2544.7 to -8348.6
Ferrous Metals	-113.4 to -873.7	n/a	n/a
Non-ferrous Metals	-8581.2 to -9297.6	n/a	n/a
Silt/Soil	11.0 to 33.3	n/a	n/a
Minerals/Aggregate	2.7 to 3.2	n/a	n/a

Uncertainties and Areas for Further Investigation

A number of assumptions have been made in quantifying the carbon, energy and greenhouse gas flows for each waste material and process assessed. Sensitivity analyses were carried out to examine which of the assumptions have the greatest influence. These pointed to a number of areas where findings should be treated with caution, or where we are currently lacking in information on which to derive accurate estimates:

- average estimates show energy recovery to be favoured over recycling for waste paper and card. In fact, there is a fine balance between these alternative recovery methods;
- estimates show net energy and/or greenhouse gas impacts associated with soil and minerals recycling. This was found to be sensitive to the transport assumptions made during modelling;
- all findings were based on, or drawn from, baseline estimates of current arisings and management and so are inhibited by limitations in data quality;
- for some organic materials we found increased greenhouse gas and/or energy demand impacts associated with composting. In practice it is considered that the balance of greenhouse gas potential may swing either way. However, little data or information exists to enable us to explore this further;
- results for all biodegradable materials were found to be highly sensitive to assumptions regarding landfill gas capture; and
- the scale of avoided greenhouse gas emissions and energy demand associated with recycling of the majority of materials, but chiefly plastics,

textiles and paper/card, varies widely with assumptions regarding the routes via which they may be processed.

Combining both the scale of potential impacts/benefits quantified and the known limitations of the study, we have identified a number of key areas in which further research could aid our understanding of the greenhouse gas and energy impacts from managing waste materials:

- the development of a long term strategy to collect and collate data regarding the availability, sources and current management of materials (building on the Defra waste data strategy [(1)]);
- a more sophisticated approach to assessing the fertiliser, sequestration, and other benefits of composting activities, relative to landfill, landspread and other waste management activities;
- the development of an improved understanding of the relative importance of alternative reprocessing routes for plastics, textiles and paper and card;
- the development of more sophisticated impact factors to describe the potential benefits and avoided burdens of soil/minerals recycling;
- further consideration of the potential for capture and utilisation of landfill gas; and
- the development of a method to quantify the greenhouse gas and energy benefits of reducing and re-using waste materials. The current work did not attempt to quantify the potential for reduction and re-use. There is undoubted benefit associated with these routes and future studies would benefits from their inclusion.

(1) Defra (2006). *The Defra/WAG Waste Data Strategy for Waste Streams across the UK*. Department for Environment, Food and Rural Affairs