7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Significance of the research

- The potential contribution of HC to reducing the disposal of biodegradable waste in landfill, required by the European Landfill Directive, is recognised by the UK Government. However, the impact of HC on waste diversion rates from landfill disposal is ambiguous and this is mainly because of the practical and logistical difficulties of quantifying its contribution to biodegradable waste reduction. This research project has quantified the waste diversion rates achieved by HC and in combination with the KC of recyclables. This has been undertaken by the direct measurement of collected residual waste using an automated weighing system fitted to an RCV and by two phases of compositional analysis on the residual waste from individual households. The maximum potential waste throughput capacity of home compost bins was determined in a controlled field experiment with managed inputs and quantities of garden, paper and kitchen waste. Subsidiary experiments examined the potential gas emissions of CH_4 to the environment from home compost bins and the biodegradability of packaging materials by HC. The data reported in this study, and previously by Jasim and Smith (2004), provide a comprehensive and quantitative assessment of the role of HC in household waste management.

7.2 Automated measurement of residual household waste

- The overall mean amount of residual waste collected from the properties monitored in RBC, across all household treatment groups, was 16.3 kg/hh/wk, which is below the mean national average value of 23.1 kg/hh/wk (DEFRA, 2005). The average occupancy of the participating households was 2.5 persons/hh and the mean amount of waste generated per individual was approximately 6.5 kg/wk.

- Households that did not engage in HC or the KC scheme were allocated to the Control group and produced approximately 17 kg/wk of residual waste.

- Recycling-only households disposed of similar amounts of residual waste compared to Control properties. This may be explained because: (a) Recycling-only households did not engage in the KC scheme in practice, or (b) the spare capacity in the residual waste bin created by the separate collection of recyclables was filled with other waste materials, such as surplus bulky garden waste.

- Smaller amounts of residual waste were generated by the Composting-only properties compared to the Control and Recycling-only groups. These households produced 1 kg (5%) less waste the Control group. Assuming that homeowners disposed of all of their dry and non-biodegradable waste materials first, the observed decrease in the mass of collected residual waste may therefore reflect the direct reduction in biodegradable waste disposal and diversion from landfill due to HC.

- Households that practiced both recycling and composting produced the smallest quantities of residual waste overall. The amount of residual waste collected from the Recycling+composting households was reduced by approximately 2 kg (12 %) compared to the Control. Therefore, this group of homeowners represented the most conscientious and effective recyclers compared to the other household groups.

- On a per capita basis, individuals within the Recycling-only group generated approximately 1 kg more residual waste than the Control group. The amount of waste produced per capita in the Composting-only group was approximately equal to the Control. However, individuals in the Recycling+composting group generated

approximately 1 kg (13 %) less waste compared to the Control. This highlighted the importance of both practices in increasing waste diversion from landfill disposal.

- Promotional activities performed within the Recycling+composting group, showed that there was no difference in the amount of residual waste collected from unsupported households compared to the Control. However, the distribution of an advisory leaflet to householders significantly reduced residual waste collection by 1.5 kg (22 %) compared to the Control, but home visits made no additional contribution to waste diversion.

7.3 Waste compositional analysis

- Two phases of residual waste analysis of were completed in June and November 2004 to complement the RCV weight data and determine the impacts of HC and KC on the amounts of biodegradable and other waste disposed in the residual waste stream.

- In the summer campaign, the largest quantity of residual waste was collected from the Recycling-only households, equivalent to 16.7 kg/hh/wk. The total amount of residual waste declined for households engaged in HC and KC in the order: Recycling-only, Composting-only and Recycling+composting. Putrescible waste represented >50 % of the total weight of residual waste collected from households in the Control and Recycling-only groups, and the amounts were marginally smaller for households engaged in HC. Garden waste was the main type of biodegradable waste disposed by all groups. Contrary to what might be expected, *HC increased the amount of garden debris in the residual waste stream*. However, food waste disposal was reduced by HC by 0.6 – 1 kg/hh/wk, equivalent to a decrease of 20 – 30 %, compared to households in the Control and Recycling-only groups and this was largely responsible for the overall net reduction in biodegradable waste disposal attributable to HC.

- Paper and card was the dominant recyclable fraction present in the residual waste samples for both recycling and non-recycling groups. The comparatively small effects of KC on the overall amounts of paper and card in the residual waste may be explained because the prominent types of waste in this category, including cardboard and other types of waste paper, which represented approximately 65 % of the waste paper and card, were not accepted for KC. The results showed that there was little variation in the total amounts of paper and card contained in the residual waste samples amongst the different treatment groups. The amount of glass, metal and textiles disposed by the Recycling+composting group was reduced by: 0.7 kg/wk (78 %) less glass, 0.2 kg/wk (42 %) less metals, and 0.1 kg/wk (50 %) compared to the Recycling-only group. The patterns of disposal of waste categories not accepted by the KC scheme were broadly similar, but were also influenced by differences in the underlying demographic and socioeconomic characteristics between households in the treatment groups.

- In the autumn campaign, the Control and Recycling-only households produced the largest amounts of residual waste, equivalent to approximately 15 kg/hh/wk. Properties in the Recycling+composting group discarded the least residual waste compared to the other two groups, equivalent to approximately 11 kg/hh/wk, which represented a reduction of approximately 30 % relative to the Control. As in the summer analysis, biodegradable waste represented the largest fraction in the residual waste, equivalent to: 37.5, 48.1 and 46.5 % for the Control, Recycling-only and Recycling+composting groups, respectively. The lowest rate of biodegradable waste disposal was recorded for households engaged in both HC and KC, equivalent to 5.00 kg/hh/wk. Home composting increased the collection of garden waste by 0.7 and 0.26 kg/hh/wk, equivalent to increases of 44 and 13 % relative to households in the Control and Recycling-only groups, respectively, but reduced the disposal of food waste by 35 - 40 % from approximately 4.0 to 2.6 kg/hh/wk. Consequently, overall biodegradable waste arisings

for the Recycling+composting group were reduced by 14 % (0.8 kg/hh/wk) and 31 % (2.26 kg/hh/wk) compared to the Control and Recycling-only groups, respectively.

- The disposal of recyclable materials was reduced by 23 and 53 % for the Recycling-only and Recycling+composting groups compared to the Control. Control properties discarded 4 kg/hh/wk of paper and card in the residual waste bin and disposal of this waste fraction was reduced by 48 and 21 % for the Recycling+composting and Recycling-only households, respectively. The Recycling+composting group disposed of less glass (0.29 kg/hh/wk) and metals (0.24 kg/hh/wk) than the other two groups of households examined in the autumn waste analysis. The reduction in glass disposal by the Recycling+composting group was equivalent to 70 and 52 % and the decrease in the amount of discarded metal was 60 and 16 % compared to the Control and Recycling-only groups, respectively. Similar amounts of textile waste were disposed by the recycling groups (0.18 – 0.23 kg/hh/wk) and, on average, disposal of textiles decreased by approximately 50 % compared to the Control. Households that engaged in recycling and composting activities also generally produced smaller amounts of other waste materials that were not accepted for KC.

- In general, the results from the waste compositional analysis showed that, in the absence of other measures to remove garden waste from the residual waste stream, the principal benefit of HC in reducing biodegradable waste was the decrease in food waste disposal. Within the suburban context of RBC, for example, prohibiting garden waste in the residual waste bin, or other measures, are necessary to control and reduce the collection of garden debris in the residual waste stream.

7.4 Overall impact of home composting on the diversion of biodegradable waste from landfill disposal

- RCV data indicated HC reduced the total amount of residual waste collected by 0.8 kg/hh/wk and this was consistent with the reduction in biodegradable waste disposal recorded for households that composted their waste compared to the control. Assuming that this value, which was measured during the autumn period, is a generally representative average figure (inputs of biodegradable waste may be higher in the summer, but lower in the winter for instance), the total reduction in organic waste disposal due to HC, extrapolated to 52 weeks (1 year) was therefore approximately 42 kg/hh. However, if the increase in garden waste disposal observed for the HC group relative to the Control, equivalent to 0.71 kg/hh/wk, was not included in the residual waste (e.g. if homeowners who compost their biodegradable waste were encouraged not to dispose of additional garden waste in the residual waste bin), the potential diversion of biodegradable waste by HC would be equivalent to 1.53 kg/hh/wk, or 80 kg/hh/y. The amount of biodegradable waste disposed by the Control group in the autumn waste analysis was 5.82 kg/hh/wk (this value was consistent with the regional data for the Runnymede area), equivalent to 303 kg/hh/y. The overall reduction in biodegradable waste achieved by HC was 14 % and this would increase to 26 % if homeowners do not increase the quantity of garden waste in the residual waste bin compared to the Control.

7.5 Waste inputs and composting process monitoring

- A field experiment with controlled inputs of biodegradable wastes to home compost bins showed that substantial amounts of waste can be treated by small-scale composting systems (290 – 330 l). Where a mixture of garden, food and paper waste is supplied, total annual additions of up to 400 kg of biodegradable waste are possible. This value was consistent with the average waste inputs to home compost bins recorded by homeowners in a two year monitoring programme in RBC reported by Jasim and Smith (2003).

- The smallest waste inputs (140 kg) were recorded for compost bins receiving only garden waste because of moisture limitation of microbial activity. Food waste supplied moisture and N to support decomposition processes and enhanced the rate of degradation and, therefore, increased the overall treatment capacity and input of waste to the bins. Compost bins receiving waste additions comprising approximately 60 % of food waste had a treatment capacity of approximately 250 kg y^{-1}. Increasing the amount of food to 80 % of the total waste supplied to the bins raised the total input >380 kg y^{-1}. Paper waste inputs equivalent to 2 % of the total amount of waste supplied to the bins increased the treatment capacity to a small extent. However, further inputs of paper reduced the overall amount of waste that could be treated to the same input values of food and garden waste achieved without waste paper.

- The temperature of decomposing materials in the compost bins was monitored during the controlled HC experiment. The temperature of the decomposing waste materials varied considerably and followed the underlying seasonal ambient temperature. However, temperature conditions were consistently above ambient values due to the generation of metabolic heat from microbial activity. Thus, biological degradation processes were active throughout the monitoring period, including the winter season when ambient temperatures were low. In general, temperature values were in the mesophilic range (15-45 ^{o}C) from mid-April for all treatments with the exception of Treatment 1 (garden waste only), which reached the mesophilic range in late May. Thermophilic microbial activity occurred only on one occasion in mid-September, when temperatures in the decomposing waste exceeded 45 ^{o}C. During cold ambient conditions (February – mid-April 2005 and late November 2005 – early March 2006) the temperature of the compost bins was in the psychrophilic range (5 - 10^{o}C) or decreased below this range in all treatments. Bin temperatures rarely exceeded 15 ^{o}C during the winter period: December 2005 - February 2006. The lowest temperatures were recorded in compost bins receiving garden waste only, which may be explained by moisture limitation of microbial activity. In contrast, compost temperature rose with increasing proportion of food inputs to the bins.

- The warmest conditions were measured in recently deposited waste, associated with higher rates of microbial activity in this layer, compared to cooler temperature conditions recorded in more stabilised material at increasing depth. Temperature readings of the upper (A) and middle (B) layers of decomposing wastes were approximately similar throughout the monitoring period. Maximum temperatures were recorded in the A and B layers 4-5 days following the addition of fresh waste inputs to the bins consistent with the development of rapid microbial activity and waste biodegradation processes. The temperature of the lower C layer was not generally affected by the input of fresh waste, except when the waste mass in the bins was mixed.

- Traces of CH_4 were detected occasionally in the interstitial gas of the decomposing materials, but no CH_4 accumulated or was detected in the void space surrounding home compost bins enclosed within a gas flux chamber. This may be due to CH_4 oxidation by active populations of methanotrophic bacteria at the interface between anaerobic-aerobic zones within the decomposing organic material. Therefore, HC is unlikely to represent a significant source of CH_4 emissions to the environment.

- In general, O_2 concentrations were in the range 18 - 21 % and showed that the home compost bins were well supplied with O_2 through diffusion processes from the atmosphere and that waste biodegradation was predominantly aerobic. In most cases, the CO_2 concentration in the interstitial gas was small and in the range 0 - 4 %. As expected, high CO_2 concentrations were associated with reduced concentrations of O_2 in response to increased microbial activity. The smallest CO_2 and largest O_2 values were recorded in the bins receiving only garden waste confirming the lower rate of microbial

activity for this waste input regime, under the conditions of the experiment, compared to the other combinations of waste inputs tested. The low rate of microbial activity detected by the gas analysis was consistent with the low temperature conditions and reduced degradation of waste observed in the treatment only receiving garden waste.

7.6 Biodegradation of packaging materials

- Degradation of packaging materials by HC varied and depended on the type, composition and treatment of packaging products.

- Potato starch packaging was degraded rapidly material by HC; 91 % of the packaging was destroyed after 67 days and complete degradation occurred after 126 days.

- Cardboard packaging decomposed to varying degrees (60 – 99 %) by HC, depending on the extent of waxing and bleaching treatment. Thus, solid bleached cardboard (doughnut box) achieved the highest degradation value (99 %) followed by waxed corrugated cardboard (Pizza box), which was degraded by 77 %. Lower rates of degradation (58-59 %) were measured for heavily waxed corrugated cardboard (laundry tablets box) and solid unbleached cardboard. Bleached white line chipboard (disposable plate) was degraded by 41 % whereas white line chipboard (breakfast cereal boxes) had lower rates of decomposition of 28 - 36 %. The degradation of folding boxboard (cheese box), which is heavily waxed for moisture resistance, and non-packaging waste cardboard (typical backing board to a notepad) was also relatively limited and equivalent to 37 and 38 % of the input mass, respectively.

- PLA-based packaging was highly persistent and showed no degradation during HC for 126 days. This may be explained because the temperature conditions in home compost are too low to support the decomposition of this material. Thermophilic temperatures are necessary to support hydrolytic reactions for degradation of PLA, but these are rare in HC.

- The results presented here demonstrate the wide potential variation in degradabilities of common packaging materials used for household products and food. Waxing and coatings tend to render packaging materials less susceptible to decomposition by HC and increase degradation times. The degradation of packaging waste also depends on the composition of the material, such as the lignin content, and bleaching treatment.

- This research emphasizes the need for improved guidance and advice regarding the suitability of different packaging materials for HC.

7.6 Recommendations

- The annual contribution of HC to diversion of biodegradable waste from landfill disposal was equivalent to approximately 40 kg/hh.

- Homeowners usually have a surplus of garden waste for disposal therefore the effect of HC on diversion of this type of waste from landfill is dynamic and complex as a variety of disposal/recycling routes are available including HC, transport to CA site, residual bin.

- The results presented here show that removal of recyclable materials or food waste from the residual waste bin increases the disposal of garden waste for collection under suburban conditions. Therefore, HC and KC should be performed in conjunction with other measures to discourage homeowners from discarding of surplus garden waste into the residual waste bin.

- The net reduction in biodegradable waste collection attributable to HC is associated with the decreased disposal of food waste.

- Promoting HC by distributing an advisory leaflet to homeowners engaged in both HC and KC was effective at reducing the collection of residual waste, compared to households that were not supported, but also visiting householders had no additional benefit for waste diversion.

- Households engaged in both HC and kerbside collection of waste were the most effective group at separating recyclable materials from the residual waste stream. The results emphasise the complementary benefits of both practices at reducing residual waste disposal.

- Small-scale composting systems are very effective at processing biodegradable food, garden and paper waste and up to 400 kg/y may be treated in a standard volume HC bin (290 l) where a mixture of wastes is supplied.

- Waste biodegradation processes in small-scale HC bins were predominantly aerobic and there was no evidence for emissions of CH_4 to the environment.

- Packaging wastes degraded to a varying degree during HC. Potato starch-based packaging was rapidly decomposed, but PLA-based packaging is unsuitable for HC and did not degrade. The degradability of card-based packaging is affected by waxing and bleaching treatments. Clearer guidance on the suitability of packaging materials for HC is required.