TIM EVANS
ENVIRONMENT

7th June 2007

ENVIRONMENTAL IMPACT STUDY OF FOOD WASTE DISPOSERS

FOR

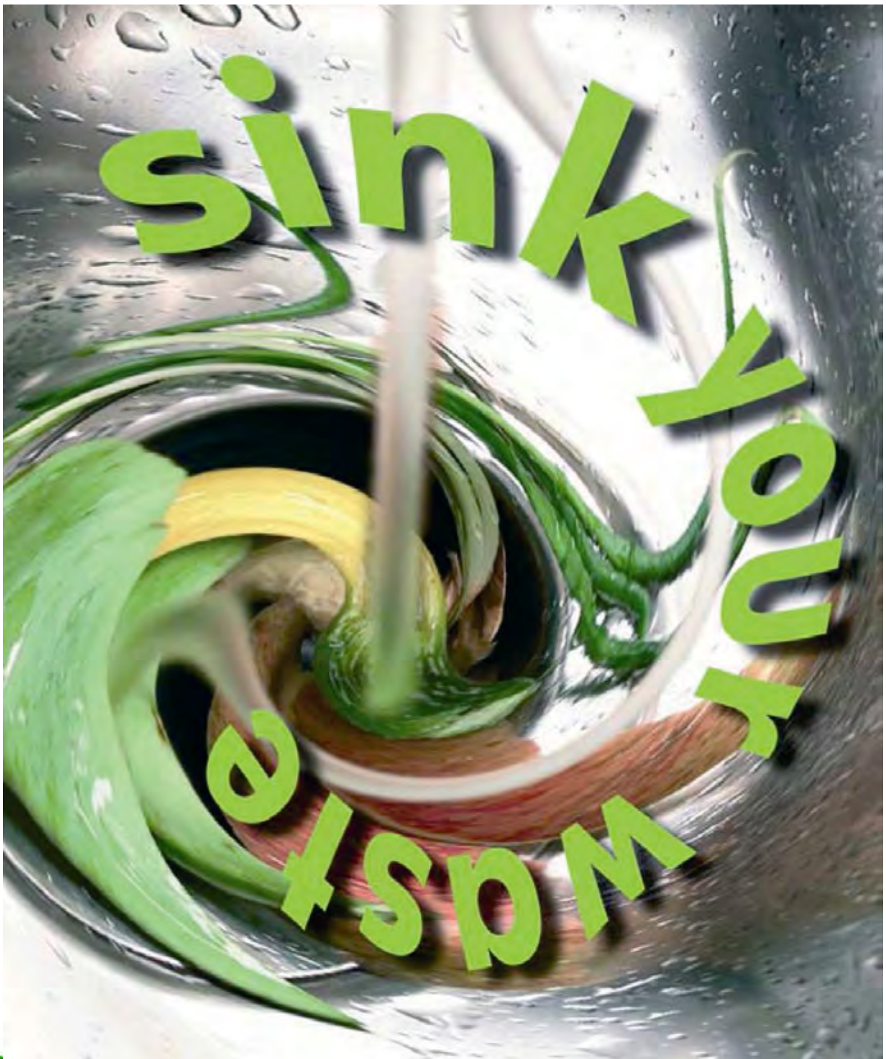
THE COUNTY SURVEYORS' SOCIETY

&

HEREFORDSHIRE COUNCIL AND WORCESTERSHIRE COUNTY COUNCIL

by

Dr Tim Evans BSc MS PhD CChem CEnv FCIWEM MRSC



HEREFORDSHIRE COUNCIL

reduce

worcestershire countycouncil

Stonecroft, Park Lane, Ashtead, KT21 1EU England.
tel/fax +44 (0) 1372 272172
email tim@timevansenvironment.com

1 Executive Summary

This study examines the financial and environmental impacts of food waste disposers (FWD) and finds that they provide a cost-effective, convenient and hygienic means of separating putrescible domestic kitchen food waste (KFW) at source and diverting it from landfill. The study also finds that this route costs less and has a smaller global warming potential than the routes comprising kerbside collection followed by centralised composting or landfill.

Home composting is ideal for garden waste because of both treating and also using the treated material where it is generated (the proximity principle). Bokashi treatment and wormeries have enthusiastic followings but users still need to have somewhere to use the treated material. Some householders are unable (e.g. apartment dwellers) or are not inclined to practise home composting.

In terms of Best Value Performance Indicators, FWD reduce BV84 (kilograms of household waste collected per head of population), BV86 (cost of household waste collection per household) and BV87 (cost of waste disposal per tonne municipal waste).

The National Audit Office concluded that England will not achieve the Landfill Directive targets without a step change in plans and that emphasising recycling alone is unlikely to be the answer. Part of the problem is lack of infrastructure for treating biodegradable municipal waste and this is linked with the delays consequent on the planning process. H&W (Herefordshire Council and Worcestershire County Council) have been pioneering in promoting installation of FWD. FWD have the benefit of separating at source a difficult fraction of biodegradable MSW (because it is wet and malodorous) and diverting it using existing infrastructure and without entailing any regulatory bureaucracy.

The net global warming potential[1] (GWP) of separate collection and treatment of KFW by composting is -14 kgCO_2e/tKFW allowing for fertiliser offset and carbon sequestration when the compost is used on land. For households with FWD feeding to wastewater treatment works where sludge is treated by anaerobic digestion, the biogas

[1] Global Warming Potential is expressed as carbon dioxide equivalent (CO_2 e) over 100 years.

is used as renewable energy and the biosolids are used on land (which is the pathway for Severn Trent Water's works in H&W and Welsh Water's works in Herefordshire) the GWP is better than -168 $kgCO_2e/tKFW$[2]. In contrast, landfill is +743 $kgCO_2e/tKFW$.

Assuming that KFW is 17.6% of household waste, the cost of collecting and disposing KFW via the solid waste route in H&W averages £18.63 per household*year and the quantity is 180 kgKFW per household*year (2005/06 actuals). This is the approximate annual saving for each installed FWD. The saving will increase, and the payback period will decrease, as the cost of treating KFW increases with ABPR compliant treatment replacing landfilling. For example, letsrecycle.com estimates the current gate fee for composting KFW at a site that complies with the Animal By-Products Regulations is £42-52 /t. By February 2007, 640 FWD had been installed under the H&W cashback scheme at a total cost of £39,650, i.e. £62 per FWD, which is a payback period [at direct cost current savings] of only 3 years and 4 months. The ground KFW is transferred to the wastewater collection and treatment system and therefore adds somewhat to the costs of the water company.

The value to H&W could be even greater when LATS (Landfill Allowance Trading Scheme) is factored into the equation. The LATS penalty is currently £150 per tonne of biodegradable municipal waste landfilled in excess of that permitted by allowances held. There could be additional penalties in the target years 2010, 2013 and 2020. The Local Government Association has warned that prices for allowances could be high from 2008/09 onwards, with a "serious deficit" of allowances potentially arising after 2009/10.

Water companies are understandably concerned about changes that might adversely affect demands on water resources or that would increase sewer blockages; field trials in several countries (none has yet been undertaken in the UK) have shown that FWD do not affect water usage or accumulation in sewers significantly. Wastewater treatment works (WwTW) are designed to treat biodegradable material suspended in water, i.e. similar to the output of FWD. Ground KFW has been found actually to improve the composition of wastewater for the advanced nutrient removal processes that are now being demanded of WwTW (this is because it has more carbon

[2] This figure is based on direct before and after measurements in a town where 30% of households had FWD installed.

in relation to nitrogen or phosphorus than normal sewage). The additional cost for water companies depends on the route for treating and using or disposing the sewage sludge; for the route most usual in H&W it would be about £0.68 per household*year, this is only 4% of the cost of the MSW-landfill route. However, the cost could be as much as £8.38 for a WwTW that incinerates its sludge and does not generate electricity (not the case in the H&W area).

Overall, food waste disposers appear to be a very cost effective means of separating putrescible kitchen waste at source and diverting it from landfill. The carbon footprint of FWD feeding to a WwTW with anaerobic digestion (AD) and electricity generation (CHP)[3] is competitive with separate collection of KFW delivering to centralised AD with CHP and significantly better than centralised composting. They are convenient and hygienic for householders but do not discourage home composting. They avoid the problems of odour and vermin that can be associated with separate collection via the solid waste route.

[3] This is the route in H&W

CONTENTS

2 Brief

To conduct desktop research into the use of food waste disposers (FWD) in Herefordshire and Worcestershire (H&W) as a means of diverting putrescible domestic kitchen waste from landfill. The study shall:

- refer to H&W's joint municipal waste strategy together with UK and European legislation to evaluate the potential impact of FWD on household waste collection and disposal in the two counties.
- assess the potential for FWD to impact relevant BVPIs.
- investigate the potential contribution of FWD towards waste minimisation targets.
- compare the notional carbon footprint of a typical household with and without FWD.
- compare the use of FWD to alternative means of disposal of putrescible domestic kitchen waste.
- prepare a report on the above for free publication.
- provide ad hoc reports on progress to the CSS Research Fund Board.
- consult with Worcestershire County Council Waste Management prior to engaging in contact with outside bodies in connection with this research.
- give prominence to European studies and refer to worldwide studies for subjects considered missing or weak in European studies. Research to refer specifically to wastewater flow and treatment facilities in the Severn Trent Water region and the Welsh Water region and also cover private domestic wastewater treatment facilities.

3 Introduction

The principles of environmental impact were summarised by Commoner (1971) in his 'Laws of Ecology':

1. Everything is Connected to Everything Else.
2. Everything Must Go Somewhere.
3. Nature Knows Best.
4. There Is No Such Thing as a Free Lunch.

Disposal of kitchen food waste (KFW) is no exception to these laws as will be discussed in this report.

3.1 Waste arisings

Parfitt (2002) analysed 70 datasets of domestic waste composition obtained in studies commissioned between 1999 and 2002 across England and Wales. He concluded that kitchen waste comprised 17% of total household waste (Figure 1); it is about 30% of the biodegradable waste. He commented that there is a degree of uncertainty because no two studies employed the same methodology but it indicates the scale of the issue.

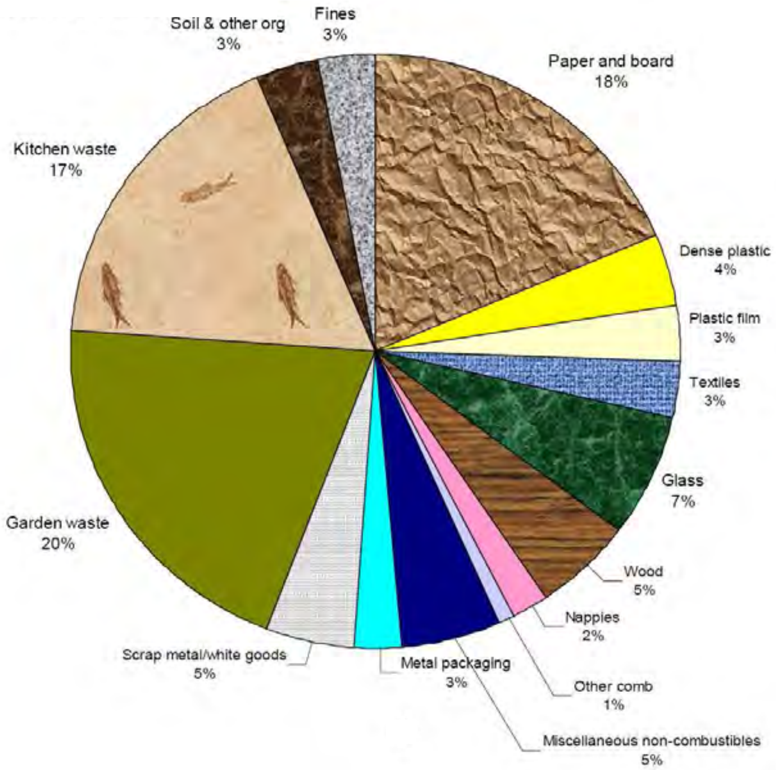


Figure 1 Total household waste composition (from Parfitt, 2002)

WRAP (2007) estimated that UK households produce around 6.7 million tonnes of food waste and it warned of the consequences saying:

> "In the UK, the vast majority of food waste ends up in landfill. As food rots in landfill it can produce methane, one of the most potent greenhouse gases and a significant contributor to climate change. When we throw food away, we also waste all the carbon generated as it was produced, processed, transported and stored. This is particularly important given that the whole food supply chain accounts for around 20% of the UK's greenhouse gas emissions. We could make carbon savings equivalent to taking an estimated 1 in 5 cars off the road if we avoided throwing away all the food that we could have eaten."

Hogg et al. (2007) estimated the proportion of food waste in UK household waste (HHW) to be 17.6% (Table 1). It appears that households in Herefordshire and Worcestershire (H&W) are less wasteful than the UK average (Appendix B); the average weight of HHW in H&W in 2005/06 was 1,023 kg/hhd*year, of which food waste would have been 180 kg/hhd*year at 17.6%.

Table 1 Estimates of food waste in household waste from Hogg et al. (2007)

	England	Wales	Scotland	N. Ireland	UK
Household waste ('000 t)	25,688	1,585	2,276	919	30,468
Food waste in HHW	17.5%	18%	18%	19%	17.6%
∴ Total food waste ('000 t)	4,495	285	410	184	5,375
Food waste 'captured'	2.00%	2.80%	1.95%	2.17%	2.04%
∴ Food waste in mixed waste ('000 t)	4,405	277	402	180	5,264
Average food waste per hhd·year					216 kg

Irrespective of the detail of precisely what is included in the statistics, the overwhelming conclusion is that the problem is large and that currently the UK does not have a significant means of capturing and diverting this biodegradable waste from landfill.

Browne (2005) (former Head of Waste and Passenger Transport Management at WCC) weighed the waste in his own house for 12 months after having had a FWD installed (Figure 2). He also measured the electricity and water use. Browne concluded from measuring his household's waste for a whole year, following installation of a FWD in September 2004, that 25% by weight of the household's waste went into the FWD. The cost of electricity to run the FWD for the whole year was less than £1 per person (it used 4.2 kWh). Browne considered that using the FWD did not change water consumption measurably. Even though 25% KFW is at the top end of the range reported by Parfitt, the electricity and water use are comparable with findings in other field studies (see later).

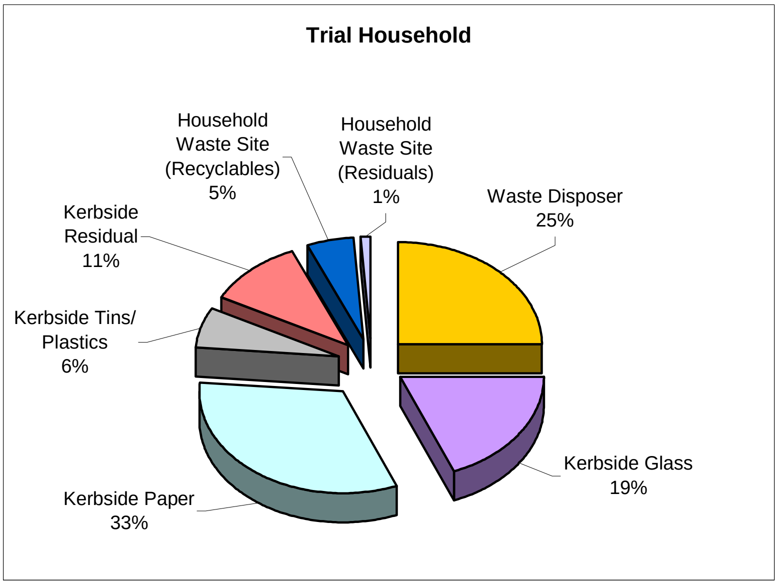


Figure 2 Twelve months' waste analysis (fresh weight) for a Worcestershire household with a FWD (Browne, 2005)

3.2 Solid waste and landfill

Member States of the European Union are obliged by the Landfill Directive (CEC, 1999) to reduce the quantity of biodegradable municipal waste going to landfills compared with the quantity produced in the reference year 1995. The directive defines municipal waste as 'waste from households as well as other waste which, because of its nature or composition, is similar to waste from household'; this definition has been interpreted differently by the different Member States (National

Audit Office, 2006). The European Union chose this strategy in order to reduce the leakage of methane-rich landfill gas rather than the strategy of setting limits on landfill gas leakage and encouraging the operation of landfills as bioreactors. Methane (CH_4) is estimated to have a global warming potential (GWP) over 100 years of 23, where carbon dioxide (CO_2) is 1 (IPCC, 2001). Reportedly, some Member States have already achieved their targets but others have a long way to go. The UK is amongst the laggards. The National Audit Office concluded “Without a step change in existing local authority plans, England will not achieve its share of the reductions in landfill the European Union requires by 2010 and 2013” and “An emphasis on increasing recycling alone is unlikely to enable the … Directive on landfill to be met.” The National Audit Office estimated that if no further action is taken by local authorities beyond that already planned the allowances for sending biodegradable municipal waste to landfill will be exceeded “by approximately 270,000 tonnes in 2010 and by approximately 1.4 million tonnes in 2013. The consequent penalties … could amount to £40 million in 2010 and £205 million in 2013.”

Member States need methods for enabling diversion of biodegradable waste from landfill that are hygienic and convenient for their citizens, have a good environmental footprint and that do not impose excessive cost. The conventional wisdom is that this can be achieved by separation at source, separate collection and centralised composting or anaerobic digestion and/or encouraging home composting and/or mixed waste collection and incineration. However it is questionable whether these necessarily meet the criteria of being considered hygienic and convenient by [some] citizens, having a good environmental footprint and not imposing excessive cost.

When one talks with operators of centralised composting or anaerobic digestion facilities in Denmark, Germany and Norway, which have more than 10 years’ experience of this practise, they complain about the amount of contrary material in the separately collected waste. Kegebein, et al. (2001) reported that in Germany communal biowaste bins generally have high contaminant fractions (plastic, glass, metal), which increases the difficulty of treatment and reuse. They also reported that only 22% of the biowaste produced in heavily populated areas is collected through separate collection, and attributed this to a lack of acceptance and high cost (approximately 100 euros/household*year). Evans et al. (2002) reported two long-established centralised treatment sites in Denmark that had stopped accepting source separated domestic and supermarket waste for composting and for anaerobic digestion because they had been unable to solve the problem of excessive physical contaminants. However, at one of these sites, a post-separation device had been developed that enabled extraction of clean 'bio-pulp' from waste with physical contaminants; the bio-pulp digested well and met the Danish quality standards.

In the face of so much negative experience from communities that are thought of in the UK as being disciplined and committed to recycling, it seems bizarre that the mantra of separate [solid] collection being the only answer to recycling of biodegradable waste is still widely preached and accepted in the UK.

Herefordshire Council and Worcestershire County Council (H&W) have been in the vanguard of exploring the potential of FWD as an alternative for people who do not wish to home compost, collect and store kitchen food waste (KFW), etc.

3.3 H&W's joint municipal waste strategy

Herefordshire's and Worcestershire's joint municipal waste strategy "Managing waste for a brighter future …" published in November 2004 (H&W, 2004) is thorough and innovative.

The concept of collecting and post-sorting dry recyclables is convenient for householders and effective for recycling/resource-recovery. A key requirement is that householders should not be inclined to 'hide' wet waste in the dry recyclable bin because this interferes with the sorting.

If there is inadequately wrapped putrescible waste in residual waste and if it is only collected on alternate weeks (AWC), the residual waste bin is likely to become malodorous, especially in hot weather. This is a risk with disposable nappies, incontinence pads, etc. but if there is unwrapped food waste, there is the added risk of rats, flies and maggots. However, Worcester City, Wyre Forest and Bromsgrove report they have not experienced this as an issue with AWC. H&W's strategy of encouraging exclusion of food waste by incentivising home composting and FWD is forward-thinking. Whilst the use of FWD is convenient and hygienic, it is not really 'retention' (as it is described in H&W, 2004) because the waste is transferred to another off-site route; an example of Commoner's 2nd and 4th laws. Severn Trent Water (who will be the recipients of most of the KFW) appear to have been willing to cooperate as part of sustainable development but when the number of installed FWD becomes significant there will be a material increase in their costs and some equable reimbursement out of the savings from not collecting [wet] KFW might be appropriate.

Experience in many countries has been reported for more than 10 years that kerbside collection of garden waste has the unintended consequence of discouraging home composting and increases the total weight of municipal waste (e.g. BioCycle magazine). Some authorities have adopted kerbside collection of garden waste as a quick win to boost the quantity composted and meet their targets [BV82a and BV82b] but from an environmental perspective it is counter-productive and it is good that H&W has been more imaginative. The innovation (H&W, 2004 section 5.3.8) of providing a greenwaste home shredding service in some areas is excellent; it facilitates and improves home composting, accords with the proximity principle and works towards Best Value Performance Indicator (BVPI) No. 84.

- BV84a kilograms of household waste collected per head of population.
- BV84b % change from the previous financial year in kilograms of household waste collected per head of population.

Separation of KFW at source and diversion via FWD does not yet count against BV82 (DCLG, 2007) which are defined as:

- BV82a(ii) Total tonnage of household waste arisings which have been sent by the Authority for recycling.

BV82b(ii) The tonnage of household waste sent by the Authority for composting or treatment by anaerobic digestion.

BV82c(ii) Tonnage of household waste arisings which have been used to recover heat, power and other energy sources.

BV82d(ii) The tonnage of household waste arisings which have been landfilled.

FWD divert biodegradable household waste from landfill and since all of the biosolids (sewage sludge) in H&W are recycled to land as biofertiliser, all of the KFW discharged to the wastewater system via FWD would be recycled and most likely would also contribute to biogas production [for renewable fuel use]. Unless a quota allowance is made for each FWD installed the amount that passes via FWDs cannot be quantified. However, the published field trial data are quite consistent and it would therefore be reasonable for Defra to assign an amount of KFW to each installed FWD in the same way that it is considering for home composting in connection with LATS (Landfill Allowance Trading Scheme). Defra (2005) says:

> "Biodegradable waste composted by householders on their domestic premises benefits WDAs, as it will not be counted in waste arisings figures. However, Defra is considering whether, if the Local Authority is actively promoting home composting, this is enough of a benefit and if there is a way of fully recognising the diversion in the mass balance calculation. WRAP are still in the process of developing such a model that will enable the calculation of the diversion of BMW through home composting."

If the case is valid for Local Authorities who promote home composting actively, it should be equally valid for those who promote FWD actively.

3.4 Food waste disposers

A FWD is an electro-mechanical device that fits in the drain line from a kitchen sink. The average cost of purchasing and installing a FWD is around £150 (In-Sink-Erator, priv. comm. 2007) and the expected life is around 12 years, thus the cost of ownership of a FWD is less than Bokashi treatment (see 3.5). A FWD is flushed with cold water and spins food waste onto an abrasive ring that reduces the waste to small sized particles (98% of particles are smaller than 2mm diameter). These fine particles join the wastewater collection and treatment system. FWD grind rather than smash so glass, stones and metal do not splinter. Thus it can be said that FWD separate kitchen food waste (KFW) at source and divert it from landfills but it does go somewhere and that somewhere is the wastewater system which is designed to convey and treat [biodegradable] material suspended in water. The cold water used for flushing coalesces fat onto the other particles and thus avoids deposition on sewer walls; also, it cools the electric motor.

Around 50% of households in the USA have FWDs; they are used with both mains drainage and septic tanks. The percentage of households with FWDs installed in Europe is much less than in the USA. In the UK, which has the greatest use, only 5% of households have a FWD. However, the situation is very different in commercial kitchens; the inclusion of a FWD is normal when a catering facility is remodelled; 40% of commercial kitchens have FWDs. They should also have, and maintain, grease traps, but sadly this is often not the case and even where there is an obligation to install a grease trap there is often no requirement to maintain them when they have been installed.

Field studies (which will be reviewed in more detail later) showed that 96% of householders trialling FWD continue to use them i.e. that the proportion that give up using them is much smaller than with home composting. The 4% who stopped using them did so because of noise, but since modern FWD are quieter, even this should not be an issue in the future. Field studies have shown that use of FWD has a negligible effect on water consumption, that the ground KFW is conveyed in sewers at normal flow velocities (i.e. well within the design criteria of sewers) and that in practice there is no increase in accumulation in sewers, that only about 3 kWh_e/household*year is used by FWD but that the food waste generates at least 33 kWh_e/household*year electricity from biogas at

wastewater treatment works (WwTW) that have anaerobic digestion, which is the most prevalent type of sludge treatment in the UK. Severn Trent Water has almost universal anaerobic digestion at its sludge treatment centres. FWD increase the amount of biosolids produced at a WwTW but the extra cost of wastewater treatment and of treating it by AD with biogas CHP and recycling the biosolids to agriculture (the most prevalent route in the UK) is less than one-tenth of the amount saved by H&W for the solid waste route.

Historically WwTW were required to remove suspended solids, biological oxygen demand (BOD) and ammonia from the water. Suspended solids are collected, together with surplus biomass from removing the BOD as sewage sludge and treated. The ammonia is converted to nitrate. Many WwTWs are now required to remove nitrogen (nitrate as well as ammonia) and phosphorus in addition to solids and BOD. The preferred treatment is ‘biological nutrient removal’ (BNR) but the wastewater at many WwTW does not have sufficient carbon to sustain the biomass needed for BNR and WwTW have to purchase additional carbon (e.g. methanol) and chemical dosing (commonly iron). FWD assist BNR by adding carbon.

Only 75% of households in the USA are on municipal sewerage; there are many septic tanks; there are also many properties on septic tanks in the H&W area. FWD installation is widespread in the USA because many years ago many municipalities saw the benefits of FWDs and mandated them in all new homes and kitchen refurbishments. Subsequent to that, homebuilders specified FWDs in more than 90% of all new build construction in the USA. Currently around 50% of US households have FWD. In the light of this extensive experience, the USA is therefore probably the best source of advice about the likely effect on septic tank sizing and emptying. The frequencies for septic tank emptying shown in Table 2 were calculated to provide a minimum of 24 hours of wastewater retention assuming 50% digestion of the retained solids and they assume year-round occupancy of the residence.

New York State (2007) describes septic tank emptying as a critical step in septic system care as it extends the life of the infiltration field. It also advises that operating a FWD is equivalent to increasing the number of occupants by one, i.e. 4 people living in a house with a 3407 litre septic tank should empty it every 2.3 years, but if they use a FWD it should be emptied every 1.7 years. KFW is more digestible than faecal waste and therefore accumulates more slowly (weight for weight) because faecal waste has already been digested.

Table 2 Septic tank emptying frequency in years (from New York State, 2007)

Septic tank size (litres)	Household size - Number of Occupants									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1893	5.8	2.6	1.5	1.0	0.7	0.4	0.3	0.2	0.1	-
2839	9.1	4.2	2.6	1.8	1.3	1.0	0.7	0.6	0.4	0.3
3407	11.0	5.2	3.3	2.3	1.7	1.3	1.0	0.8	0.7	0.5
3785	12.4	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8	0.7
4732	15.6	7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2	1.0
5678	18.9	9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5	1.3
7571	25.4	12.4	8.0	5.9	4.5	3.7	3.1	2.6	2.2	2.0
9464	30.9	15.6	10.2	7.5	5.9	4.8	4.0	3.5	3.0	2.6

3.5 Home composting, Bokashi, wormeries, etc.

Home composting, Bokashi, wormeries, green cone digesters etc. can all treat KFW at source, which is ideal provided there is somewhere to use the treated material. The principles of home composting appear simple. It is only necessary to purchase or construct a bin (or preferably three so that there is a sequence of filling, maturing, mixing and emptying) to chop the material going into the bin, ensure there is an adequate, balanced mix of nitrogenous and carbonaceous materials and that they are mixed periodically and it should work. However, questions about composting are amongst the perennials asked of gardening programmes and periodicals. The Bokashi system uses a pair of proprietary bins (costing £60) in which KFW ferments anaerobically with the aid of bran inoculated with microorganisms; the bran costs about £2.50 per month (i.e. £30 per year). It produces a leachate that can be used as plant food and a digestate that can be added to the compost heap or worked into soil. Wormeries use ‘compost worms’ to convert KFW to vermi-stabilised material that can be used as a soil improver. “Green cone” is an anaerobic digester that should be sited in a warm sunny location and on soil where the leachate will drain. Dr Julian Parfitt (WRAP, priv. comm. 2006) tried a green cone but abandoned it because of the smell adjacent to the sunny sitting area of his family garden. Whilst the emissions of composting are short-cycle CO_2, the anaerobic systems emit CH_4 and thus have an adverse carbon footprint.

These treatment-at-source systems have their enthusiastic users, but they are not for everybody. They score well on the proximity principle of treating KFW (and other biodegradable material) at source and of using the treated material at source. However many people, such as those living in apartments or with very small gardens, do not have the opportunity for treatment at source, or do not have the interest or inclination to do treatment at source. Alternatives are needed for these members of society.

3.6 Land application of sewage sludge

The use of biosolids as a nutrient-rich soil improver and biofertiliser has been practised for decades. Within the EU it is regulated by national implementations of the sludge directive (CEC, 1986). This was the first soil protection directive; the European Commission says it has been a success because there have been no adverse effects where it has been applied. Compliance with the sludge directive and nitrates directive are cross-compliance requirements of the Single Payment Scheme of the EU Common Agricultural Policy. The scientific literature on the subject is extensive with more than 50,000 publications (Evans, 2004). There is a persistent myth that sewage sludge is heavily contaminated but it is untrue. Control of inputs of pollutants has been a considerable success. Dangerous substances legislation has eliminated some substances, e.g. PCBs. Controls imposed at factories have reduced the concentrations of potentially toxic elements [heavy metals] (Figure 3).

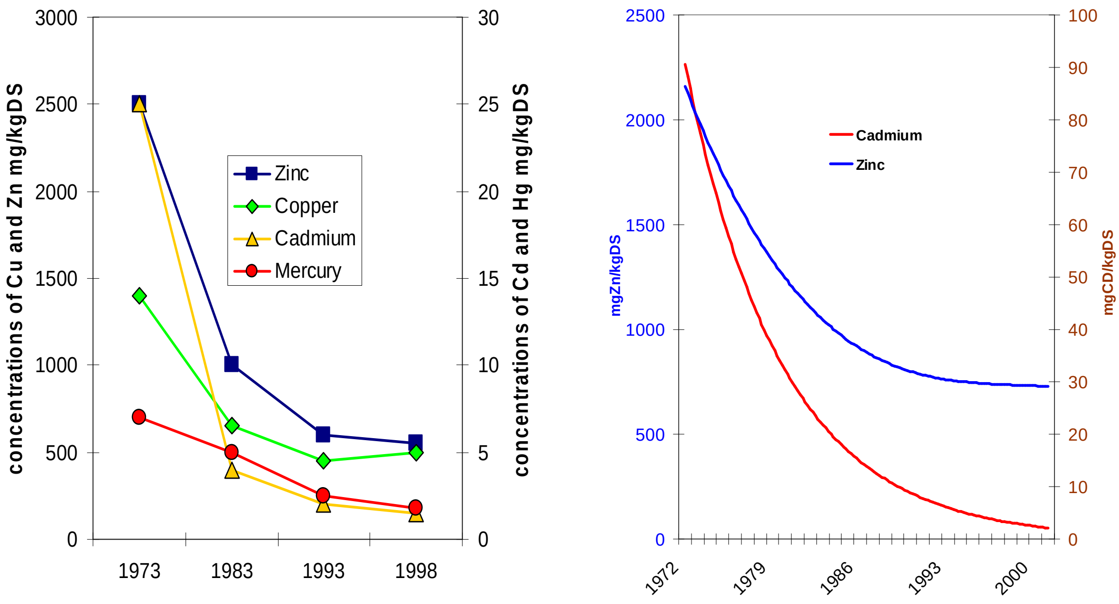


Figure 3 Changes in trace element concentrations in sewage sludge with time (Stockholm, left and West London, right)

4 Environmental Impact – Component Analysis

This section will review the information that is available about each step in the process from production of KFW to ultimate use or disposal for the two selected alternatives, i.e. separate collection as solid waste and treatment by composting or anaerobic digestion, compared with source separation by FWD and co-treatment at a WwTW with anaerobic digestion of the sludge. When considering the carbon footprint the direct CO_2 evolution from KFW [or compost or digestate] is of no consequence to global warming potential (GWP) because it is short-cycle CO_2 but escape of CH_4 from whatever source does have GWP as does CO_2 from road transport and public-supply electricity generation, etc. (Smith et al., 2001). Landfilling is included in this report as a reference i.e. the current situation.

4.1 KFW separation and storage

4.1.1 Solid waste

When KFW is separated at source and separately collected as solid waste, it must be stored on site; almost inevitably, this means a bin in the kitchen and another outside. KFW bins are generally made from petrochemical derived plastic.

KFW is about 75% moisture; in hot weather it becomes smelly quickly and it attracts flies and other vectors. Collection agencies have been advised that separate collection need not cost more than combined collection because the recyclable waste can be collected bi-weekly alternating with non-recyclable waste. This is known as AWC (alternate weekly collection). Understandably, people have objected to AWC of KFW in hot weather because of odour and flies. Some municipalities in southern Europe have found it necessary to collect KFW very frequently (even daily) in the heat of summer to avoid odour. Bags of KFW left out for collection (especially by weekend and other visiting householders) are likely to be opened by foxes, gulls and other scavengers, which creates a mess, odour, etc. Matheson (2005) reported that the main motivation for residents in tower blocks to participate in community composting was their desire to get rid of rats around the communal Paladin food waste collection bins.

The National Pest Technicians Association reported that rat infestations have increased by 39% from 1998-99 to 2004-05 (NPTA, 2007). They attributed this increase to a variety of causes but prominent amongst these was the increased access to food as a result of inappropriate [as NPTA regarded it] recycling of KFW which NPTA considered provided a source of food for rodents and flies. NPTA advised that containers provided to householders should be large enough and properly secure so that the waste is contained safely. NPTA recommended special collection facilities should be made available, particularly in hot summer months, and segregated organic household waste should be stored in such a way as to prevent fly infestation. Provisions should be made to guard against other pest infestations such as rats, mice and urban foxes. NPTA advised alternate weekly collection (AWC) should only be where wheeled bins are provided and cited World Health Organisation advice that AWC is questionable for KFW in hot weather.

Odour development is also an indication of oxygen depletion in the waste and conditions that would favour *Clostridium botulinum*. Böhnel et al. (2002) have reported an increase in botulism in Germany, which they link to separate collection, storage and treatment of biowaste; they report that greenwaste is much less of a risk. They have also found that the conditions favouring botulinum neurotoxin production favour the larvae of flies (*Calliphoridae*) and postulate they could be vectors.

Wouters et al. (2002) reported that keeping separated food waste in kitchens increases bioaerosols and allergens compared with mixed waste that contains food waste; they concluded this is a respiratory risk to susceptible individuals. It appears that an unintended consequence of obliging people to store food waste might not only be causing them nuisance [odour and vermin] but might additionally be exposing them to health risks.

4.1.2 FWD

Using FWD eliminates the need for storing KFW in the home or outside in individual or communal collection bins and would thus satisfy the main concern of

Matheson's tower block residents. The KFW is disposed to the FWD as soon as it is produced. It eliminates the resources and energy embedded in collection bins. FWDs themselves are constructed of steel and copper [mainly] so their constituent materials are 92.5% recyclable (steel 50%; stainless 9%; iron 20%; copper 8.5%; aluminium 5.0%).

4.2 KFW conveyance

4.2.1 Solid waste

Via the solid waste route KFW is transported in refuse lorries with all of the emissions, road wear and accident risk associated with road haulage vehicles. A large proportion of kerbside collected waste is delivered to a Refuse Transfer Station (RTS) from where it is transported to a centralised composting or anaerobic digestion (AD) site by a large refuse transport vehicle (RTV). A smaller proportion will be transported to the composting site by the Refuse Collection Vehicle (RCV). According to Smith et al. (2001), the average emissions of an RCV and a RTV are 0.84 and 0.71 kg CO_2 /km and their payloads are 6.67 and 20 t respectively. Neither vehicle runs full all of the time. The RCV travels to its collection round empty, and is not full until the end of the round when it travels to the RTS or composting site, thus its effective load averages approximately 50% of its payload, which is the same as the RTV, which returns from the treatment or disposal site empty. The specific emissions are thus 0.25 kg CO_2 /km*t waste and 0.071 kg CO_2 /km*t waste respectively. In comparison Smith et al. reported the average emission of a medium sized petrol powered car is 0.21 kg CO_2 /km and the payload 0.01 t, which equates to the specific emission for a private car delivering waste to a civic amenity site and returning empty being about 42 kg CO_2 /km*t waste. Even if the payload is 100 kg, rather than 10 kg, the specific emission is 4 kg CO_2 /km*t waste.

It is arguable whether separate collection affects 'garbage miles'. If the weight of waste on each collection round divides equally between the collections, i.e. if a weekly mixed collection goes to AWC of separated fractions and if each is 50% of the combined weight, the 'garbage miles' will be unchanged. However, a KFW collection would be a third collection (dry recyclables, KFW/putrescible and residual) and if unacceptable odour is to be avoided it would have to be weekly in hot weather at least. The analyses of Parfitt (2002) and Hogg et al. (2007) agree that KFW is around 17% of the total weight of household waste (HHW). In H&W, 12.6% of HHW is taken to household waste sites [civic amenity sites]. It therefore appears inevitable that separate collection does increase garbage miles and 10 kg CO_2e / t KFW has been allowed (Table 3) for separate collection of KFW.

4.2.2 FWD

When KFW is eliminated via a FWD it is ground using electricity and then transferred to the sewerage system as a suspension in water. In this section each of these elements will be assessed.

4.2.2.1 Water use

Each time they are used, FWD are flushed with cold water, this cools the motor and conveys the food waste out of the grinding chamber. Water resources in south east England, which has the highest population in the UK and has low rainfall, are already under pressure, however the Chartered Institution of Water and Environmental Management has concluded (CIWEM, 2003) "The change in water usage associated with operation of FWD has been measured to be trivial or not significant."

A detailed stratified survey in the USA (Ketzenberger, 1995) reported that FWD were used for about 15 seconds per start irrespective of the number of people in the household; subjectively this seems sensible (because FWD use is linked to food preparation events) and accounts for the range of reported water-use when expressed as litres per capita. A study in Sweden fitted FWDs in a community of 100 apartments (155 adults and 56 children); the duration of use per start was 38 seconds (Nilsson et al. 1990). The per capita water use was 13 L/day less during the 11 months after the FWDs had been installed than the 6 months prior to installation. Another Swedish study (Kalberg et al., 1999) and one from Canada (Jones, 1990) were unable to detect any greater per-capita volume of water used where FWD had been installed. Both Swedish studies found that water use actually decreased during the period when FWD were used but they concluded it would not be appropriate to attribute this directly to the fact that FWD had been installed. The Canadian study concluded the influence on water use was not significant within the overall “noise” in measured water use. Whilst this inability to measure an increase in water use when FWDs are installed seems counter intuitive initially, it is perhaps understandable when one thinks about the routine of food preparation, etc. After using the sink it is normal to wash it down to clean it, if there were a FWD this would also flush the FWD.

The studies that have been able to measure water use associated with FWD operation found data ranged from 0.29 L/person*day (large families) to 6.4 L/person*day. The extremes of the range are probably anomalous. There has only been one study of water use in the UK that has included FWD, however the methodology used was fundamentally flawed. Even when the paper was presented, the statistical analysis used was criticised as having been demonstrated to be inappropriate for this type of work (Thackray et al., 1978).

The study by the New York City Department of Environmental Protection (NYDEP, 1999), which was undertaken to inform its decision whether to change the regulations regarding FWD installation, is probably the largest field study ever undertaken. It involved 514 apartments with FWD compared with 535 apartments without FWD; they were divided into 4 localities to reflect some of the city’s diversity. The survey comprised 2014 people in total, i.e. 1.92 people per apartment. The report concluded the average water use attributable to FWD was 3.6 L/person*day. If uses/day averaged 2.2 as in Ketzenberger’s study, this would equate to 3.1 L/use, i.e. the same as Ketzenberger. The overall result of the NYDEP study was that the 18-year restriction on FWD installation in New York City was removed.

4.2.2.2 Electricity

Domestic FWDs typically have a 350 to 500 W motor (0.5 to 0.75 horsepower), if usage averages 2.4 times per day for 16 seconds per use the annual electricity consumption is about 2 to 3 kWh/household*year. Surveys have found that usage (starts/day) is largely independent of the number of people in a household because it is determined by food preparation events.

The EU-average electricity generation emission factor (cited by Smith et al., 2001) is 0.45 kg CO_2e /kWh (range coal = 0.95 to wind = 0.009 kg CO_2e /kWh)[4]. Thus the annual GWP of the electricity used by a FWD is around 1 kg CO_2e /household. If the average KFW per household is 180 kg/year (Appendix B), this equates to approximately 6 kg CO_2e /t KFW.

4.2.2.3 Sewers

Sewer systems are designed to remove wastewater to prevent urban flooding and disease; the pipe diameters and gradients are designed such that the flow velocity keeps the typically encountered solids in suspension. During periods when the flow velocity is low, solids might settle but they should be re-suspended when velocities increase. Design standards for “self-cleansing velocity” range from 0.48 m/s to 0.9 m/s (Ashley et al., 2004). An obvious concern is that use of FWD might result in sediment build-up in sewers. The field studies already cited in this paper have checked the effect of FWDs on the conditions in sewers and found no significant accumulations. The times of day when FWDs are used corresponds with times of high flow (Nilsson et al., 1990). In an experimental rig using different types of KFW, sediment-free transport of the output from FWD was observed at 0.1 m/s, i.e. well within the normal design standards (Kegebein et al., 2001). 40-50% of the output was <0.5 mm and 98% was <2 mm by sieve analysis. All of the output passed a 5 mm sieve. The largest particles were fragments of lettuce leaves. Depending on the type of KFW, between 15 and 36% of the output of the FWD was dissolved. The output of the FWD was very finely divided and very biodegradable.

FOG (fat, oil and grease) is a significant problem in sewerage operations, it can reduce the capacity of sewers and even block them; FOG can also accumulate inside the cooling jackets of pumps and cause them to overheat if it is not removed. It appears that FOG undergoes chemical transformations (possibly involving proteins)

[4] CO_2 e = carbon dioxide equivalent according to the Global Warming Potential (GWP) over 100 years.

that increase its hardness. Field studies have found that domestic FWDs do not increase FOG; it is supposed that the constituents of FOG coalesce onto food waste particles in the cold water flush and that they are therefore not "free" to attach/solidify onto sewer surfaces. De Koning (1996) concluded that even in Holland where the gradients of sewers are shallower than elsewhere (and as a consequence sedimentation would be more likely) ground KFW from FWD would not result in sewer obstructions from sedimentation or FOG deposition. WRc in the UK is undertaking (2005-2009) a major collaborative research project into FOG through the sewers and WwTWs (http://www.wrcplc.co.uk/default.aspx?item=316). Most of the UK water companies are subscribing to the project as well as interests in Ireland and possibly the USA. The project includes social science into how people use sewers and how to influence their behaviour. It is important that people do not put FOG down the drain so one objective of the project is to identify how to encourage this good behaviour.

An important question is whether putting more food into the sewers will increase the number of rats. NPTA (2007) is critical of the sewerage operators but as discussed below, the outputs of FWD are not pertinent to the criticism. A spokesperson for the British Pest Control Association [Adrian Meyer, Rodent Control Consultant, priv. comm. 2005] advised that installing FWDs would probably be detrimental to rats and certainly not advantageous because finely ground food waste would be less attractive to sewer rats than un-ground waste. Apparently, nobody really knows how rats find their food in sewers, which are dark, but rats have been seen scooping grains etc. out of the flow. There is invariably identifiable food such as sweet corn grains in the grit and screenings skips at WwTWs; these would have been large enough to be identifiable by rats. However, if they had been through a FWD they would have been liquidised and hence not identifiable by rats; food residues <2mm would be non-identifiable by rats. Alternatively, rats might not feed in sewers at all but merely use them as refuges and feed on the surface from waste bins, etc.

4.3 KFW treatment

Separating KFW makes it easier to sort, recover and recycle other fractions of municipal solid waste (MSW) because KFW is wet and therefore contaminates recyclable materials rendering them more difficult and more costly (or impossible) to sort and/or recycle.

4.3.1 Solid waste

The alternative treatments for KFW via the MSW route are landfill, incineration, composting and anaerobic digestion. Landfill will not be discussed because it must be phased out to comply with the Landfill Directive. Autoclave treatment will not be discussed either because it is probably much less suitable for separated KFW than AD because of odour and loss of revenue from biogas; however this should not be taken as questioning the potential for autoclave treatment with residual waste from which dry recyclables and KFW have been removed.

Incineration (Energy from Waste, EfW) is attractive because of its practicability. It is not subject to the problems of physical contaminants that are significant for the other routes. The cities of Aarhus in Denmark and Rotterdam in the Netherlands both decided in 2006 to stop composting of separately collected KFW and supermarket waste because of physical contaminants and to incinerate the wastes instead. Whilst Danish and Dutch citizens accept incineration and appear satisfied that emissions are controlled adequately, this is not the case in the UK where a significant proportion of the public is opposed to incineration. On 9th January 2007 Hull City Council and the East Riding of Yorkshire Council announced that approval had been given for an EfW plant costing £30 million to burn 240,000 tonnes of rubbish every year to generate electricity and heat, however this was after a long planning battle and the opposition groups have said they will continue to protest.

Severn Trent Water has two incinerators near Birmingham burning digested sludge, one at Coleshill and the other at Roundhill. The moisture content of KFW is similar to dewatered digested sludge and it might be possible to co-incinerate them if

Severn Trent Water was interested and if the incinerators had spare capacity, if the EA would grant the necessary variation to the licences and if Ofwat would agree acceptable financial terms. Using an existing incinerator would have the obvious advantage of avoiding some of the planning hurdles but public acceptance would still need to be handled carefully and proactively before malicious misinformation became established. However, it is an expensive option both in terms of transport distances to the incinerators and the cost of operating waste incinerators and their emission controls; the value of electricity and heat from burning KFW are relatively trivial. Smith et al. (2001) found incineration was one of the more expensive options for whole MSW; the putrescible fraction has the lowest net calorific value of any of the combustible fractions[5] confirming that income offset would be negligible. Yorkshire Water Services, which operates four sludge incinerators, estimates the cost of sludge incineration at £160/tDS (priv. comm. 2006). The incineration option will not be considered further in this report.

The status of KFW in the solid waste route is Animal By-Products Regulations Category III (catering waste) unless it can be proved not to have come in contact with meat. In the solid waste scenario, this would be difficult to assure. Thus, KFW must be treated in an ABPR compliant system licensed by the State Veterinary Service as well as the Environment Agency.

4.3.1.1 Composting

The energy consumption of in-vessel composting (not necessarily ABPR) has been estimated to be 40 kWh electricity per tonne of waste, i.e. 18 kg CO_2e/tonne at the EU-average power emission factor. This is the average of the 16 plants surveyed by Wannholt (1998) (cited by Smith et al., 2001). It includes the use of gas cleaning systems to remove odour emissions as well as the electricity used for blowing air to aerate the piles and maintain correct temperature and humidity. The additional requirements of ABPR would probably result in somewhat greater energy use because ABPR defines shredding and two stages of treatment to prevent by-pass. Apparently

[5] Net calorific values of plastics, textiles, paper/card and putrescibles, are 31.5, 14.6, 11.5 and 3.98 MJ/t respectively (Smith et al., 2001) for comparison coal that has a CV of 24,000MJ/t

Wannholt reported that the yield of compost was 47% of the weight received and that only 6% of the weight of the waste received was rejected [contaminants] and diverted to landfill or incineration. This is a very low reject rate, Smith et al. proposed 40% yield and 10% reject as a more realistic performance to expect.

There are undoubtedly anaerobic microzones in composting material where the oxygen supply is inadequate to satisfy the oxygen drawdown of the microorganisms. Methane is produced in these microzones but the consensus is that, except in the worst cases, the methane is oxidised to carbon dioxide in the surface layers of the composting material or in the biofilter and that methane emission from composting material can be neglected as not significant for practical purposes.

The question of occupational health issues related to composting has been debated for several years. Bünger et al. (2007) reported significant impairment of lung function etc. of compost workers, compared with office workers; they attributed this to exposure to dust and bioaerosols containing pathogens, glucans and allergens. This reinforces the advice to monitor workers subject to such occupational exposure for the sake of their own health and to protect employers from possible claims for industrial injury.

4.3.1.2 Anaerobic digestion

Anaerobic digestion (AD) has several practical and revenue advantages for separately collected food waste:

a) whereas composting converts biodegradable carbon to CO_2 which does not have GWP because it is short cycle, AD converts it to biogas which is about 65% CH_4 and 34% CO_2 with traces of other gases; the CH_4 is contained and can be used as renewable energy, i.e. it has a negative GWP contribution (because of offsetting fossil fuel) and a significant income generation potential from sales of electricity and Renewables Obligation Certificates (ROCs).

Figure 4 Co-digestion facility for food, manure and other wastes in Denmark – biogas holder left; two digesters right with the two 70 °C sanitisation towers in their shadow.

b) Operational experience has shown in Denmark (Evans et al. 2002) and Germany (Hese Umwelt priv. comm. 2006) that it is more practicable to extract the physical contaminants (which have proved inevitable in separately collected food waste) prior to AD than it is with composting. The answer to this issue is a high-pressure screen like that shown in Figure 5.

c) If regulatory issues (Ofwat and EA) can be overcome, and with Severn Trent's cooperation it would be possible to use the AD infrastructure that already exists at their larger WwTWs, which would obviate many of the planning issues of developing a treatment site *de novo*. The factors that might make this interesting to Severn Trent could be financial (Ofwat permitting) and transforming the sludge to "enhanced treated" status plus better dewatering.

Mesophilic anaerobic digestion (MAD) at 33 to 40 °C is a stable and reliable process. The methane-rich biogas can be used as renewable energy. AD and CHP have been used in the UK for sewage sludge for more than 70 years. Performance is described in terms of VS destruction; VS is 'volatile solids' actually 'loss on ignition', i.e. it is equivalent to organic matter. Typically fully mixed MAD achieves 40% VS destruction, this can be increased to 60% by pretreating the feed using thermal hydrolysis (TH). The yield of biogas depends on the makeup of the material being digested, e.g. fat has a very high gas yield. The yield for sewage sludge is typically about 1.3 m^3/kg VS destroyed. Half the additional gas from TH is used in the steam

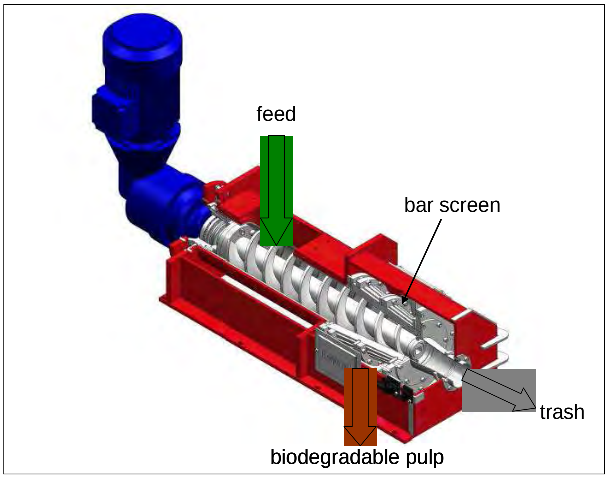


Figure 5 Dewaster® for separating bio-pulp from physical contaminants prior to digestion

boiler to drive the process; the other half is available for CHP. TH pressure cooks the feed at 160 °C for 30 minutes, which increases the digestibility of the organic matter, sterilises the feed and reduces its viscosity to such an extent that the solids loading can be trebled and the digesters continue to be fully mixed, i.e. the capacity of existing digesters could be trebled by retrofitting TH (Evans, 2003). TH exceeds the time-temperature requirements for ABPR. The digestate from TH + MAD dewaters much better than from other MAD configurations; e.g. using a conventional belt filter press the cake dry solids increases from about 22%DS to 34%DS. The combined effect of increasing VS destruction and increasing cake %DS is that the mass of cake is halved.

Smith et al. (2001) included AD of separately collected organic fraction of MSW (OFMSW) but they assumed that the digestate has to be composted before it can be used on land. It is unnecessary and counter-productive to compost digestate from an ABPR AD plant because the readily degradable carbon has already been stabilised and there is therefore no necessity to use more energy to create short cycle CO_2 when this carbon would be better feeding soil biomass as soil improver. ABPR requires that feed containing Category III material is pre-sanitised (at 70 °C for 1 hour) prior to AD, thus post-composting would have no additional hygienic value. Thirdly post-composting volatilises ammonia, which is a waste of valuable fertiliser-replacement nitrogen.

A calculation for this study of the biogas yield, electricity generation potential, revenue from electricity inclusive of Renewables Obligation Certificates (ROCs) and the GWP offset is shown in Appendix C for MAD preceded by ABPR-compliant 'pasteurisation' or TH. The GWP offset at the EU-average electricity generation emission factor (cited by Smith et al., 2001) which is 0.45 kg CO_2e /kWh would be -131.9 and -183.2 kg CO_2e /t feed respectively (Appendix C).

4.3.1.3 Landfilling

As a generalisation in this report, the collection of KFW and its delivery to landfill has been assumed to be the same as that for composting or AD. The landfill site has been assumed to be modern and constructed and managed to best practice standards with efficient landfill gas collection and use of that landfill gas for electricity generation. When biodegradable (putrescible) waste is placed in a landfill, the first stage of degradation is aerobic; this releases short cycle CO_2 that has no GWP. Degradation switches to anaerobic when the available oxygen has been used; initially the pH decreases because of VFA (volatile fatty acid) production, this mobilises metals, pH later increases as methanogens develop and convert the VFAs to landfill gas. Metals are re-precipitated as the pH increases. Even the best techniques of landfill construction and landfill gas pumping result in some landfill gas leakage, and since this is 40-65% CH_4 by volume the GWP is very significant. On the positive side, landfills sequester significant amounts of carbon. Smith et al. (2001) estimated that electricity generation from putrescible waste has a GWP of -32 kgCO_2e/t KFW, short-cycle carbon sequestration contributes -272 kgCO_2e/t KFW, but fuel use within the landfilling operations is +8 kgCO_2e/t KFW and methane from leaking landfill gas contributes +1025 kgCO_2e/t KFW resulting in an overall GWP for 'treatment' of +729 kgCO_2e/t KFW. When 14 kgCO_2e/t KFW is added for 'conveyance' (i.e. collection in mixed waste through to delivery to the landfill) the total for the route is +743 kgCO_2e/t KFW.

4.3.2 FWD

KFW is discharged to the sewer even without a FWD in the form of dishwasher output, washing up, sink cleaning after meal preparation, etc. The treatment requirements for wastewater and the rules for use of biosolids on land mean that equivalence to ABPR Category III risk management is achieved (Defra priv. comm.).

Kegebein et al. (2001) estimated that where the wastewater treatment works (WwTW) receiving the KFW treated its sludge by AD, the biogas from KFW would amount to approximately 300 MJ/resident*year, which they said corresponds to a heating value of 8 litres of diesel fuel or 183 kWh/household*year (2.2 people per household). At 40% electricity generation efficiency, this is 73 kWh_e/household*year electricity generation, which at the EU average for electricity generation is a GWP of -33 $kgCO_2e$/household*year (i.e. a saving). If the average KFW content of household waste is 17.6% (Hogg et al., 2007), the average quantity for H&W is 180 kg KFW/household*year (Appendix B). Thus, the GWP according to the work of Kegebein et al. is -183 $kgCO_2e$/t KFW. This is probably an overestimate because no allowance was made for biodegradation in the sewer and in wastewater treatment but it is a similar order of magnitude to the figure for KFW transported directly to co-digestion (Appendix C). More than 50% of UK sewage sludge is treated by AD (Gendebien et al., 1999) and the proportion treated, and the efficiency of biogas production, are both increasing as more water companies seek to gain from the income potential of renewable energy. Most of Severn Trent Water's sludge treatment centres use AD and so does Hereford WwTW.

As discussed in section 4.2.2 it has proved difficult to measure the impact of FWDs on most of the parameters measurable at a WwTW because of the variations that occur naturally and because there have been few cases where the number of FWD installed has been a sufficiently large proportion of the contributing properties. A notable exception has been the town of Surahammar in Sweden (Kalberg and Norin, 1999). After an initial pilot investigation, Surahammar decided to offer FWD to householders as an alternative to a new refuse collection charge for separate collection. Between May 1997 and October 1998, 1100 of the 3700 households had a FWD installed. No significant difference was found at the WwTW in grit, BOD, COD, N or P or in the quantity of chemical used for P-removal. Kalberg and Norin suggested that changes in these parameters were not visible because of the variation that happens because of weather, etc. However, there was a significant change in three parameters. The average weight collected on the 3 mm inlet screens increased from 26 kg/day (average for 1996-97) to 46 kg/day for the period March to December 1998. 3 mm screens are very fine by UK standards; in the UK, 6 mm screens are considered to be the normal fine screens. The amount retained on the 3 mm screens was reduced if the screens were cleaned more frequently (i.e. solids were <3 mm but were retained on other debris). The ratio of BOD_7:N increased from approx. 3.7 before May 1997 to 4.5-4.6 mg/L after October 1998, this was greater than the value of 4.2 mg/L that the authors predicted by theory; they speculated the reason for the difference, if it is real, could be the result of denitrification in the sewers. KFW is more carbonaceous than toilet waste. Increasing BOD_7:N is desirable for biological nutrient removal (BNR). There was also a significant increase in daily biogas production [averaged over the 4 months September to December] from about 340 m^3/d to about 420 m^3/d (Figure 6). Biogas production could be considered to be a value that integrates the impact of FWD inputs over time (see also Appendix D).

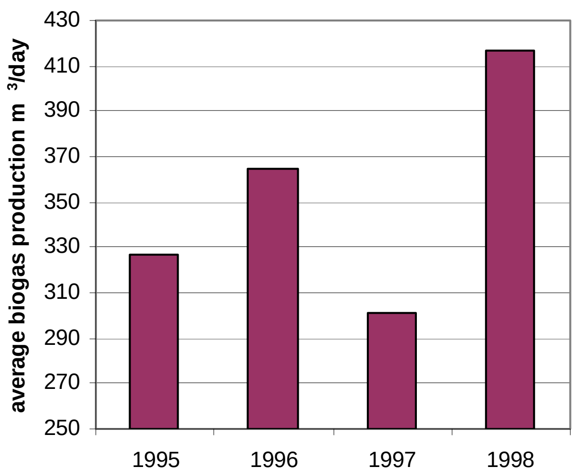


Figure 6 Daily biogas yield averaged for September to December each year (Kalberg and Norin, 1999)

Formerly WwTWs were required to remove suspended solids, BOD and ammonia, now many are required to remove nitrogen and phosphorus as well. The sewage at many WwTWs has insufficient carbon for denitrification and biological phosphorus removal and they therefore have to use supplementary carbon, such as methanol, to feed their BNR. KFW could be a useful input of much-needed carbon if there were sufficient FWDs.

4.4 Use or disposal of treated KFW

Using treated KFW on land as nutrient-rich soil improver completes nutrient cycles and conserves organic matter irrespective of whether it is done via the solid waste route or via FWD and biosolids recycling. The organic matter in treated KFW feeds soils; it increases soil microbial biomass and it improves soil structure. Soils with better soil structure allow more rainwater infiltration, which reduces run-off, they have better reserves of plant-available water in dry periods and they are more resistant to erosion. Furthermore, there is a positive relationship between the amount of soil organic matter and the efficiency of fertiliser use and resilience of plants to soil-borne plant pathogens.

4.4.1 Solid waste

4.4.1.1 Compost

Compost can be used as a soil improver for horticulture, agriculture or land reclamation. There has been considerable interest in using compost as an alternative to peat in growing media; whilst this is technically feasible (Evans and Rainbow, 1998) the pursuit of it has been something of a distraction. Growing media have demanding technical requirements, which are difficult to match with composted greenwaste, let alone KFW, because the pH and nutrient content are high. Peat has very good horticultural properties and its cost as a raw material entering a growing medium factory is only £5-8 per m^3. Composted KFW has an advantage of proximity to domestic customers but the established growing media producers have the advantages of economy of scale, automation and brand recognition. KFW also comes with the problem of physical contaminants, which are really not tolerated by domestic customers. Using composted KFW as bulk soil improver for 'professional' [commercial] users is much less difficult.

Smith et al. (2001) estimated that allowing for the decay of compost added to soil over 100 years (which is the conventional time scale for GWP calculation) the use of compost on land would sequester the equivalent of 22 kg short-cycle CO_2 /t KFW treated by composting. Smith et al. also estimated 36 kg CO_2e avoided /t waste for the fertiliser replacement value of the compost; they have somewhat overestimated nitrogen value for H&W conditions because they have used data from pot experiments and southern European field trials. In pot experiments, the density of rooting is much greater than in the open ground, and the temperature in the pot is also greater than open-ground soil temperatures; these factors result in greater extraction of nutrients and greater rates of mineralisation of organic nitrogen than in open soil. The amount of nitrogen available to plants from an organic source depends on microbial mineralisation from organic-N via ammonium-N to nitrate-N. Mineralisation is temperature dependent. Field experiments in Costa Blanca, Spain found 40-60% availability of organic-N where the comparable figure in UK was 20%.

4.4.1.2 Digestate

It is easier to produce digestate that is free of physical contaminants than compost, especially when something like Dewaster® is used (4.3.1.2). Using digestate on land has the same benefits as using compost and conserves more of the nitrogen fertiliser value. Dewatered digestate is somewhat sticky and therefore not as well suited to manual application as compost, which is friable and easily spread with hand tools. However, there is no difficulty in spreading dewatered digestate on a commercial scale using manure spreader type machines.

The benefits of carbon sequestration and fertiliser replacement are similar to those discussed for compost and within the approximations of this report it is appropriate to use the same 22 kg short-cycle CO_2 sequestered /t waste and 36 kg CO_2e GWP avoided /t waste for the fertiliser replacement value. The latter is an underestimate because AD conserves nitrogen from the feedstock whereas composting volatilises it as ammonia gas. Thus, digestate contains more nitrogen than compost and the proportion of nitrogen that is plant-available is greater in digestate than it is in compost.

4.4.2 FWD

KFW separated at source and despatched from the premises via a FWD is conveyed by the sewers to a WwTW where the solubilised fraction is treated as wastewater and the settleable solids become part of the sludge. In the case of Severn Trent Water, sludge is anaerobically digested and the digestate is recycled to farmland as with the MSW-AD routes (section 4.4.1.2). The amount of digestate is less than the MSW-AD route because some is biodegraded in the water phase; however, similar assumptions can be made.

4.5 Summation of component analysis

The principal components of GWP that have been discussed in this report are summarised in Table 3. The assumptions and approximations have been discussed in the appropriate sections, including the appendices. Some elements have not been quantified because they are too uncertain, such as the GWP of the wheeled bins and disposal of the rejects from the centralised treatment site. Rejects from FWD will go to the residual waste; rejects from MSW composting and AD will also go to residual waste but at a later point of entry to the route. The GWP associated with the additional biogas yield at a WwTW with AD has been derived from two sources; it is encouraging that they are in good agreement. A further apparent omission from Table 3 is the GWP associated with wastewater treatment but this has been shown (Monteith et al. 2005) to be trivial in the context of this study because emissions are mostly short-cycle CO_2 in well-managed plants.

Table 3 Summary of the main GWP contributions (kg CO_2e / t KFW)

	MSW route					FWD route	
	compost	70℃+AD	TH+AD	landfill	incineration	Kegebein	Surahammar
separation and storage	bins, odours, vermin, health					0	0
conveyance (from hhd to treatment)	14.3	14.3	14.3	14.3	14.3	6.2	6.2
RCV separate collection (extra distance)	10	10	10	0	0	0	0
treatment (incl. electricity generated)	18	-132	-183	-24	-2	-183	-119
C-sequestration	-22	-22	-22	-272	0	-22	-22
landfill gas leakage	0	0	0	1025	0	0	0
fertiliser offset	-36	-36	-36	0	0	-36	-36
delivery (from trt 60km round trip in RTV)	1.70	3.83	1.84	0	0.30	2.84	2.84
Total	-14	-162	-215	743	13	-232	-168

Table 3 shows that all routes have less GWP than landfill. In terms of the options for source separated KFW, (co)incineration has the worst carbon footprint because of the low net calorific value and the large volume of flue gas associated with KFW. Composting is intermediate but the routes where the KFW is delivered to anaerobic digestion with CHP (via FWD or directly by road) have the best carbon footprint. In the H&W area, sewage sludge is treated at sludge treatment centres and WwTW that have AD. The value would be even greater if all of the hot water [from cooling the engines and recoverable from the hot exhaust gases] could be used. For example, Worcester WwTW is sited next door to a public swimming pool that can use the heat from hot water effectively. In Denmark where district heating infrastructure has been in place for many years, the hot water can be used for heating buildings. Sadly, it is not often the case in the UK at present that the full value of this heat can be used.

5 Cost comparison of FWD and MSW routes

Waste statistics (quantities and costs) derived from Best Value Performance Indicators are shown in Appendix B. In the context of this study these data have their limitations because they do not categorise the component parts of the waste, but they are the best available. Parfitt (2002) analysed 70 datasets of domestic waste composition obtained in studies commissioned between 1999 and 2002 across England and Wales. He concluded that kitchen waste comprised 17% of total domestic waste (Figure 1). He commented that there is a degree of uncertainty because no two studies employed the same methodology; most were reportedly "dustbin waste". Hogg et al. (2007) reported a similar percentage of food waste in household waste at 17.6%.

The quantity of kerbside waste collected from households by the local authorities in H&W ranges from 314 to 469 kg/person*year (Appendix B) because, for example, some offer kerbside collection of greenwaste and others do not. The weighted annual averages, from the total BV84a weight collected, total population and total number of households, together with Hogg et al.'s 17.6% for KFW in the domestic waste stream, yield the following:

Table 4 Summary of annual cost and quantity household waste savings (see Appendix B)

Description		
Mass of KFW if it is 17.6% of BV84a	**180.1**	**kg/hhd**
Pro rata KFW [BV86] collection cost	£7.72	/hhd
Pro rata KFW [BV87] disposal cost	£10.91	/hhd
Combined pro rata KFW collection and disposal [current] cost	**£18.63**	**/hhd**

If KFW were collected separately, treated and recycled in compliance with ABPR the cost would be much more expensive than the average of the household waste costs shown in Table 4. Thus the average combined financial saving for the collection agencies and the disposal agency is likely to be in excess of £18.63 /hhd*year for each FWD installed. KFW comprises about 25.9% of the biodegradable waste and, in addition, it is the most difficult fraction because it is so wet. Eliminating KFW at source via FWD immediately contributes to achieving the LFD targets (BV84) and there is a ‘multiplier effect’ in that it also facilitates post-separation and recycling of dry biodegradables. There is an additional multiplier effect if LATS (Landfill Allowance Trading Scheme) is factored into the equation. The LATS penalty is currently £150 per tonne of biodegradable municipal waste landfilled in excess of that permitted by allowances held. There could be additional penalties in the target years 2010, 2013 and 2020. The Local Government Association has warned that current data imply that prices for allowances could be high from 2008/09 onwards, with a "serious deficit" of allowances potentially arising after 2009/10 (letsrecycle.com).

Estimating the cost transfer to the sewerage and wastewater operator is also problematic because of the uncertainties in quantities involved. By definition, KFW is biodegradable and therefore some of it will never reach the WwTW because it will biodegrade in the sewers.

Table 5 Summary of cost transfer to wastewater sector (see Appendix D[6])

Description of WwTW and sludge treatment and recycling or disposal	/hhd*y
Anaerobic digestion, CHP, land-application	£0.68
Anaerobic digestion and land-application but no CHP	£3.63
Lime stabilisation and land-application (no AD)	£5.96
AD + CHP + ROC + incineration	£2.18
Incineration (no AD)	£8.38

[6] based on the measurements made in the Surahammar field study

6 Conclusions

This study has examined the environmental, health and financial impacts of using FWD to divert KFW from landfill and concluded that, in agreement with H&W's joint municipal waste management strategy, FWD can have a very positive role.

Many field studies have shown that FWD have negligible effect on the use of water or energy. If the wastewater treatment works (WwTW) that receives the KFW has anaerobic digestion (AD) and electricity generation the energy balance is very positive (2.5 kWh_e /household*year used against at least 33 kWh_e /hhd*year generated from the biogas and could be as much as 73 kWh_e). The majority of sludge produced by WwTW in Severn Trent Water is treated by AD, as is the sludge at Hereford WwTW. The current trend in the water industry is to increase the efficiency of biogas generation and to exploit its value as renewable energy more effectively.

Laboratory experiments have shown that the output from FWD is finely divided and that the density of particles is such that it is carried easily in the flow velocity used for designing sewers. Field studies have confirmed that FWD do not influence sewer blockage neither are the particles large enough to block the screens at CSOs (combined sewer overflows) – the screens are 6mm; 98% of the output of FWD was <2 mm and 100% was < 5 mm. When sewage sludge is used on land (which is the route for the majority in the UK), the organic matter in KFW is conserved and the nutrient cycles are completed.

The carbon footprint of FWD use is better than the solid waste route with centralised composting (-168 and -14 kg CO_2e GWP /t KFW respectively) and is approximately equivalent to centralised AD. Landfill is +743 kg CO_2e GWP /t KFW. At the average rate of KFW production per household in H&W, this is only -30 and -3 kg CO_2e GWP / household and +134 kgCO_2e GWP / household for landfill. These figures are small by comparison with the annual 10,920 kg CO_2e carbon footprint of the average Briton (The Independent, 2006) but look more relevant when compared with the 100 kg CO_2e for lighting. The most significant factor differentiating FWD and centralised composting is whether the readily degradable carbon is stabilised by being converted to carbon dioxide or to methane that is used as renewable fuel. Ultimately, the product of either is short-cycle CO_2 but AD produces useful energy (CH_4 that burns to CO_2) and composting consumes energy.

De Koning and van der Graaf (1996) concluded that until the proportion of households with FWD installed exceeds 30% there is unlikely to be any substantive effect on WwTW operating capacity. However, Kalberg and Norin (1999) found that even when 30% of the households connected to a WwTW did have FWD they were unable to measure any change in the power consumption by the air blowers used for secondary treatment of the wastewater (the power consumption is an 'integrator' of the load). Even if more than 30% of households installed FWD, it would only be WwTW that are close to the limits of their operating capabilities that would need capital investment in extensions to treatment. For biological nutrient removal (BNR) [of nitrogen and phosphorus] WwTW are often limited because sewage is too 'weak'; installation of FWDs would be beneficial by adding to the carbonaceous strength of sewage, which would aid BNR.

Sewage pumping is not affected by installation of FWD since it has been found in field studies that FWD do not increase water usage. By transferring KFW from the MSW route to the waterborne route, FWD will add to the cost of wastewater treatment; the amount depends on the routes for sludge treatment and for sludge use or disposal. The most frequent combination in Severn Trent Water is AD with CHP followed by beneficial use of the digested sludge on land, which is the same for Hereford WwTW; the cost increase for this is only about £0.68 per household*year.

The average direct cost saving to the collection and disposal agencies in the Herefordshire and Worcestershire area is more than £18.63 per household*year. The payback on the average cashback payments to date is only 3 years and 4 months. There could be additional financial benefit from LATS trading. The saving will increase, and the payback period will decrease, as the cost of treating KFW increases with ABPR compliant treatment replacing landfilling. For example, letsrecycle.com estimates the current gate fee for ABPR compliant composting is £42-52 /t.

This study has found that food waste disposers (FWD) provide a convenient and hygienic means for householders to separate kitchen food waste (KFW) at source; they divert it from municipal solid waste landfill. Importantly, FWD do this using existing infrastructure and, by taking wet putrescible matter out of the solid waste stream, they make management of the dry fractions easier and less expensive and avoid odour issues, which have proved so detrimental to public acceptance of AWC. There is no reason that FWD should discourage home composting since FWD are not designed to take garden waste and indeed exclusion of cooked KFW from home composting might encourage home composting.

7 Acknowledgements

The County Surveyors' Society contributed funding to this research as Project No. 59 – "Using Food Waste Disposers to Divert Putrescible Kitchen Waste from Landfill". It was managed by Jeremy Howell-Thomas, Project Development Officer, Waste Management, Worcestershire County Council.

8 References

Ashley, R.M.; Bertrand-Krajewski, J.-L.; Hvitved-Jacobsen, T. and Verbanck, M (2004) *Solids in sewers: characteristics, effects and control of sewer solids and associated pollutants.* IWA Publishing, London.

BioCycle - Journal of Composting & Organics Recycling. JG Press, Inc., 419 State Avenue, Emmaus PA, 18049 USA

Böhnel, H. (2002) *Household biowaste containers (bio-bins) – potential incubators for Clostridium botulinum and botulinum neurotoxins*. Water, Air and Soil Pollution 140: 335-341

Brighton & Hove (2004) *Sustainability Strategy – Waste* http://www.brighton-hove.gov.uk/downloads/bhcc/sustainability/waste2004-06.pdf

Browne, P. (2005) *Food Waste Disposers as a means of waste diversion from landfill*. County Surveyors Society Waste Committee and unpublished data

Bünger, J.; Schappler-Scheele, B.; Hilgers, R. and Hallier, E. (2007) *A 5-year follow-up study on respiratory disorders and lung function in workers exposed to organic dust from composting plants*. Int. Arch. Occup. Environ. Health 80:306–312

CEC (1986) *Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture* (86/278/EEC). Official Journal of the European Communities, No L181/6 12.

CEC (1999) *Directive on the landfill of waste*. (1999/31/EC) Council Directive. Journal of the European Communities 16.7.1999 No L 182/1

CEC (2002) Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 *laying down health rules concerning animal by-products not intended for human consumption*. Official Journal of the European Communities L 273/1 10.10.2002

CIWEM (2003) *Policy Position Statement (PPS) Food Waste Disposers* February 2003

Commoner, Barry (1971) *The closing circle; nature, man, and technology*. Knopf, New York.

DCLG (2007) *Best Value Performance Indicators: 2005/06* http://www.communities.gov.uk/pub/119/BestValuePerformanceIndicators200506GuidanceDocumentAmended010405PDF6386Kb_id1136119.pdf (accessed 23 April 2007)

Defra (2005) *The Landfill Allowance Trading Scheme (LATS): Monitoring the scheme.* http://www.defra.gov.uk/environment/waste/localauth/lats/pdf/latsfaq-07.pdf (accessed 10 April 2007)

Evans, T.D. (2003) *Independent review of retrofitting Cambi to MAD*. Water Environment Federation 17th Annual Residuals & Biosolids Conference, 19-22 February 2003, Baltimore

Evans, T.D. (2004) *Layman's guide to the use of sludge in agriculture.* (unpublished) European Commission, Brussels

Evans, T.D., Jepsen, S.-E., Panter, K. P. (2002) *A survey of anaerobic digestion in Denmark*. 7th CIWEM AquaEnviro European Biosolids & Organic Residuals Conference, 18-20 November 2002

Evans, T. and Rainbow, A. (1998). *Wastewater biosolids to garden centre products via composting*. Acta Horticulturae no 469, 157-168.

Gendebien, A. Carlton-Smith, C. Izzo, M. Hall, J.E. (1999) *UK Sewage sludge survey 1996/97* TR P165, WRc, Medmenham, SL7 1FD, England

H&W (2004) *Managing waste for a brighter future*. The Joint Municipal Waste Management Strategy for Herefordshire & Worcestershire 2004-2034.

Hogg, D.; Barth, J.; Schleiss, K. and Favoino, E. (2007) *Dealing with Food Waste in the UK*. WRAP http://www.wrap.org.uk/downloads/Dealing_with_Food_Waste_-_Final_-_2_March_07.667fd840.pdf (accessed 29 March 2007)

IPCC (2001) Intergovernmental Panel on Climate Change - *Climate Change 2001: The Scientific Basis*. Cambridge University Press, UK. http://www.grida.no/climate/ipcc_tar/wg1/index.htm

Jones, P. H. (1990) *Kitchen garbage grinders (KGGs/food waste disposers) the effect on sewerage systems and refuse handling*. Institute for Environmental Studies, University of Toronto.

Kalberg, Tina & Norin, Erik, VBB VIAK AB. (1999) *Köksavfallskvarnar – effekter på avloppsreningsverk, En studie från Surahammar*. VA-FORSK RAPPORT 1999-9.

Kegebein, J.; Hoffmann, E. and Hahn, H.H. (2001) *Co-Transport and Co-Reuse, An Alternative to Separate Bio-Waste Collection?* Wasser. Abwasser 142, 429-434

Ketzenberger, B.A. (1995) *Effect of ground food wastes on the rates of scum and sludge accumulation*, University of Wisconsin-Madison.

Koning, J. de and Graaf, J.H.J.M. van der (1996) Kitchen food waste disposers, effects on sewer system and wastewater treatment. Technical University Delft.

letsrecycle.com (2007) Landfill Allowances. http://www.letsrecycle.com/legislation/landfillallowances.jsp (accessed 23 April 2007)

Matheson, C. (2005) *Case study: Setting up community composting and recycling projects in Hackney*. LARAC Conference '20:20 Vision – Driving recycling through innovation'.

Ministry of Land, Infrastructure and Transport (2005) *Summary of Report on Social Experiment of Garbage Grinder Introduction.* Compiled by National Institute for Land and Infrastructure Management Ministry of Land, Infrastructure and Transport, Japan. March 2005 Translated by Gitter, M. (2005)

Monteith, H.D.; Sahely, H.R.; MacLean, H.L. and Bagley, D.M. (2005) *A rational procedure for estimation of greenhouse-gas emissions from municipal wastewater treatment plants*. Water Environment Research 77, 390-403

National Audit Office (2006) *Reducing the reliance on landfill in England*. The Stationery Office, London

National Pest Technicians Association (2007) *National Rodent Survey Report 2006* http://www.npta.org.uk/

New York City DEP (1999) *The impact of food waste disposers in combined sewer areas of New York City*. New York City Department of Environmental Protection

New York State (2007) Septic system maintenance - septic tank pumping table shows when to clean the septic tank. http://www.inspect-ny.com/septic/tankpump.htm (accessed 06/02/2007)

Nilsson, P.; Lilja, G.; Hallin, P.-O.; Petersson, B. A.; Johansson, J.; Pettersson, J.; Karlen, L. (1990) *Waste management at the source utilizing food waste disposers in the home; a case study in the town of Staffanstorp*. Dept. Environmental Engineering, University of Lund.

Parfitt, J. (2002) *Analysis of household waste composition and factors driving waste increases*. http://www.cabinetoffice.gov.uk/strategy/downloads/su/waste/downloads/composition.pdf (accessed 27 March 2007)

Rosenwinkel, K.-H. and Wendler, D. (2001) *Influences of food waste disposers on sewerage system, waste water treatment and sludge digestion*. Proc. 8th Int'l Waste Management & Landfill Symp. CISA Env. Sanitary Eng. Centre, Sardinia, Italy.

Smith, A.; Brown, K.; Ogilvie, S.; Rushton K. and Bates, J. (2001) *Waste Management Options and Climate Change: Final Report*. Office for Official Publications of the European Communities, Luxembourg

Strategy Unit (2002) *Waste not, Want not - A strategy for tackling the waste problem in England*. http://www.number-10.gov.uk/su/waste/report/00-pdf.html

Thackray, J.E.; Cocker, V.; Archbald, G. (1978) The *Malvern and Mansfield studies of domestic water usage*. Proc. Inst. Civ. Eng. (1978) 37-61 *and discussion* 483-502

The Independent (2006) *Your carbon footprint revealed.* reporting research by The Carbon Trust and University of Surrey. 9th December 2006

WRAP (2007) *Research Summary: Understanding Food Waste*. http://www.wrap.org.uk/document.rm?id=3659 (accessed 10 April 2007)

Wouters, I.M., Douwes, J., Doekes, G., Thorne, P.S., Brunekreef, B. and Heederik, D.J. (2000) *Increased levels of markers of microbial exposure in homes with indoor storage of organic household waste.* Appl. Environ. Microbiol. 66, 627-31

Appendix A Acronyms and Abbreviations

ABPR	Animal By Products Regulations
AD	anaerobic digestion
AWC	alternate weekly collection
BNR	biological nutrient removal
BOD_7	biological oxygen demand measured with 7 days incubation
CHP	combined heat and power
CO_2e	carbon dioxide equivalent over 100 years
COD	chemical oxygen demand
Defra	Department of Environment Food and Rural Affairs
DS	dry solids (drying at 105 °C)
EA	Environment Agency of England and Wales
EfW	energy from waste
FOG	fat, oil and grease
FWD	food waste disposer
GWP	global warming potential
H&W	Herefordshire Council and Worcestershire County Council; also Herefordshire and Worcestershire geographic area
hhd	household
HHW	household waste
HWS	Household Waste Sites
IPCC	Intergovernmental Panel on Climate Change
KFW	kitchen food waste
kWh_e	kilowatt hour of electricity
LFD	landfill directive
MAD	mesophilic anaerobic digestion
MSW	municipal solid waste
NPTA	National Pest Technicians Association
OFMSW	organic fraction of municipal solid waste
Ofwat	Water Services Regulation Authority
RCV	refuse collection vehicle
ROC	Renewables Obligation Certificate
RTS	refuse transfer station
RTV	refuse transfer vehicle
TH	thermal hydrolysis
VFA	volatile fatty acids [fatty acids with a carbon chain of $\leq$6C atoms]
VS	volatile solids (loss on ignition at 550 C°)
WCA	Waste Collection Authority
WCC	Worcestershire County Council
WwTW	wastewater treatment works

Appendix B H&W Waste statistics

The data used in Appendix B are from the websites of the individual local authorities, H&W (2004) and 2005/06 BV84 data provided by Worcestershire County Council, Waste Management Services. WCC, WMS was unable to provide data about the average round-trip distances travelled by RCV or RTV and therefore assumptions have been made in Table 7 together with the rationale outlined in section 4.2.1 on conveyance of solid waste.

Table 6 Waste and population statistics (2005/06 actual)

	BV84a	BV84b	BV86
Bromsgrove	468.8	-14.15%	£71.19
Malvern Hills	313.6	0.50%	£50.52
Redditch	414.0	-0.27%	£50.54
Worcester City	355.8	-1.76%	£25.98
Wychavon	354.5	-7.36%	£48.96
Wyre Forest	365.1	-1.60%	£41.34
Herefordshire	521.7	1.42%	£44.69

Note: Herefs is a unitary authority and its BV84a includes w aste from HWS totalling 24606 tonnes

BV84a	kg household w aste collected per head of population
BV84b	annual change in household w aste collected per person
BV86	cost of household w aste collection £/household
BV87	Cost of w aste disposal per tonne municipal w aste

	population	total kerbside t	h'holds	total £	averages
Bromsgrove	90,000	42,192	36,859	£2,623,992	£62.19 /t
Malvern Hills	73,800	23,144	31,169	£1,574,658	£68.04 /t
Redditch	79,200	32,789	33,159	£1,675,856	£51.11 /t
Worcester City	93,500	33,267	40,677	£1,056,788	£31.77 /t
Wychavon	115,000	40,768	48,437	£2,371,476	£58.17 /t
Wyre Forest	97,800	35,707	41,758	£1,726,276	£48.35 /t
Herefordshire	177,800	68,152	76,410	£2,508,928	£36.81 /t
totals	727100	276,018	308,469	£13,537,974	

weighted average kerbside collection cost [from BV84a]	£49.05 /t
BV84a weighted average kerbside collection cost	£43.89 /hhd
weighted average kerbside collected weight from BV84a	894.8 kg/hhd
BV87 disposal cost per tonne (incl. tax) Worcestershire CC	£60.56 /t
BV87 disposal cost per household	£61.97 /hhd
Worcs CC total household waste (kerbside+HWS)	291053 t
Herefs total household waste (kerbside+HWS)	24606 t
H&W total household waste (kerbside+HWS)	315659 t
H&W average household waste	1023 kg/hhd
KFW if 17.6% of total	180.1 kg/hhd
minimum KFW [BV84] kerbside collection cost	£7.72 /hhd
minimum KFW [BV87] disposal cost	£10.91 /hhd
combined minimum KFW collection and disposal cost	£18.63 /hhd

Note 1: the pro rata costs for collection and disposal are derived from combined collection; they would be significantly greater if there was separate collection and treatment

Note 2: HHW comprises waste collected by the WCA + waste collected by the HWS + all waste collected from 'Bring' schemes: it excludes trade waste, fly tipped waste and soil & rubble.
MSW comprises all of the components of HHW plus trade waste, fly tipped waste and soil & rubble.

The payload of RTV might have increased since Smith et al. (2001) because maximum permitted gross vehicle weights have increased but since the contribution of RTV is much less than RCV it was not thought worth changing this. The assumption for RCV is that the distance to the start of the collection round and the distance back to the RTS are the same; if collection rounds were approximately radial from the RTS, i.e. the RCV travelled empty a long distance to the start of the round and a short distance full back to the RTS, the CO_2 per tonne waste would increase.

Table 7 Estimation of GWP associated with transporting KFW as solid waste (from Smith et al. 2001)

	payload tonnes	$kgCO_2$/km	$kgCO_2$/ km*t waste	round-trip km	$kgCO_2$/ t waste
RCV	6.67	0.84	0.252	40	10.07
RTV	20	0.71	0.071	60	4.26
			total		14.33

Note: vehicles run full 50% of the time

'Household waste' means[7]:

– All waste collected by Waste Collection Authorities (WCAs) under Section 45(1) of the Environmental Protection Act 1990, plus
– All waste arisings from Civic Amenity (CA) Sites established under Section 51(1)(b) of the Environmental Protection Act 1990, and
– Waste collected by third parties for which collection or disposal recycling credits are paid under Section 52 of the Environmental Protection Act 1990.

'Household waste' includes waste from the following sources:
– Waste collection rounds (including separate rounds for collection of recyclables);
– Street cleansing and litter collection;

---

7 http://www.communities.gov.uk/pub/119/BestValuePerformanceIndicators200506GuidanceDocumentAmended010405PDF6386Kb_id1136119.pdf

– Bulky waste collections, where “bulky waste” is defined as
  - any article of waste which exceeds 25 kilograms in weight
  - any article of waste which does not fit, or cannot be fitted into:
    - (a) a receptacle for household waste provided in accordance with section 46 of the Environmental Protection Act 1990; or
    - (b) where no such receptacle is provided, a cylindrical container 750 millimetres in diameter and 1 metre in length.

– Hazardous household waste collections;

– Garden waste collections;

– Drop-off/bring systems;

– Park litter (but not grass cuttings, leaves, etc);

– House clinical waste collections;

– Any other household waste collected by the authority.

Household waste does not include:

– Incinerator residues;

– Beach cleansing wastes (i.e. produced by the specific activity of cleaning up a beach);

– Rubble (including soil associated with the rubble) ;

– Home composted waste;

– Clearance of fly-tipped wastes;

– Vehicles (whether abandoned or not);

– Re-used waste material;

– Grass cuttings, leaves etc in parks

Appendix C Biogas, electricity and GWP from AD of KFW

The GWP is calculated as the saving from other electricity generated using the EU-average electricity generation emission factor (cited by Smith et al., 2001) which is 0.45 kg CO_2e /kWh (range coal = 0.95 to wind = 0.009 kg CO_2e /kWh). Two alternative AD processes are considered, one with 70 °C for 1-hour pre-sanitisation and the other with thermal hydrolysis to sterilise and increase the digestibility of the feed.

Table 8 Estimation of GWP associated with AD of separately collected KFW[8]

Description	unit	70℃+AD	TH+AD
feed	tonne	1	1
reject	%	10%	0.1
feed dry solids	%DS	30%	0.3
feed volatile solids	%VS	85%	0.85
feed VS	tDS	0.2295	0.2295
feed ash (i.e. non-VS)	tDS	0.0405	0.0405
VS destruction	%	40%	60%
ash in digestate	tDS	0.0405	0.0405
VS in digestate	tDS	0.1377	0.0918
total digestate	tDS	0.1782	0.1323
cake DS	%DS	22%	34%
cake	tonnes	0.810	0.389
biogas yield /kg VS destroyed	m^3	1.3	1.3
energy value of methane	MJ/Nm^3	37.78	37.78
methane content of biogas	%	65%	0.65
energy value of biogas	MJ/Nm^3	24.557	24.557
conversion MJ to kWh		0.2778	0.2778
energy value of biogas	kWh/Nm^3	6.8214	6.8214
biogas yield /t feed	Nm^3	119.34	179.01
methane yield /t feed	Nm^3	77.6	116.4
biogas used for sanitisation or TH	Nm^3	11.934	29.835
net biogas for CHP	Nm^3	107.406	149.175
net energy /t feed	kWh	732.7	1017.6
electricity @ generating efficiency = 40%	kWh/t feed	293.1	407.0
income (incl ROCs) @ 9 p/kWh	£/t feed	£26.38	£36.63
GWP at EU average 0.45 kg CO_2e /kWh	kg CO_2e/t feed	-131.9	-183.2

[8] This estimate is only for the anaerobic digestion step, i.e. it does not include collection and delivery to the AD plant or removal and recycling of the digestate.

Appendix D Costs and GWP from Surahammar field measurements

As discussed in section 4.3.2 the only field study in which there has been a sufficient proportion of the households connected to a single WwTW that have had FWD installed to be able to observe any significant effect at the WwTW was reported by Kalberg and Norin (1999). Base-line observations were made for 2 years before the trial when one-third of the connected properties volunteered to have FWD installed as an alternative to new 'pay-by-weight' solid waste charges. Surahammar WwTW has MAD and a significant increase in biogas production was measured (Figure 6). Kalberg and Norin did not attempt to measure the amount of KFW disposed via the FWD but using their data and some reasonable assumptions it is possible to back-calculate the amount of KFW; this is shown in Table 9. The back-calculated value is a similar order of magnitude as the weight of KFW calculated for households in Herefordshire and Worcestershire (Table 6). Furthermore, the estimate of additional biogas derived by Kegebein et al. (2001) is a similar order of magnitude to the field observation of Kalberg and Norin, as do the derived values for GWP.

Table 9 includes estimates of the additional costs that would be incurred by WwTWs that do not have AD and CHP though this does not apply to Severn Trent Water's WwTWs. The figure of £65 /tDS for the additional cost of wastewater treatment is an assumption based on the 'Trade Effluent' charging schemes published by Severn Trent, Yorkshire, Thames and Anglian water companies. Since these charges are audited and approved by Ofwat as fair, it is probably reasonable to use them as a basis for this exercise. Even the most expensive is less than half the saving to the MSW route that would result from KFW diversion and the least expensive is only 4% of the cost of the MSW-landfill route.

Table 9 Additional cost of wastewater treatment resulting from FWD based on the field measurements of Kalberg and Norin (1999)

Number of FWD installed at Surahammar	number of units	1100
extra biogas measured at Surahammar	m^3/d	70
∴ extra biogas	m^3/y	25550
∴extra biogas	m^3/FWD*y	23.23
assumed gas yield from VS destroyed	m^3/kgVS destroyed	1.3
∴VS destroyed	kg/FWD*y	17.87
assumed VS destroyed	%	60%
∴ original VS	kg/FWD*y	29.78
assumed original VS % of total solids	%VS	80%
∴ original TS	kgTS KFW /FWD*y	37.22
assume TS of KFW	%TS	30%
∴ KFW (fresh weight) per household	kg/y	124.1
∴ non-VS (i.e. ash)	kg/FWD*y	7.44
∴ VS in digestate kg/FWD*y	kgVS/FWD*y	11.91
∴ yield of digestate	kgDS/FWD*y	19.36
∴ content of VS in digestate	%VS	61.5%
assume digestate cake DS	%DS	24%
∴ yield of cake	kg cake/FWD*y	80.65
assumed recycling cost	£ /t cake	£15.00
∴ digestate recycling cost	£ /FWD*y	£1.21
assume cost of wastewater treatment	£/tDS received	£65.00
∴additional cost for wastewater treatment	£/FWD*y	£2.42
electricity generated calculated from biogas produced	kWh/FWD*y	32.76
GWP calculated from EU average for electricity generation	kgCO_2e/FWD*y	-14.74
∴ GWP calculated to KFW	kgCO_2e/t KFW	-118.80
assume electricity value with ROC	£/kWh	£0.09
∴ electricity value with ROC	£/FWD*y	£2.95
∴ net additional cost to a WwTW with AD+CHP	£/FWD*y	£0.68
or net additional cost to a WwTW with AD but no CHP	£/FWD*y	£3.63
For a WwTW with lime stabilisation assume lime dose	% on DS	30%
assume cost of lime	£/t	£60
∴ cost of lime stabilising extra sludge	£/FWD*y	£0.67
∴ net extra cost for a WwTW using lime stabilisation (no AD)	£/FWD*y	£5.42
assume cost of incineration (Yorkshire Water)	£/tDS	£160.00
∴ extra cost of incineration (no AD)	£/FWD*y	£5.96
∴ net additional cost Ww treatment + incineration	£ /FWD*y	£8.38
cost of incineration at a WwTW with AD	£/FWD*y	£3.10
∴ net additional cost Ww treatment + AD + ROC + incineration	£/FWD*y	£2.57