LITERATURE OVERVIEW

Impacts of Disposers
and
Food Waste Management

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List of Acronyms

AD	Anaerobic Digestion
BNR	Biological Nutrient Removal
BOD	Biological Oxygen Demand
CO_2e	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
CFWC	Curbside Food Waste Collection
FFA	Free Fatty Acid
FOG	Fats, Oils, and Greases
FWD	Food Waste Disposer
GWP	Global Warming Potential
LCA	Life Cycle Analysis
MLE	Modified Ludzack-Ettinger
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
rbCOD	Readily Biodegradable Chemical Oxygen Demand
SP	Smog Potential
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TSS	Total Suspended Solids
VS	Volatile Solids
VSS	Volatile Suspended Solids
WTE	Waste-to-Energy
WW	Wastewater
WWTP	Wastewater Treatment Plant

1.0 Introduction

Food waste disposers were invented in the 1940's, initially as a convenience for residential kitchens and cooks. As interest developed in the post-WWII era's housing boom, disposers were thoroughly evaluated by municipalities to assess their efficacy with respect to local solid waste and wastewater collection and treatment systems.

By the end of the 20th century, disposers had become a standard appliance, installed in the majority of U.S. homes and nearly ubiquitous in new residential construction. The market for commercial food waste disposers – in a variety of food-serving establishments, such as restaurants, cafeterias, and markets – also has grown. International acceptance of food waste disposers also is growing, in response to significant concerns about diverting organic food waste from landfills and increasing the beneficial use of food waste for land application. Everything municipalities normally do with food waste is environmentally noxious: stored inside buildings (even refrigerated); piled in bags on sidewalks; collected in trucks; and shipped to distant landfills, where it generates leachate and greenhouse gases. This process is not cheap, hygienic, environmentally friendly, nor sustainable.

In sum, food waste disposers form an impressive part of an integrated modern waste management system in many parts of the world.

This document reviews forty one (41) of the most recent studies and reports, three (3) executive summaries, two (2) literature reviews, one (1) textbook, two (2) specifications and requirements, and one (1) internal calculation, for a total of fifty (50) research references. All information in this document was conducted by universities, research institutions, and government agencies across the United States and in many countries that examine the efficacy of food waste disposers. It compiles the findings regarding all facets of the sewage collection, treatment, and disposal process and organizes the information according to major concerns and assumptions regarding garbage disposers. In sum, these studies have largely determined that the impacts of disposers are manageable, and that disposers provide a significant set of environmental benefits that merits their acceptance and use in conjunction with (rather than in competition to) other alternatives to divert organic waste from landfills.

2.0 Food Waste Disposer Background

2.1 Advantages

- Removing kitchen waste from compost produces cleaner and better compost [de Koning, 2004].
- Reduced transportation noise [de Koning, 2004].
- Reduced space concerns for food waste storage [de Koning, 2004].
- Renewable energy value of Wastewater Treatment Plant (WWTP) anaerobic digestion biogas [de Koning, 2004][Hernandez, 2002, “Los Angeles Digesters”][Karlberg, 1999][Karrman, 2001][Kegebein, 2001][Rosenwinkel, 2001][Shpiner, 1997].
- Reduced incidence of disease-causing vector attraction in comparison to food waste storage/collection [de Koning, 2004][Diggelman, 1998][Shpiner, 1997][Terpstra, 1995].
- Reduced truck collection, which blocks narrow streets [de Koning, 2004][Kegebein, 2001].
- Natural selector of organic wastes, whereas, composting relies on the education and goodwill of the participants [CECED, 2003].
- Reduces the potential of uncontrolled biochemical processes in landfills (i.e., leachate treatment) [Rosenwinkel, 2001].
- Reduced transportation emissions and costs [Karlberg, 1999][Karrman, 2001][Kegebein, 2001].
- High carbon content of food waste improves the overall WWTP nitrogen and phosphorus nutrient removal process [Diggelman, 1998][Kegebein, 2001][Rosenwinkel, 2001].
- Improved hygienic environment in comparison to food waste storage/collection [Kegebein, 2001][Rosenwinkel, 2001][Shpiner, 1997]Terpstra, 1995].
- Healthier Municipal Solid Waste (MSW) working environment [Karlberg, 1999].
- Less expensive and complicated than source-sorting food wastes [Karlberg, 1999].
- Reduced MSW garbage collection amount and frequency [Diggelman, 1998][New York City Department of Environmental Protection, *Executive Summary*, 1997][New York City Department of Environmental Protection, 1997][Shpiner, 1997].
- Promotes nutrient recycling from organic wastes when WWTP biosolids are land-applied [Diggelman, 1998].
- Environmentally friendly and sustainable food waste disposal option [Diggelman, 1998].
- As food waste is 70% water, the WWTP is a more natural system of waste processing than hauling the waste to a “solid waste” facility [Diggelman, 1998].
- As food waste is 70% water, the WWTP system reduces leachate diverted from landfill and compost systems, which reduces potential contamination to groundwater [Diggelman, 1998].
- Most convenient and likely-used source selector of organic kitchen wastes [Diggelman, 1998].
- As food waste is 70% water, the WWTP system anaerobic digestion process will produce a viable energy source, whereas, incineration offers a very small net energy gain that also produces contaminated emissions requiring additional treatment [Diggelman, 1998].
- As food waste is 70% water, the WWTP system is a more natural method of waste processing than composting, which, although enhanced by the additional moisture, does

require stricter operational control to avoid anaerobic conditions, and results in the loss of most nutrients to the extent that the final product is of low value [Diggelman, 1998].
- Ease of use [Shpiner, 1997].
- WWTPs are equipped to treat food waste due to high water and organic content [Shpiner, 1997].

2.2 Disadvantages

- Increased potential loadings impact on combined sewer overflows [Rosenwinkel, 2001].
- Increased water consumption [Rosenwinkel, 2001].
- Increased energy consumption for both disposer use and WWTP aeration [Rosenwinkel, 2001].
- High initial costs for the user (not the municipality) [CRC, 2000][Diggelman, 1998][Karrman, 2001][Rosenwinkel, 2001].
- Potential grease/solids build-up in the sewer collection system, which increases maintenance costs [Kegebein, 2001][New York City Department of Environmental Protection, *Executive Summary*, 1997][New York City Department of Environmental Protection, 1997].
- Increased WWTP biosolids generation and disposal costs [de Koning, 1996][Karrman, 2001][Rosenwinkel, 2001][Shpiner, 1997][Terpstra, 1995].
- Increased loadings of BOD and TSS to the WWTP [Shpiner, 1997].

2.3 Disposer Specifications

- Association of Home Appliance Manufacturers (AHAM) provided testing specifications to test for the criteria in the ASSE Standard #1008 in a systematic way [AHAM, 2009].
- Sink mounted food waste disposer units should be designed to fit a sink with a 3.5 inch (89 mm) nominal drain opening (this is the normal drain opening size to which sinks are designed) [AHAM, 2009, p. 2].
- Residential Disposer Specifications as set by ASSE International [ASSE, 2006]
    - Discharge not less than 6.0 GPM (0.36 L/s) at a head of 10.0 inches (254.0 mm) [ASSE, 2006, p. 3].
    - Terminal outlet shall be 1.5 inches (40 mm) nominal tube size [ASSE, 2006, p. 1].
    - Ground product retained on the sieve should not weigh more than 1.0 ounces (28 grams) [ASSE, 2006, p. 4].
    - Particles on the inside of the FWD shall not exceed 0.25 inches (6.7 mm) [ASSE, 2006, p. 5].
    - For FWDs with a dishwasher connection, the water level shall not rise more than 1.0 inch (25.4 mm) above the water level in the sink [ASSE, 2006, p. 5].
    - For FWDs without a dishwasher connection, the water level shall not rise above the sink mounting flange to any degree [ASSE, 2006, p. 5].
    - There shall be no evidence of leakage during or after the cycle of running the FWD [ASSE, 2006, p. 6].
- Disposers have a 600W electric motor, used on average 2.4 times/day and 30 seconds each time [Karrman, 2001].
- Approximately 98% of all particles pass through a 2 mm sieve [Kegebein, 2001].

- The food waste disposer can be described as a mill rather than a cutter. It works with a rotary disk in which two hammer-cheeks mobile in horizontal direction are fastened. The disk is provided with 5 mm holes. In opposition to frequently heard prejudices, a disposer does not contain rotating knives [Rosenwinkel, 2001].
- Non-food wastes cannot be ground since the attempt will cause a resistance, which if it becomes excessive, will cause the resistor to switch off [Rosenwinkel, 2001].
- A 1400 rpm rotating disk with a number of 3-4 mm holes [Karlberg, 1999].
- The energy requirement for use is 3-4 kW-h//household/yr [Karlberg, 1999].
- A Japanese study found food waste particle dispersion between 2-5 mm [Karlberg, 1999].
- A grinding distribution of heaviest components show 62% of particles are <1.7 mm, 86% are <2.83 mm, and 94% are <3.36 mm [Shpiner, 1997].

2.4 Food Waste Composition

- Food Waste Composition varies depending on the culture and diets of the local community. Therefore, it is difficult to define a uniform composition of food waste. In some studies a "standard diet" is created in order to study local food waste compositions [Kim, 2015, p. 62].
- Since the COD/N and BOD/N ratios (63 and 27, respectively) were higher than the particulate ratios (42 and 22, respectively), this suggests that the non-settleable fraction (aqueous phase) can enhance the denitrification process and impact secondary aeration [Kim, 2015, p. 69].
- Considering 50 grinded food waste samples, the relative mass ratios of COD: BOD5: TSS: TN: TP: dry food waste was 1.21: 0.58: 0.36: 0.025: 0.013: 1 [Nakhla, 2014, p. 11].
- Assuming wet food waste consists of 30% dry waste and 70% water, dry food waste is defined by the following chemical formula: $C_{21.53}H_{34.21}O_{12.66}N_{1.00}S_{0.07}$ [PE Americas, 2011, p. 19].
- Assuming wet food waste is 30% dry waste and 70% water and 95% of the dry food waste is VS with the remaining 5% being inert, then 100kg of wet food waste would equate to a dry food waste of 44 kg COD with a 1.54 kg COD/kg dry food waste ratio applied [PE Americas, 2011, p. 19].
- For 30 kg of dry food waste, 17 kg is TSS while the remaining 13 kg is soluble and is removed during biological treatment [PE Americas, 2011, p. 20].
- The impact of FWDs depends on the food waste composition, which depends on the type of food waste [Thomas, 2010, p. 6].
- Daily person equivalent contributions due to organic food waste through disposers is 75 g/person/day for Chemical Oxygen Demand (COD), 50 g/person/day for Total Suspended Solids (TSS), 2.5 g/person/day for Total Kjeldahl Nitrogen (TKN), and 0.25 g/person/day for Total Phosphorus (P). This equates to a COD/TKN ratio of 30 [Bolzonella, 2003].
- Typical organic waste composition is 25.6% TS (74.4% water), 96.5% VS, 3.2% TKN, 0.2% P, and 1,200 mg/L COD [Bolzonella, 2003].
- Grindable food waste is about 35% of total household waste, which equates to 235 g/person/day (85 kg/person/yr.) [CECED, 2003].
- Airport food waste sample analysis results were moisture 72.9%, Total Solids (TS) 27.1%, and Volatile Solids (VS) 94.9% [Hernandez, 2002, "Los Angeles Digesters"].

- Generated food waste is 76 kg/person/yr., with 67% able to be ground through a disposer (i.e., 50.9 kg/person/yr.) [Karrman, 2001].
- Food waste generation is about 40-60 kg wet/person/yr. [Kegebein, 2001].
- Average food waste generation is 182 kg/household/yr. or 0.24 kg/person/day [CRC, 2000].
- Lagerkvist & Karlson, 1983 and Nilsson et al, 1990 both indicate that about 20% of food waste suitable for composting is not suitable for disposer grinding [Karlberg, 1999].
- Olsson & Retzner, 1998 indicates that 75 kg/person/yr. of food waste are generated [Karlberg, 1999].
- De Koning & Van der Graaf, 1996 assume that the total amount of food waste that can be ground through a disposer is 44 kg/person/yr. [Karlberg, 1999].
- Nilsson et al, 1990 state that about 75% of food waste Biochemical Oxygen Demand (BOD) is in particle form and 25% in dissolved form [Karlberg, 1999].
- The average person generates 0.29 lb./day of food waste with 0.21 lb./day (75%) able to be processed through a disposer [Diggelman, 1998].
- Food waste is 70% water and 30% solids [Diggelman, 1998].

Table 1 – Waste Compositions. Typical Food and Human Waste Compositions [Diggelman, 1998].

Waste Compositions					
Type	**C**	**H**	**O**	**N**	**S**
Food Waste	50.5%	6.72%	39.6%	2.74%	0.44%
Human Waste	59.7%	9.5%	23.8%	7.0%	0%

- Food waste is 64.3% water (35.7% solids) with 75.5 g/person/day generated through a disposer [Shpiner, 1997].
- Food waste moisture content is 60% with a production of 0.08 wet kg/person/day (0.048 dry kg/person/day) [de Koning, 1996].
- Average household food waste disposal is 260 g/person/day [Terpstra, 1995].
- Food waste is 30% dry solids (70% water) [Terpstra, 1995].

3.0 Food Waste Disposer Common Concerns

3.1 Water Use

- Disposers account for only about 1% of a household's daily use of water [Nakhla, 2014, P. 6].
- Estimate 1 gal/capita/day with disposer use **[Nakhla, 2014, p. 6]**[New York City Department of Environmental Protection, *Executive Summary*, 1997].
- Disposer water usage is 3-6 L/household/day [Karlberg, 2012].
- After installation of FWDs, the extra water consumption was marginal (less than 2% increase in water use) [Clauson-Kaas, 2011, p. 6].
- DeOreo et al, 2011 found that residential disposers save 13 gallons of water/household/day [DeOreo, 2011, p. 205].

- Based on grinding food waste in the laboratory, the water usage per capita added after the use of FWD increases only 4.45%, and the utility fee is only 0.02 Chinese Yuan (CNY) (per capita per day) [Tongji University, 2010, p. 59].
- The change in water use from FWDs is trivial [Evans, 2007, p. 23].
- After the introduction of FWDs, no water consumption changes were noticed [Imanishi, 2005, p. 14]. [Yoshida, "Impacts of Food Waste Disposers"].
- De Koning, 2004 reports the use of disposers does not result in a noticeable increase in the volume of wastewater [de Koning, 2004].
- Nilsson et al, 1990 estimate that water consumption does not change because of disposer use [Karlberg, 1999].
- Increased water demand from disposers is 0.02% at 3% market penetration, and 0.24% at 38% market penetration (assuming a 1% disposer market growth per year). Therefore, no significant impacts on the city water supply from disposers are expected [New York City Department of Environmental Protection, *Executive Summary*, 1997].
- There is no statistical evidence that city water consumption has changed since the installation of disposers [New York City Department of Environmental Protection, 1997].

Table 2 – Water Consumption Rates. FWD Water Consumption Rates (L/person/day).

Source	**FWD Water Consumption Rate (L/person/day)**
Clauson-Kaas, 2011, p. 6	3-6
CECED, 2003	3-4.5
Kegebein, 2001	3-4.5
Cooperative Research Centre, 2000	2.95
Shpiner, 1997	1.01
de Koning, 1996	4.5
Terpstra, 1995	4.48
Waste Management Research Unit, 1994	4
Average	**3.99 (1.05 gallons/person/day)**

3.2 Electricity

- Assuming a FWD is used for 30 seconds per person daily with a power draw of 1000 W, the estimated power consumption for FWDs is 0.008 kWh/capita/day [Leverenz, 2013, p. 11].
- The power consumption for FWD is 0.119 kWh/capita/day, which equals a utility fee of 0.073 CNY/capita/day considering 0.617 CNY/kWh in Shanghai [Tongji University, 2010, p. 60].
- With electricity being roughly $0.10 per kilowatt-hour and a disposer using 2.3 uses per day with each use running for 30 seconds while the average disposer uses 500 watts while in use, the average cost is about $0.35 per year [Strutz, 2005].
- The Plumbing Foundation City of New York, 2001 indicates that using the upper time limit for disposer usage of 2 min/day and the most common 0.5 hp motor, the disposer consumes less than a 75W light bulb uses in 10 minutes [Marashlian, 2004].

Table 3 – FWD Energy Consumption Estimates and Price Estimates. Prices were calculated based on the average cost of electricity estimated at $0.10 per KWh. The energy consumption estimates range from less than 3 to 6 KWh/home/year, which is small in comparison to the average household energy consumption.

Source	FWD Energy Consumption Estimate (KWh/home/year)	Price (US Dollars per home per year)
Leverenz, 2013	4	$0.40
PE Americas, 2011	4	$0.40
Tendaj, 2008, p. 11	5-6	$0.60
Evans, 2007	2-3	$0.30
Balzonella, 2003	4.3	$0.43
Waste Management Research Unit, 1994	< 3	$0.30
Average	**4.1**	**$0.41**

3.3 Plumbing and Sewers

- A study of 181 concrete pipes serving single family households comparing FWD usage with sewers revealed that FWDs have an impact on the use of sewers, but the majority of deposits were small, indicating that the impact of FWDs on sewer performance is minor [Mattsson, 2014, p. 1].
- The long-term impacts of FWDs on small diameter sewer systems of residential areas were shown to be minor [Mattsson, 2014, p. 1].
- More troubles aroused in sewers when households used food waste that was not compatible with FWDs, such as eggshells, which suggests the importance of proper education and use of FWDs [Mattson, 2014, p. 9].
- Many of the problems observed with the use of FWDs and sewers/plumbing could be avoided by having pipes with a steep inclination [Mattsson, 2014, p. 8].
- Deposits in pipes with large inclinations could be caused by sags in the pipes [Mattsson, 2014, p. 8].
- In a nine month study in PuDong, the use of FWDs did not result in sewer blockages or sedimentation [Tongji University, 2013].
- Long term impacts on sewer degradation is unknown. The Sustainable Food Waste Evaluation assumes a 5% aerobic and 10% anaerobic degradation [WERF, 2012, p. A31].
- Processing food waste will not increase sedimentation and blockages since the density of ground food waste usually has a lower specific density than waste water [Clauson-Kaas, 2011, p. 57].
- The PE Americas LCA assumes a negligible (0%) degradation [PE Americas, 2011, p. 113].
- The FWDs effect on the sewer system will be small [Tendaj, 2008, p. 40].
- Nilsson et al, 1990 showed that a stimulated optimal usage of disposers for 15 years did not exhibit operational problems within the plumbing system. Regular inspection and videotaping of the piping system found a buildup of sewage was reported at water level with a width of 2-3 cm along the envelope surface at a thickness of 0.5-1.5 cm [Marashlian, 2004].

- Some trouble could arise from increased O&G discharge in sewers. However, studies have shown that no problems were caused [Bolzonella, 2003].
- Sewage velocity is sufficient enough to maintain sewers clean. Generally, self-cleansing velocity is in the range of 0.5-1.6 m/s for sewers with a diameter of 200-2000 mm [Bolzonella, 2003].
- Study results revealed that only 16.8% of TS (from ground organic wastes) settled in sewers, whereas, the residual 83.2% reached the WWTP. Therefore, sewers should be considered a feasible way to transport food waste [Bolzonella, 2003].
- Another aspect to consider is to avoid disposer installations in areas where blockages or hydrogen sulfide formation already are problems in the sewage system [Karrman, 2001].
- A daily minimum flow velocity of 0.5 m/s is seen as sufficient for food waste transport free of sedimentation. The density and settling velocities of food waste particles is very much less in comparison to mineral particles [Kegebein, 2001].
- Increased costs in sewer maintenance (from disposers) cannot be ruled out. At 100% market penetration, a 20% increase could result [Kegebein, 2001].
- At a 50% market share, disposers contribute <0.1% flow to instantaneous maximum flow in sewer systems [CRC, 2000].
- At a 50% market share, disposers increase hydrogen sulfide generation in the sewerage system by 30% [CRC, 2000].
- Up to a 15% market penetration, the use of disposers in multi-unit dwellings would have a small impact on sewage collection systems [CRC, 2000].
- About 91% of solids in disposer effluent are <1 mm (0.25 in) in size, therefore, this small size would be unlikely to clog or become deposited in sewers or plumbing pipes [CRC, 2000].
- De Koning and Van der Graaf, 1996 state that the concern over grease and fats (from disposers) clogging sewers is invalid because the use of cold water causes grease and fat to congeal and attach to other food waste solids [CRC, 2000].
- There does not appear to be any sound evidence in literature to suggest that disposers cause clogging or deposits of solids in pipes [CRC, 2000].
- In a 1993 apartment disposer use study, sewer pipes were flushed and videotaped with no differences observed (i.e., no additional particle, sludge, or grease accumulation) after both 1 and 3 years following installation [Karlberg, 1999].
- Disposers may cause increases in TSS and Oil & Grease (O&G) in the sewer system. There may be an increase in sewer maintenance costs estimated at 0.61% at a 3% market penetration and 7.6% at a 38% market penetration (assume 1% market penetration per year) [New York City Department of Environmental Protection, 1997].
- In combined sewer systems built with an adequate self-cleaning velocity (ex., sanitary sewers 2.0-2.5 ft./sec or about 0.61-0.76 m/s and storm sewers 2.5-3.0 ft./sec), no additional deposits are expected due to ground food waste since its specific gravity of 1.01 is less than that of sewage (1.05), and much less than the suspended solids carried by storm runoff (specific gravity 2.65) [New York City Department of Environmental Protection, 1997].
- In combined sewer systems, the introduction of disposers will cause increases in suspended solids of about 20% on a per capita basis, and expected to increase O&G discharges. As a result, combined sewer systems with insufficient self-cleaning velocities

will require routine cleaning, which will increase maintenance costs [New York City Department of Environmental Protection, 1997].

- Videotaping done before and after the study detected no noticeable deposits of solids build-up. Therefore, no potential significant adverse impacts on the sewer system are expected from disposer use [New York City Department of Environmental Protection, *Executive Summary*, 1997].
- Wicke, 1987 states that a concentration of less than 1% solids (10,000 mg/L) will not cause an increase in solid sedimentation, or for every 12 gal of water (45 L) there should be no more than 1 lb. (454 g) of ground garbage [Shpiner, 1997].
- There is no literature example to prove that the use of disposers causes clogging or deposits in sewers. Most food solids have a density about equal to water and are easily suspended in water. Thus, it is unlikely that ground food waste contributes to sewer clogging [de Koning, 1996].
- Discharged with cold water, any grease or fat found in food waste will congeal and attach itself to the other ground waste particles. Running cold water will prevent coating of the sewer with grease [de Koning, 1996].

Table 4 – Cleaning Velocity. Cleaning Velocities/Minimum Flow Velocities

Source	Cleaning Velocity/Minimum Flow Velocity (m/s)
Evans, 2007	0.48-0.9
Bolzonella, 2003	0.5-1.6
Kegebein, 2001	0.5
New York City Department of Environmental Protection, 1997	0.61-0.76
Average	**0.94**

3.4 Wastewater Treatment Plant Impacts

3.4.1 Pollutant Loading

- Figures 1-3 show estimated loading increases in TSS, COD, BOD, oil and grease, potassium, total P, inorganic P, organic P, TKN, organic N, and NH_3.

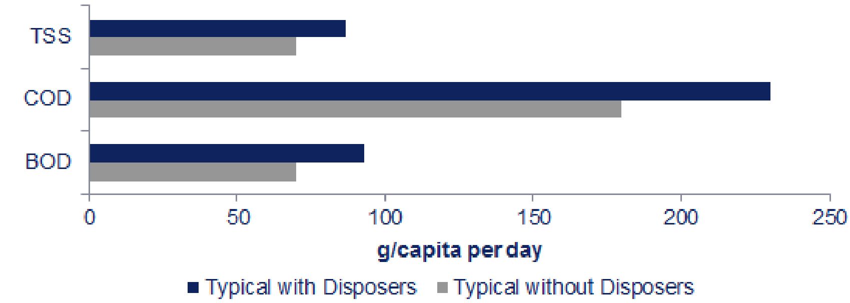

Figure 1 – Estimated Loading Increase from Disposers (TSS, COD, and BOD) [Metcalf, 2014]

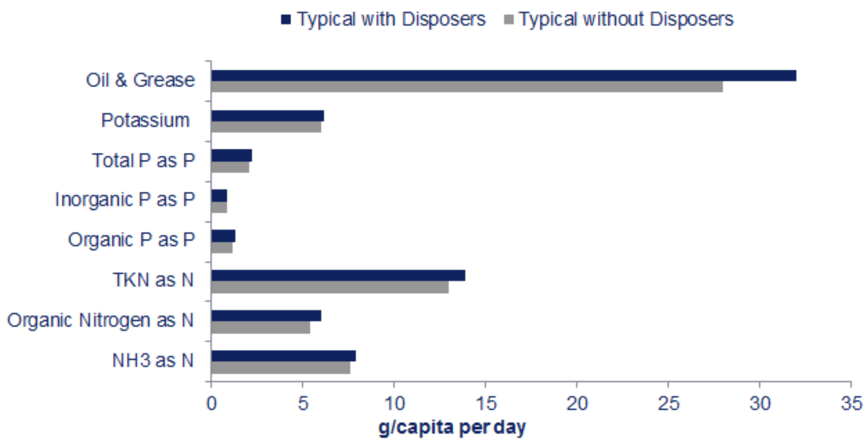

Figure 2 – Estimated Loading Increase from Disposers [Metcalf, 2014]

	%Increase
TSS	33
COD	28
BOD	24
Oil & Grease	4
K	11
Total P	7
Inorganic P	8
Organic P	0
TKN	5
Organic N	3
NH_3	14

Figure 3 -- Estimated Percent Increase in Loading from Disposers [Metcalf, 2014]

- In Nakhla's study (2014), the experimentally determined COD and BOD of food wastes were 22% lower than the theoretical values, suggesting that the impact of food wastes on the WWTP is lower than originally supposed [Nakhla, 2014, p. 11].
- Installing FWDs will not affect hydraulic load of the WWTP [Clauson-Kaas, 2011, p. 58].
- WWTPs are designed to treat biodegradable material suspended in water, i.e. similar to the output of FWD [Evans, 2007, p. 4].
- Additional pollutant loading due to disposer use is 66 g/person/day BOD, 60 g/person/day TSS, 2.1 g/person/day TKN, 0.3 g/person/day P, and 2.5-5% biosolids [de Koning, 2004].
- The effect of disposers on WWTP processes is very limited [de Koning, 2004].
- At a 15-20% disposer market share, loadings do not result in significant variations in the characteristics of sewage. At a 20-35% disposer market share, an increased WWTP system energy consumption is observed due to greater respiration of the active biomass and a larger production of excess biosolids. Beyond a 35-40% disposer market share, additional works must be done at the WWTP. European Union (EU) market levels will not exceed 15% in 25-30 years, thus, normal WWTP upgrades will allow for an accommodation of increased disposer loading [CECED, 2003].
- Disposer discharge to a WWTP equates to 73 g/person/day dry matter, 25 g/person/day BOD, 0.25 g/person/day phosphorus, and 1.3 g/person/day nitrogen [Karrman, 2001].
- At 100% disposer market share, additional loadings from disposers are 3-5% for flow, 5-10% for screenings, 5% for grit, 10-25% for BOD, 40-60% for TSS, 5-10% for TKN, 7-14% for P, 50-70% for primary sludge, 10-40% for waste activated sludge, 30-50% for digested sludge, and 90-100% for biogas [Rosenwinkel, 2001].
- The additional loads for wastewater treatment and sludge digestion can be estimated very well and, due to slow market penetration, will not lead to uncontrolled overloading to the WWTP "overnight" [Rosenwinkel, 2001].
- At a 50% disposer market share, increases in sewage flows are very small (additional 0.5% to the mean average daily flow) [CRC, 2000].
- At a 15% disposer market share, no operational problems should be caused in terms of BOD, TSS, or O&G loadings [CRC, 2000].
- Up to a 15% disposer market share, the use of disposers in multi-unit dwellings would have a small impact on sewage treatment systems. Beyond this figure are increasing impacts, with potentially significant impacts at a 50% market share. However, this level of market share is unlikely in the near future [CRC, 2000].
- No operational problems are expected for market levels up to 15% in regard to BOD and O&G loadings, or up to 20% market for additional TSS loadings [CRC, 2000].
- Up to a 50% disposer market share, the transport and treatment of disposer effluent would require an additional 0.5% energy, and total WWTP costs would increase 0.5% [CRC, 2000].
- Up to a 50% disposer market share, additional loadings from disposers are <1% for TSS and nutrients, and <2% for BOD [CRC, 2000].
- At a 100% disposer market share, flows would increase 0.4%, biosolids production would increase 18.1%, BOD would increase 16.5%, and nutrients would increase 3.0% for TKN and 4.6% for P [Waste Management Research Unit, 1994].

3.4.2 Preliminary Treatment

- Using FWD to divert food waste results in a waste stream that is fairly free from contaminants and debris, so it is not subject to additional processing, cleaning, and preliminary treatment at the WWTP [Leverenz, 2013, p. 10].
- It is expected that food waste will contain no grit [Hernandez, 2002, “Hyperion Digestion Pilot Program”].
- With disposer usage, WWTP screens and grit chambers will only be affected to a small extent [Rosenwinkel, 2001].
- Screenings are not expected to be added by food waste disposers [New York City Department of Environmental Protection, 1997].
- Grit was assumed to be 5% of TSS. A method to evaluate scum or grit production impact could not be determined [New York City Department of Environmental Protection, 1997].

3.4.3 Primary Treatment

- The large particulate fraction of FW tends to be removed in primary sedimentation while the soluble fraction of FW in primary effluent can be utilized for nutrient removal [Kim, 2015, p. 68].

Table 5 – Particulate Fractions. Particulate Fractions in 50 grinded food waste samples [Kim, 2015, p. 69]

Parameter	Particulate Fraction
COD	58%
BOD_5	67%
TN	74%
TP	100%

Table 6 – Percent Removal. Removal percentages of TSS, BOD_5, and COD after a 3 hour (180 minute) time period [Nakhla, 2014, p. 11]

Parameter	Percent Removal after 3 hours
TSS	59-62%
BOD_5	46-53%
COD	49-56%

- During primary sedimentation, 80% of the solids and 90% of ground food waste are removed [PE Americas, 2011, p. 26].
- FWD use increases COD and TSS by 12% and 24% respectively, still in the allowable range for municipal sewers [Tongji University, 2013].
- The use of FWDs increases the COD in the sewage, as well as the C/N and C/P ratios, therefore sewage treatment will benefit with improved biological nitrogen and phosphorus removal [Tongji University, 2013].
- Thomas’s study in 2010 noted that when the food waste settled in buckets (in order to simulate primary clarification), the results indicated roughly 62% TP and 90% ammonia

were in the supernatant while 77% and 90% of the TSS and RSS were in the sediment fractions [Thomas, 2010, p. 7].

- Battistoni, 2007 did not find any solid sedimentation [Battistoni, 2007, p. 896].
- Primary settling food waste removal is 20% BOD, 90% TSS, 5% TKN, and 10% P [de Koning, 2004].
- The average settling velocity of food waste is 13.2 m/hr. (43.3 ft./hr.) [Bolzonella, 2003].
- According to lab experiments, 75% (of disposer food waste) is assumed to be settled in the pre-sedimentation step [Karrman, 2001].
- With disposer usage, most of the particulate food waste fraction will settle in the WWTP primary clarifier [Rosenwinkel, 2001].
- Disposer solids settle readily under gravity. Sinclair Knight, 1990 state that the addition of disposer solids enhances the settling characteristics of sewage [CRC, 2000].
- The portion of BOD from disposer use that does not settle in primary treatment was determined using filtrate BOD. The portion of BOD from food waste that settled was 68.7% [New York City Department of Environmental Protection, 1997].
- According to literature, over 90% of food waste is removed in primary sedimentation [Shpiner, 1997].
- Brillet et al., 1986 reported that sedimentation removed 80% BOD and 90% TSS from disposer waste [Shpiner, 1997].
- Nilsson et al, 1990 reported that 75% of TS in wastewater and 90% of solids from disposer grinding are removed in primary sedimentation, thus, overall removal is 80% [Shpiner, 1997].
- Normal wastewater TSS removal is 58-64% and the food waste mixture TSS removal is 78-86% [Shpiner, 1997].
- The majority of additional BOD/COD and nutrient from disposer loading is concentrated in settled primary sludge [de Koning, 1996].

3.4.4 Secondary Treatment (Biological Treatment)

- The additional soluble food waste fraction will lead to higher BOD/COD loading within the biological treatment steps, which on one hand will cause a higher oxygen demand, but on the other can serve as a cheap and continuously available carbon source (for nutrient reduction). A basic condition for the appropriate biological nitrogen and phosphorus removal is a sufficient supply of easily degradable substrate (i.e., carbon) [Rosenwinkel, 2001].
- At a 25% disposer market share, influent BOD would increase 12%, TKN and P would increase 2% [Karlberg, 1999].
- After a decade of city-wide disposer distribution, costs would increase $4.1M for the most expensive N-control measure (a 0.27% increase). This represents a *de minimis* impact [New York City Department of Environmental Protection, *Executive Summary*, 1997].
- Brillet et al., 1986 reported that at a 100% disposer market share, biological treatment loading increased 9.5-16% BOD and 7.5-10% TSS [Shpiner, 1997].
- Increased loading to the biological processes from disposer usage is negligible (at 10% market share) [de Koning, 1996].

3.4.5 Anaerobic Digestion and Food Waste Energy Recovery

- The efficiency of converting the potential chemical energy contained in food waste to electrical energy is estimated to be about 20% [Leverenz, 2013, p. 17].
- Typical observed values for biogas yield from various food waste digestion studies are 157 and 600 m^3/MT for a wet and dry basis, respectively [Leverenz, 2013, p. 18].
- The power generated from biogas is derived to be approximately 80 kWhe/d [Leverenz, 2013, p. 37].

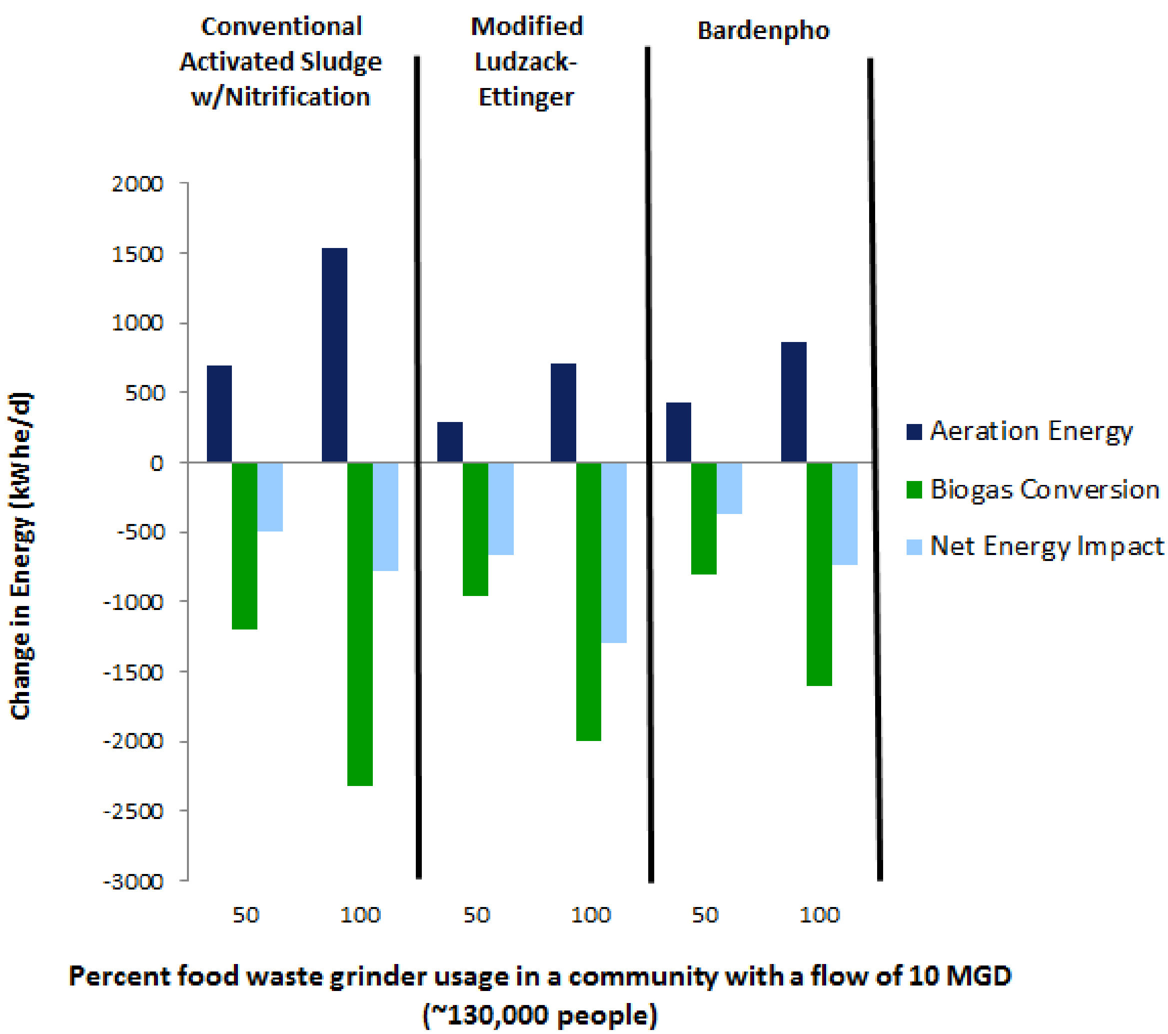

Figure 4 –Change in Energy. Change in Energy in three different wastewater treatment processes at 50 and 100% disposer usage [Leverenz, 2013].

- In a comparison of five studies regarding anaerobic digestion, four found an increase in production of biogas and one study found that BNR was enhanced as the carbon to nutrients ratio increased after FWD were introduced [LGA, 2012, p. 23].
- Upon reviewing 82 studies regarding end of life management methods for source separated organics, it was found that anaerobic digestion and aerobic composting have a lower climate impact than waste-to-energy and landfilling [Morris, 2012, p. 6].

- The town of Surahammar, Sweden had a 0-50% increase in market penetration rate in a ten year period. Digesters produced 46% more biogas after FWDs were installed [Evans, 2010, p. 1].

Table 7 – Added Sludge, Biogas, and Electricity. Various penetration rates' effects on sludge volume, biogas volume, and electricity gain [Tongji University, 2010].

Penetration Rate	Added Sludge Volume (t/d, 80% water content)	Added Biogas Volume (m^3/d)	Electricity Gain (kWh/day)
1%	18	493	68
5%	91	2465	4437
10%	182	4930	8875
100%	1818	49304	88748

- At a disposer market share of 10%, biogas production increased about 3% [Tendaj, 2008, p. 40].
- Biogas production from food waste is 1.15 m^3/day of digested organics with a content of 22,000 kJ/m^3 of biogas [de Koning, 2004].
- The use of disposers will increase electric self-supply from 72% (at 0% disposer market share) to 82% (at 10% market share). Profits gained in electrical supply will cancel out additional biosolids treatment costs [de Koning, 2004].
- Food waste (with 90% settling in primary treatment sludge) contains a high percentage of easily digestible organics (i.e., 80% VS) [de Koning, 2004].
- The potential energy value from food waste by anaerobic digestion was assumed insignificant [Marashlian, 2004].
- At a 60% disposer market share, an increase of additional energy potential due to anaerobic digestion in the range of 54-73% was observed [Bolzonella, 2003].
- Food waste Volatile Solids Destruction (VSD) is 83.7% (for thermophilic digestion at 55°C and food waste fruit and vegetables ground to a slurry) [Hernandez, 2002, "Hyperion Advanced Digestion Pilot Program"]
- The optimum digester operating temperature was found to be 55°C and 57°C (thermophilic digestion). As the temperature increased from that point, VSD and gas production decreased and volatile acids increased [Hernandez, 2002, "Los Angeles Digesters"].
- The value of the biogas produced from food waste anaerobic digestion appears to exceed the cost of processing the food waste and disposing of the residual biosolids (based on a LAX Airport proposal to divert 8,000 tons/year of bulk food waste) [Hernandez, 2002, "Los Angeles Digesters"].
- Methane gas generated in the anaerobic digesters is transported to a city-owned power generation steam plant, which is used as a supplemental fuel and burned in the production of steam and electrical energy (15 scf of digester gas produced per lb. of VS destroyed). In digesting fruits and vegetables only, the value of the biogas appears to exceed the cost of processing the food waste and disposing of the biosolids [Hernandez, 2002, "Los Angeles Digesters"].
- The food waste disposer system generates more energy than consumed through the digestion (biogas) [Karrman, 2001].

- Food waste fermentation (anaerobic digestion) has an energy potential of 300 MJ/person/yr., which contributes about 25 kW-h/person/yr. to electric supply (about the electrical usage of 1 WWTP) [Kegebein, 2001].
- As most of the food waste from disposers settles in the WWTP primary clarifier, the majority will reach the anaerobic digester and cause an increase in biogas production and a regenerative energy source [Rosenwinkel, 2001].
- Diverting food waste through a disposer to a WWTP should be encouraged when solids handling systems are adequate, methane is combusted (through anaerobic digestion) to produce energy, and effluent and/or sludge (biosolids) are returned to soil. Food waste is effectively being recycled [Diggelman, 1998].
- Additional gas production is generated from the volatile portion of food waste loading (7 ft^3 of gas is produced per lb. of VS that enter the digester) [New York City Department of Environmental Protection, 1997].
- Anaerobic digester gas production averaged 346 m^3/day before disposer usage and 417 m^3/day after disposer usage for an increase of 20.2% (at 65% methane, this equates to 160,000 kW-h/yr.) [de Koning, 1996].

3.4.6 Biosolids Handling and Disposal

- Biosolids have a chemical formula: $C_5H_7NO_2$ with a carbon content of 53.1% and a nitrogen content of 12.4% by mass [PE Americas, 2011, p. 30].
- For every 100 kg wet food waste, there are approximately 7.3 kg biosolids for the conventional treatment with anaerobic digestion[PE Americas, 2011, p. 30].
- Concerns about increased biosolids generation persist, and its potential environmental and economic implications may differ with location [Marashlian, 2004].
- Disposer usage showed minimal to no impact on the WWTPs total biosolids production and handling processes as the high VSD from food waste yielded a minimum amount of solids in the residue [Hernandez, 2002, “Hyperion Advanced Digestion Pilot Program”].
- Bench-scale jar testing showed food waste dewaters easily and used less polymer than primary sludge/thickened waste activated sludge [Hernandez, 2002, “Hyperion Advanced Digestion Pilot Program”].
- Food waste appears to possess a natural settling capability [Hernandez, 2002, “Los Angeles Digesters”].
- Before disposers are installed in large scale a long-term solution for the use of sludge should be agreed, because disposers will increase sludge production [Karrman, 2001].
- It is unlikely that biosolids produced by disposer usage would affect the contaminant level or reuse options of biosolids [CRC, 2000].
- Ground food waste will significantly increase the quantity of biosolids, however, Nilsson et al, 1990 notes that these biosolids will decompose easier than regular wastewater biosolids and more gas can be produced [Shpiner, 1997].

Table 8 – Disposer Market Share Effects. Various sources reporting on effects at certain disposer market share values are presented.

Source	Disposer Market Share	Effect
de Koning, 1996	10%	Solids to thickeners and digesters increase of 5%
Terpstra, 1995	10%	5% more biosolids
CRC, 2000	25%	No adverse effects to solids processing
Karlberg, 1999	25%	Sludge volume increase of 4%
Karrman, 2001	50%	Sludge increase is 7.2%, a 10% increase compared to no FWD use
Terpstra, 1995	100%	50% more biosolids

3.4.7 Effluent Characteristics

- The soluble and colloidal fraction of food waste that passes through primary treatment has a positive impact on the removal of nitrogen and phosphorus from wastewater [Leverenz, 2013, p. 6].
- The effluent total N was determined to range from 8.9 to 13.0 mg/L, decreasing as the percent of FWDs in use increased [Leverenz, 2013, p. 25].
- The effluent total Phosphorus was determined to be around 6.7-7.0 mg/L, decreasing as the amount of FWDs in use reached 100 percent [Leverenz, 2013, p. 25].
- Compared to no FWD usage, FWD usage can increase TN removal by 7 to 12 percent for the biological nutrient removal (BNR) process with 50 and 100 percent FWD usage, respectively, and TP removal could be increased by 52 to 74 percent in the BNR process with 50 to 100 percent FWD usage, respectively [Leverenz, 2013, p. 30].

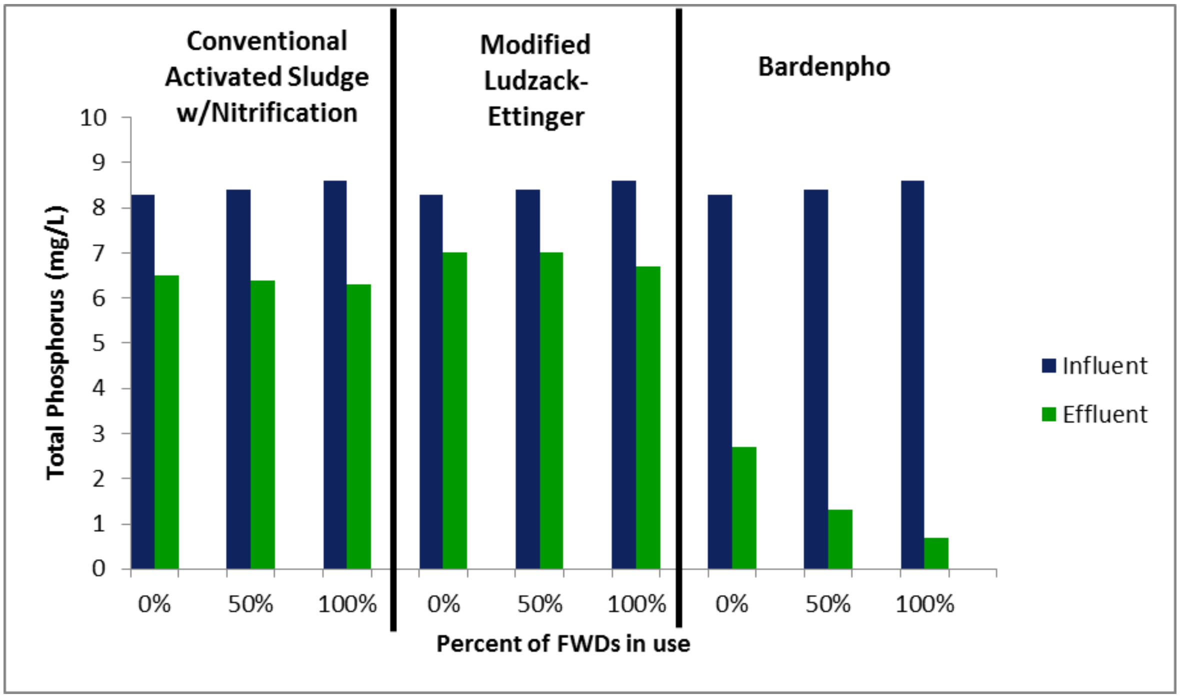

Figure 5 – Change in total Phosphorus. The influent and effluent TP in three wastewater scenarios [Leverenz, 2013].

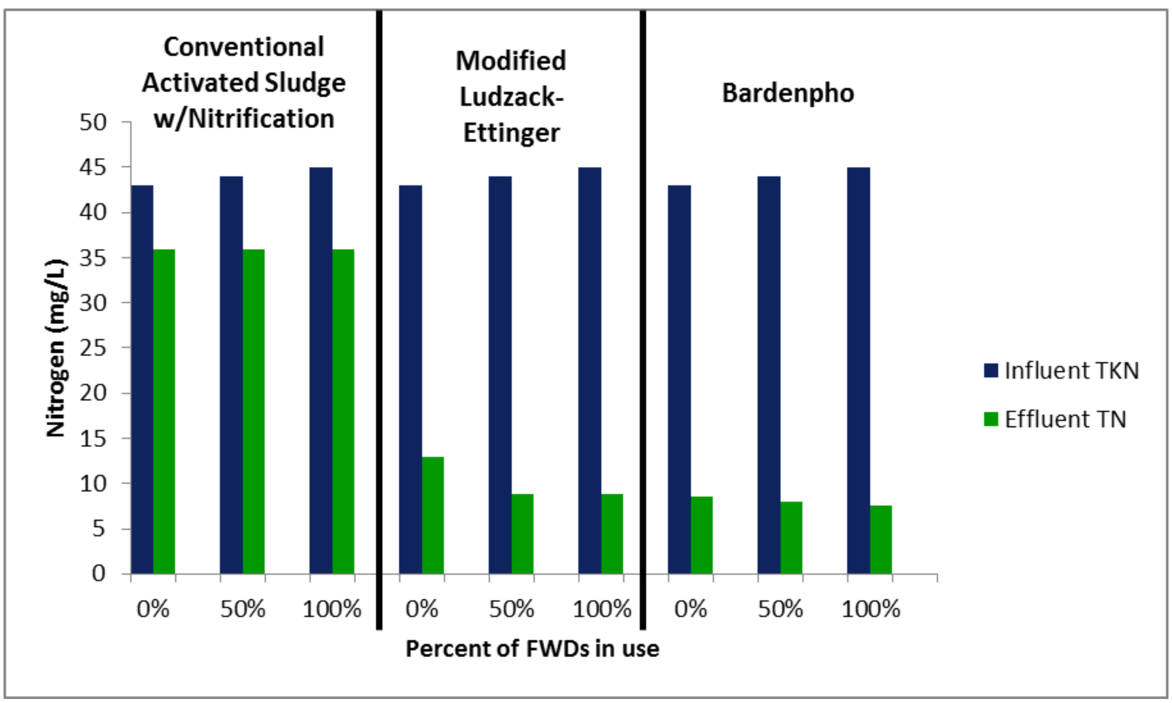

Figure 6 – Change in Nitrogen. The influent (TKN) and effluent (TN) in three wastewater scenarios [Leverenz, 2013].

- Both the COD removal and total nitrogen removal increased. The rbCOD/COD ratio increased from 0.20 to 0.25 and the COD/TN ration increased from 9.9 to 12 with a specific denitrification rate of about 0.06 kg NO_3-N/(kg MLVSS day) [Battistoni, 2007, p. 893].

- The COD and total nitrogen removal increased, creating a denitrification efficiency of 85% and a 39% reduction of energy requirements [Battistoni, 2007, p. 893].
- The composting system does not impact the waterborne wastewater system, while the food waste disposer system is estimated to cause some minor increases in discharges of nutrients and heavy metals to water. All impacts in both systems are rather small [Karrman, 2001].
- At a 50% disposer market share, disposers are unlikely to affect biosolids reuse, the marine environment, or energy consumption [CRC, 2000].
- The BOD increase in the effluent due to disposer usage equates to a 0.01 mg/L dissolved oxygen decrease in New York Harbor in 10 years (*de minimis* impact) [New York City Department of Environmental Protection, *Executive Summary*, 1997].
- Combined sewer overflow total stream BOD concentration increased 5% and TSS 2% over baseline from disposer usage. In the worst case area, the 4 mg/L minimum dissolved oxygen standard was exceeded by 1.5% over the baseline. This increase is considered to be *de minimis* [New York City Department of Environmental Protection, *Executive Summary*, 1997].
- At a 20% disposer market share, effluent quality can be maintained through operative WWTP adjustment. A higher market share will necessitate plant expansion, but will take many years to occur [Shpiner, 1997].

3.5 Fats, Oils, and Greases

- A small number of FOG deposits were found in pipes connected to upstream FWDs. However, FWDs were not the major contributors to the formation of FOG deposits [Mattsson, 2014, p. 8].
- Williams, 2012 research identified two possible mechanisms that may affect the formation and properties of FOG deposits in sewers [Williams, 2012, p. 6327]
    - Transformation of fatty acids from unsaturated to saturated form [Williams, 2012, p. 6327].
    - Biocalcification where higher levels of water hardness lead to harder deposits with higher melting points [Williams, 2012, p. 6327].
- An introduction of FWDs will probably not lead to a significant increase in fat in the sewer system considerably [Clauson-Kaas, 2011, p. 57].
- FFAs are likely to react with calcium ions by means of van der Waals forces or electrostatic repulsion (DLVO theory) [He, 2011, p. F].
- The primary lipid reacting in the FOG deposits was palmitic acid ($C_{16}H_{32}O_2$). Other lipids commonly found include oleic ($C_{18}H_{34}O_2$) and linoleic acid ($C_{18}H_{32}O_2$) [He, 2011, p. C].
- Deposits are likely formed primarily from free fatty acids (FFAs) reacting with ions such as calcium [He, 2011, p. F][Keener, 2007, p. 2241].
- The saturated fats and calcium levels in the FOG deposits are higher than background levels, suggesting that a chemical process is responsible for deposit formation [Keener, 2007, p. 2246].

4.0 Alternative Management Comparisons

- Using a disposer in combination with advanced wastewater treatment results in the lowest primary energy demand and a lower global warming potential as compared to alternative food waste management methods [InSinkErator - *Executive Summary* "Systems for the Management and Disposal of Food Waste," 2011, p. 2].

4.1 Landfills

- According to the EPA, after MSW has been recovered by recycling and composting, food waste is the largest component of MSW discarded to the landfill in the US at 21.1% [EPA, 2013, p. 7].
- FWDs would decrease the amount of moisture in the garbage by 10%. This reduction of moisture in the garbage results in a 16% higher calorific value for incineration from 15,345 kJ/kg to 17,783 kJ/kg [Tongji University, 2013].
- In a study in PuDong, the use of FWDs reduced the amount of wet waste in garbage by 10%. Based on current waste generation rates, this could equate to a reduction of over 1000 tons per day in Shanghai [Tongji University, 2013].
- If organic waste is removed from garbage collection, the amount of garbage is reduced by approximately 20-30%, which also results in fewer odor problems and better hygiene for workers who collect the garbage [Clauson-Kaas, 2011, p. 59].
- Food waste is the single largest component of municipal solid waste sent to landfills and many communities worldwide are focusing efforts to divert this organic waste in order to reduce greenhouse gas emissions at landfills [InSinkErator - *Executive Summary* "Systems for the Management and Disposal of Food Waste," 2011, p. 2].
- Using a disposer in conjunction with any of the eight wastewater treatment systems results in lower global warming potential than alternative landfilling options [InSinkErator - *Executive Summary* "Systems for the Management and Disposal of Food Waste," 2011, p. 2].
- Using a wastewater treatment route rather than a landfill in an area with 30,000 households would result in a carbon footprint reduction of 1.9 million kg, which is the equivalent of not driving 4.6 million miles [InSinkErator - *Executive Summary* "Systems for the Management and Disposal of Food Waste," 2011, p. 2].
- A study in Surahammar, Sweden, reported that the waste diverted to landfills decreased from 3600 tons/year in 1996 to 1400 tons/year in 2007, after the installation of FWDs increased from 0-50% [Evans, 2010, p. 1].
- Characteristics of Collected Garbage in landfills as compared to cases with no FWD use [Yang, 2009, p. 17]
    - Dry ratio of food waste declined by more than half [Yang, 2009, p. 17]
    - Moisture content decreased at least by half [Yang, 2009, p. 17]
    - Combustible matter increased about at least 1.7 times [Yang, 2009, p. 17]
    - Lower heating value increased about at least 2.0 times [Yang, 2009, p. 17]
- Lower heating value of flammable garbage collected after FWD installation increased to 12,500 kJ/kg [Yang, 2009, p. 23].
- Raising the lower heating value leads to less fuel needed for the incineration process of waste [Yang, 2009, p. 23].

- Raising the lower heating is more suitable for use as a solid fuel, rather than being solid waste [Yang, 2009, p. 23].
- Flammable garbage with a higher lower heating value (greater than 12,560 kJ/kg) and lower moisture content is best for use as a solid fuel, and the presence of food waste disposers provides these conditions [Yang, 2009, p. 23].
- According to Yang (2007), through field surveys regarding the use of FWDs in a village of 327 people with a 97% disposer penetration, the average reduction rate of garbage being sent to landfills was 31% [Yang, 2009, p. 24].
- Using FWDs causes a decrease in the generation rate of garbage being sent to landfills, so a cost-savings benefit in terms of garbage collection and transportation can be obtained and materials recycling and thermal energy recovery will become easier [Yang, 2009, p. 24].
- In this study, the introduction of food disposers into the waste and wastewater management systems led to net economic benefits that ranged between 7.2% and 44.0% of the current solid waste management cost. Food waste disposers can constitute a viable option (economically and environmentally) that could reduce the load on the solid waste stream and minimize the amount of end waste requiring landfilling [Marashlian, 2004].
- The neuslavage study shows increased upper respiratory infections for garbage collectors than supervisors related to microbiological exposure during work [CRC, 2000].
- The Department of Sanitation recognizes the potential of disposers to make a positive impact in New York City residential waste management. Benefits include reduced odors and pest attraction, and better separation of recyclables [New York City Department of Environmental Protection, 1997].
- At a 38% disposer market share, grinding 50% of the food waste through disposers will save $4 M in solid waste export costs [New York City Department of Environmental Protection, *Executive Summary*, 1997].

4.2 Composting and Curbside Food Waste Collection

- FWD can be used in conjunction with curbside food waste collection (CFWC) to maximize the overall diversion. Therefore, FWD and CFWC are complementary, rather than competing technologies [Leverenz, 2013, p. 4].
- FWD eliminates the need for additional processing at the wastewater treatment plant, unlike CFWC. CFWC requires additional processing besides grinding to eliminate the additional debris and contaminants in the food waste [Leverenz, 2013, p. 10].
- Total cost for composting facility is estimated at $40 per ton [WERF, 2012, p. A23].
- Based on several steps for the compost alternative, such as transportation to compost facility, ventilation, handling, turning, composition, land application, application as fertilizer the total CO_2 emissions for composting is 1050 tons/year [WERF, 2012, p. A25].
- The GWP for composting is -14 kgCO_2e/tKFW whereas the GWP for using a FWD in conjunction with AD is -168 kgCO_2e/tKFW [Evans, 2007, p. 4].
- FWDs are not meant to discourage composting. Rather, FWDs can be seen as a convenient and hygienic method to divert food waste from landfills [Evans, 2007, p. 5].

- The main difference between using a FWD with AD and composting is that using a FWD creates energy (renewable fuel from the CH_4), whereas the composting method consumes energy [Evans, 2007, p. 42].
- Food waste collection followed by anaerobic digestion and biogas utilization in power plants has been judged more positive than separate collection followed by composting [de Koning, 2004].
- The food waste disposer is designed to grind only food waste. Materials other than food waste (ex., bottle caps, textiles, etc.) will lead to device jamming. Thus, the disposer is a natural selector of food waste. In contrast, composting largely depends upon the education and goodwill of participants as to the quality of collection [CECED, 2003].
- The food waste disposer system appears to be slightly less costly than central composting when only the costs for water and refuge handling are considered, and the user pays for the purchase and installation of the disposer themselves [Karrman, 2001].
- The food waste disposer alternative causes 3 times less global warming than the composting alternative, due to the reduction of truck transport [Karrman, 2001].
- Concentrations of bacteria and molds that can interfere with human health and wellbeing are greater when there are organic waste buckets and bins used for composting purposes [CRC, 2000].
- Most people are unwilling to separate food scrap for Department of Sanitation pickup [New York City Department of Environmental Protection, 1997].
- Home composting produces a high strength (BOD) leachate when food waste is present. There is no readily available mechanism to manage this leachate [Waste Management Research Unit, 1994].
- Methane has a much greater greenhouse effect (on the environment) than the equivalent of carbon dioxide. Environmentally, therefore, it is desirable to minimize methane release. There is no readily available mechanism for achieving this with household composting. In contrast, landfills and sewage treatment works can be constructed to maximize methane recovery as a fuel [Waste Management Research Unit, 1994].

5.0 Life Cycle Analyses

5.1 "Sustainable Food Waste Evaluation"

Water Environment Research Foundation (WERF)

The Life Cycle Analysis is a comparison of five systems for the processing wastes based on a representative community of 100,000 people in North America. The five systems are:

1. Mixed Material Recovery Facility (MRF)
2. Landfill
3. Wastewater Treatment Plant (WWTPP)/Hauled
4. Composting
5. Wastewater Treatment Plant (WWTP)/Sewered

The LCA analyzed capital and operating costs, carbon footprint, space footprint, labor demands, diesel fuel demand, electricity demand, and water demand for each of the five systems.

Capital and Operating Costs: The costs of the five systems ranked from highest to lowest cost are: Mixed material recovery facility, landfill, WWTP/hauled, composting, and WWTP/sewered.

Carbon Footprint: The carbon footprint (CO_2e) from the five food waste management options ranked from highest to lowest is: landfill, mixed MRF, WWTP/sewers, compost, WWTP/hauled. The lower carbon footprint in the WWTP/hauled method is probably due to the electricity generation from biogas produced by the digesters. The WWTP/sewered alternative has a relatively high carbon footprint, probably due to the uncertainty of the methane released in the sewers. Additionally, since there is little information known about the anaerobic decomposition that occurs in the sewers, so the CO_2e emissions for the WWTP/sewered alternative provides a large degree of uncertainty.

Space Footprint: The space footprint, or area requirements, of the alternative methods ranked from highest to lowest are: composting, landfill, mixed MRF, WWTP/hauled, WWTP/sewers.

Diesel Fuel Demand: The diesel usage for the five systems ranked from highest usage to lowest is: composting, mixed MRF, landfill, WWTP/hauled, WWTP/sewered.

Water Demand: The water demand for the five systems ranked from highest water demand to lowest water demand (measured in Mgal/year) is: WWTP/sewers, WWTP/hauled, mixed MRF, composting, landfill.

Overall, the use of a FWD has the lowest cost of all other alternatives studied, a small space footprint, and low diesel requirements. However, the use of a FWD does require water. There is a greater electricity use to account for the aeration necessary to process the addition of the food waste, but there is also additional energy production due to anaerobic digestion.

[WERF, 2012]

5.2 "Life Cycle Assessment of Systems for the Management and Disposal of Food Waste"

PE Americas

The Life Cycle Analysis (LCA) is a comparison of a total of twelve end-of-life disposal options, including two landfilling options, eight wastewater treatment options that occur in conjunction with a FWD, one incineration system, and one composting system. The twelve systems are:

1. Landfill with Generation

2. Landfill with Flare
3. Extended Aeration
4. Extended Aeration/Landfill
5. Extended Lime/Slab
6. Conventional Treatment/Incineration
7. Conventional Lime Slab
8. Conventional Treatment/Anaerobic Digestion/Flare
9. Conventional Treatment/Anaerobic Digestion/Boiler
10. Conventional Treatment/Anaerobic Digestion/Cogeneration
11. Incineration
12. Composting

This LCA found that using a disposer in conjunction with any of the eight wastewater treatment systems results in lower global warming potential than both landfilling options. Additionally, using a disposer in combination with advanced wastewater treatment results in the lowest primary energy demand as compared to the landfill systems as well as the waste-to-energy and emissions-controlled composting systems.

[PE Americas, 2011]

5.3 "Life-Cycle Comparison of Five Engineered Systems for Managing Food Waste"

Dr. Carol Diggelman, University of Wisconsin

The Life Cycle Analysis (LCA) is a comparison of five systems for the processing of 100 kg of food waste. The five systems are:

1. Food Waste Disposer/Wastewater Treatment Plant (FWD/WWTP)
2. Municipal Solid Waste Collection/Landfill (MSW/L)
3. Municipal Solid Waste Collection/Compost (MSW/C)
4. Municipal Solid Waste Collection/Incineration (MSW/I)
5. Food Waste Disposer/On-Site Septic System (FWD/OSS)

The LCA analyzed land requirements, total system energy, total system materials, total emission to the environment, and total system cost for each method. The ranking for these areas were:

Total land requirements: FWD/WWTP < MSW/I < MSW/L < MSW/C < FWD/OSS
Total system energy requirements: FWD/WWTP < MSW/L < MSW/C < MSW/I < FWD/OSS
Total system materials: MSW/C < MSW/I < FWD/WWTP < MSW/L < FWD/OSS
Total flows to environment: MSW/C < MSW/L < MSW/L < FWD/WWTP < FWD/OSS
Total system costs: MSW/L < MSW/C < FWD/WWTP < MSW/I < FWD/OSS

Overall, of the five systems, the FWD/WWTP has the lowest municipality cost (system cost due to disposer cost, which is paid by the homeowner); least air emissions; converts food waste to a recycled resource; is the most convenient system of food waste disposal; is the most likely system for organic source separation; and overall is the most environmentally friendly and sustainable option.

[Diggelman, 1998]

5.4 "Assessment of Food Disposal Options in Multi-Unit Dwellings in Sydney"

CRC for Waste Management and Pollution Control Limited

The Life Cycle Analysis (LCA) is a comparison of four systems for the processing of 182 wet kg of food waste. The four systems are:

1. Food Waste Disposer/Wastewater Treatment Plant (FWD/WWTP)
2. Home Composting (HC)
3. Co-Disposal or Municipal Solid Waste Collection/Landfill (MSW/L)
4. Centralized Composting or Municipal Solid Waste Collection/Compost (MSW/C)

The research was undertaken as five separate but interlinked studies examining technical and operational, environmental, economic, social acceptance, and microbial risk impacts. [Note: The beneficial use of by-products (i.e., compost and biosolids) was not part of the study. Also, the amount of recovered energy is uncertain should biogas be used for energy recovery. Electricity generation from biogas can lead to high environmental improvements for the FWD/WWTP and Co-Disposal (MSW/Landfill) systems. However, little biogas was being recovered at the WWTP (Bondi STP) that was used in the study. In addition, the Bondi STP is a "high rate primary" plant, thus, nutrients (nitrogen and phosphorus) are released to treated effluent, which caused a poor eutrophication rating for the FWD/WWTP system.]

Environmental Impacts: Home Composting has the smallest environmental impacts. The FWD/WWTP system ranked second in terms of energy consumption, global warming potential, and eutrophication potential; but fourth in terms of human, aquatic and terrestrial toxicity potential. Co-Disposal ranked second highest in toxicity potential and eutrophication potential; ranked slightly behind FWD/WWTP for energy consumption and acidification; and had the lowest ranking for global warming potential. Centralized Composting has a relatively poor environmental performance due to its energy intense collection activities, ranking fourth for energy and acidification; and third in the remaining categories.

System Cost Comparison: Home Composting is the least expensive option for multi-unit residents; then Centralized Composting; Co-disposal; and FWD/WWTP is the most expensive (due to a high initial unit and installation cost paid by homeowner). From a system point-of-view, the FWD/WWTP system was again the most expensive; Co-Disposal (the current system utilized by Sydney) has landfill space and does not require capital investment; Centralized Composting would necessitate capital investment. The FWD/WWTP system may require capital investment beyond a 25% market share.

Health Risk Comparison: The FWD/WWTP system may only marginally increase the rate of sanitary sewer overflows during periods when the sewer is flowing at 100%. Home Composting without pet fecal waste or meat products addition should result in acceptably low infection rates for all pathogen groups. Centralized Composting (including human fecal waste) should be satisfactory from the point of no significant pathogen risks. Overall vector-based diseases were not considered significantly different due to the operation of food waste disposal units and domestic composting containers.

Social Impact Comparison: Disposal of food with municipal waste was judged as the least satisfactory option (current Sydney system). Home Composting was judged impractical for multi-unit dwellings. FWD/WWTP and food waste collection with Centralized Composting were much more appropriate, provisional on the level of treatment that would enable reuse of the waste residuals (which was not studied).

[CRC for Waste Management and Pollution Control Limited, 2000]

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