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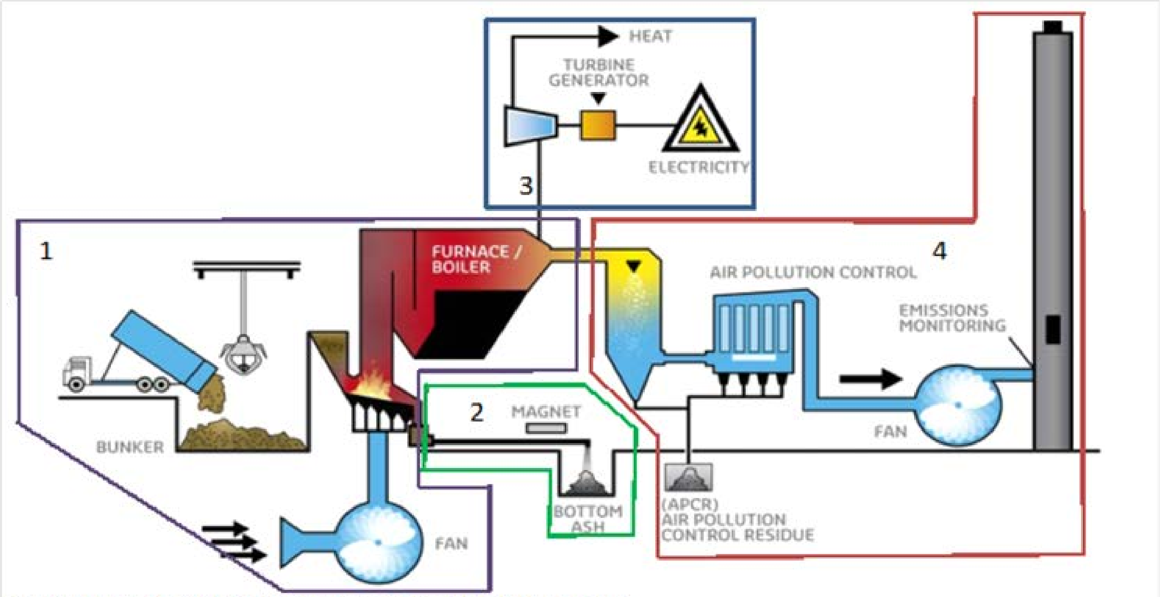
Considerations for Net Zero Waste Installations

Treatment of Municipal Solid Waste

Stephen D. Cosper

September 2015



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Final Report

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Abstract

Today's Army faces significant threats to our energy and water supply requirements both home and abroad. Addressing energy/water security and sustainability is essential to mission accomplishment. The Army's goal is to manage "net zero installations" (NZI), i.e., installations that operate not only on a net zero energy basis, but net zero water and waste as well. A net zero waste installation reduces, reuses, and recovers waste streams, converting them to resource values with zero landfill over the course of a year. This work outlines a plan for U.S. Army Engineer Research and Development Center (ERDC) researchers to support the Army NZI vision by developing an NZI-Optimization tool that includes energy and water tracking and optimization features. This preliminary stage of work was undertaken to characterize Municipal Solid Waste (MSW), and describe the processes and technologies that may be integrated to support a Net-Zero Water (NZW) installation.

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Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Research, Development, Test and Evaluation (RDT&E) project, "Integrating Installation Energy, Water, and Waste Modeling," via work units 8609C7 and BH01K8, Integrated Installation Energy, Water and Waste (EW2) Modeling and LG7452, "Computational Framework for Energy, Water and Waste."

The work was performed by the Environmental Processes Branch (CN-E) of the Environmental Division (CN), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). The CERL principal investigator was Stephen Cosper. At the time of publication, Garth Anderson was Acting Chief, CEERD-CN-E, and Michelle Hanson was Chief, CEERD-CN. The associated Technical Director was Kurt Kinnevan, CEERD-CV-T. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel.

COL Jeffrey R. Eckstein was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

Background

The U.S. Army faces significant challenges in meeting its energy and water supply requirements both at home and abroad. Addressing energy/water security and sustainability at Army installations is operationally necessary, financially prudent, and essential to mission accomplishment. Moreover, the Army is required by law to reduce overall facility energy use by 30% by 2015 and to eliminate fossil fuel use in new and renovated facilities by 2030 (EPACT 2005, EISA 2007). To that end, Army policy is to achieve eight net zero energy pilot installations by 2020, 25 net zero energy installations by 2031, and for all installations to achieve net zero energy status by 2058 (HQDA 2012a). More generally, the Army's vision is to appropriately manage all its natural resources with a goal of "Net Zero Installations" (NZI), the goal of which is to manage its installations not only as net zero energy, but net zero water and waste as well.

The approach to creating a net zero waste installation is similar to creating a net zero energy installation. A net zero waste installation reduces, reuses, and recovers waste streams, converting them to resource values with zero landfill over the course of a year. The components of net zero solid waste start with reducing the amount of waste generated, re-purposing waste, maximizing recycling of waste stream to reclaim recyclable and compostable materials, recovery to generate energy as a by-product of waste reduction, with disposal being non-existent. The best strategy is to consider the waste stream when purchasing items, reduce the volume of packaging, reuse as much as possible, and recycle the rest. A true cradle-to-cradle strategy considers the end state at the time the purchase decision is made. A net zero waste strategy eliminates the need for landfills, protects human health, optimizes use of limited resources and keeps the environment clean (HQDA 2012b).

This work was undertaken to support the Army NZI vision by developing an NZI-Optimization tool that includes energy and water tracking and optimization features. This tool will incorporate portions of the Municipal Solid Waste Decision Support Tool (MSW-DST), a comprehensive modeling and planning system for local government units developed by the Research Triangle Institute (RTI) and the U.S. Environmental Protection

Agency (USEPA) Air Pollution Prevention and Control Division. This preliminary stage of work was undertaken to characterize Municipal Solid Waste (MSW), and to describe the processes and technologies that may be integrated to support a NZW installation.

Objectives

The objectives of this stage of work were to characterize MSW, and describe the processes and technologies that may be integrated to support a NZW installation.

Approach

A literature search was done to characterize the various waste streams that make up MSW in terms of: (1) content, (2) collection, (3) diversion, and (4) disposal. Methods of MSW disposal were investigated and summarized, including energy and water use factors to help integrate net zero waste concepts with those of net zero energy and net zero water.

Mode of technology transfer

It is anticipated that the results of this work will be instrumental in developing an NZI-Optimization tool that includes energy and water tracking and optimization features.

2 Mixed Wastes

2.1 Terminology

MSW typically refers to solid wastes that are routinely generated from the daily operation of a given municipality. For the purposes of this work, an Army installation is considered equivalent to a municipality. In this document, the term “MSW” is defined as household wastes and wastes from business and commercial office activities. Excluded from this definition are mining wastes, construction and demolition wastes, hazardous wastes, industrial and manufacturing wastes, wastes associated with training, and commercial vehicular wastes.

MSW is a relatively small fraction of the total amount of solid waste produced in the United States. Mining wastes and construction and demolition wastes are produced in much greater quantities (McLeod and Cherrit 2011). However, because MSW is produced continuously and because it contains significant organic content, particularly wet organic material, management of MSW is generally more costly per unit volume or mass than most other waste types, except hazardous wastes and many industrial/manufacturing wastes (McLeod and Cherrit 2011). Also, while the mixed nature of MSW creates recycling and reuse challenges, those challenges can be overcome.

The term “waste diversion” refers to the reduction in the amount of wastes that are disposed. This includes both reducing the amount of waste generated in the first place, and recycling and reusing the waste product. Waste to energy (WTE) is a form of disposal in which energy is recovered from the wastes. Similarly, other waste treatments produce beneficial products from waste, i.e., composting and anaerobic digestion, which recover nutrients from the processed waste stream. “Disposal” refers to the final disposition of wastes that cannot otherwise be recycled or reused.

2.2 Waste characterization

The simplest way to characterize waste is by the total amount of MSW generated. This can be done by auditing waste collection vehicles used to pick up the wastes, or by monitoring total wastes taken at the waste disposal or treatment facility. Waste trucks may be weighed before and after collection, enabling calculation of accurate quantities of wastes collected. By relating these quantities to specific pick up routes, it is possible to identify areas that produce more wastes than others. Technology is even available for trucks to weigh wastes collected at specific collection sites, which can be further refine waste generation information.

A physical waste audit can yield a more detailed waste characterization of a given waste stream. This involves collecting wastes from the area of interest, physically sorting the wastes, and then weighing the fractions of waste of interest. Note that physical waste audits do *not* depend on curbside garbage separation. Because environmental factors can affect waste generation over time (Tchobanoglous et al. 1977), such audits are usually conducted several times over a year. Modeling approaches may then be applied to fully develop a waste generation profile for a given area.

The USEPA has conducted national assessments of hazardous wastes in the United States. Figure 1 shows a breakdown of the typical composition of MSW in the United States. (USEPA 2011). The majority of MSW, well over 80%, is organic. Most of the constituents, if separated, could be recycled, composted, treated for nutrient recovery, or burned to produce energy. It is reasonable to expect that the types of MSW generation at military bases would be similar to that of the nation as a whole, particularly at housing/residential areas. Office wastes might be expected to have a higher level of paper.

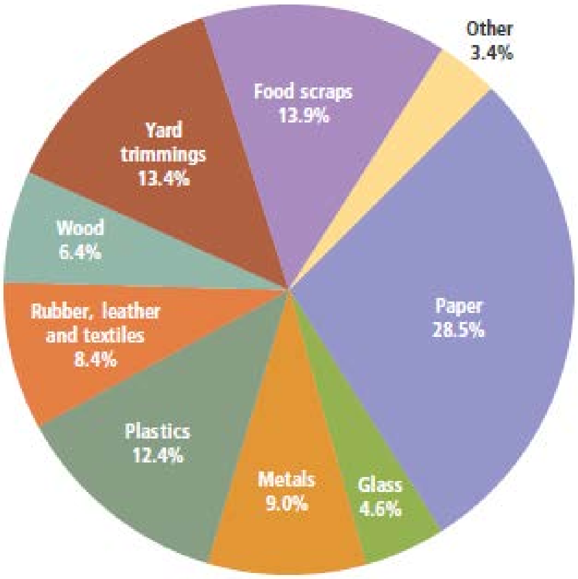


Figure 1. Typical composition of MSW (USEPA 2010).

Medina and Waisner (2011) conducted a study of solid and hazardous waste generation at military installations, focusing on Joint Base Lewis-McCord, WA (JBLM) and Picatinny Arsenal, NJ. Because the study focused on all solid wastes, the findings were greatly affected by large building and demolition projects and soil remediation projects. However, this study also found that the fluctuation in populations at these installations was a critical issue that contributed to waste generation. For example, between fiscal year 2003 (FY03) and FY08, the population on these installations varied from 25,494 to 51,132. (The U.S. Federal fiscal year is from 1 October to 30 September.) These population changes were related to preparing units for large deployments during Operations Enduring Freedom and Iraqi Freedom.

Residential areas at military installations are likely to be similar to national averages in waste generation. However, one key difference is the rate of turnover at military residential areas, which is higher than that of civilian communities. When a residence is vacated, a large amount of waste is typically generated, as residents dispose of unwanted clothes, electronics, furniture, household items, food, etc. Managing these departures will be critical in meeting net zero goals.

2.3 Waste collection

MSW collection is done with specialized motor vehicles. In the United States, curbside collection is considered standard. Household (family housing) residents place waste in containers (often specified or provided by the service provider) in a designated curbside area outside the house for pickup. Apartment or condominium (single soldier barracks) residents typically take their garbage to central dumpster. However, curbside collection is not the only waste management option. In many other countries, residents are expected to sort their refuse and take it to the appropriate disposal site. At office complexes, a janitorial service usually places the building's waste in a central dumpster.

Each of these options can include a source separation. Typical separations include white paper, cardboard, plastic bottles, glass, and yard waste. However, source separation is not universal, and has even been discontinued in some areas due to a lack of market for recycled materials.

Net zero waste must also consider the energy efficiency of the waste collection vehicle itself. A variety of refuse collection vehicles can be used

(Tchobanoglous et al. 1977). Front loading vehicles are ideal for collection of dumpsters, whereas side and rear loading are preferred for curbside pickup. Some vehicles have separate compartments to facilitate collections of sorted wastes. Refuse vehicles normally achieve 6 mpg (range 5 to 7) on a regular pickup route (Robertson 2011). It is expected that this will likely change within the next 5 years due to new regulations.

The USEPA and the National Highway Traffic Safety Administration (NHTSA) have jointly developed new regulations that take into account the vehicle and the type of work it performs. The regulation develops a unit of gallons per 1,000 ton-mile, which is the energy required by a gallon of fuel to move a ton 1 mile (USEPA and USDOT 2011). By these new standards, a new refuse vehicle must have a fuel consumption of 22.1 gallons per 1,000 ton-mile (2,862 BTU per ton-mile). This calculation is a more accurate description of fuel consumption since it takes into effect the weight that is added to the refuse vehicle during collection and transport of solid wastes.

2.4 Diversion options

“Waste diversion” is the prevention and reduction of generated waste through source reduction, recycling, reuse, or composting (USEPA 2012). As a result, the material never actually becomes waste. Waste diversion generates a host of environmental, financial, and social benefits, including conserving energy, reducing disposal costs, and reducing the burden on landfills and other waste disposal methods. Waste diversion is the preferred goal of the Net Zero program.

Separation of wastes is a critical part of waste diversion. Although separation is probably most efficiently conducted at the point of generation, post collection separation is also feasible.

2.4.1 Metal

Diversion of metals in waste streams begins with the reduction of metallic items in the waste stream. Perhaps the largest source of metals in MSW is from single use metallic beverage containers. Encouraging households to use larger (typically plastic) containers or reusable drink containers (such as thermoses) can reduce the amount of metals in the waste stream. Fountain drink loyalty programs with reusable cups can also reduce the amount of metals in the waste stream.

Most metals found in MSW can be recovered and recycled (Pretz and Julius 2011). Aluminum, which is widely used in drink containers, is the most commonly recycled metal. Metallic cans can also be recovered and recycled, as can ferrous metals. The economics of recycling can change quickly over time, particularly for aluminum. Sometimes recycled metal is competitive with or even less expensive than newly produced metal from ore. Since cost savings associated with the environmental advantages of recycling have not yet been quantified for inclusion in economic analyses, it may make sense to subsidize recycling efforts to help keep recycled metal competitive with new materials.

2.4.2 Glass

Glass is another readily recyclable material (Butler and Hooper 2011). Glass comes in three main forms: (1) containers for beverages, food stuffs, etc., (2) flat glass, which is primarily windows in houses, cars, picture frames, and mirrors, and (3) glasses associated with high value technical and consumer products. Glass bottles can be cleaned and reused. This is a common practice throughout most of the world, though it is no longer widespread in the United States where plastic has replaced glass as a preferred drink container. Glass can also be ground and reused as a feedstock for new glass production. Ground glass can also be used as a sand substitute in some construction fill applications. Rounded glass pieces can be incorporated in concrete or plaster to achieve a decorative effect.

2.4.3 Cardboard

Cardboard is generally used as a packaging material. Overpackaging often results in the excessive use of cardboard and other packing materials. An easy way to reduce cardboard waste is to work with vendors to reduce over packaging. Many cardboard boxes can be reused for packing, shipping, and storage. The key to this reuse is to keep the boxes dry and to limit damage to them. Cardboard can also be sent to paper recycling facilities for use as a raw material in paper mills (Scott 2011).

2.4.4 Paper

A major source of paper use is from printing of electronic information. A simple means of reducing paper use from this is to encourage two-sided printing by setting printer defaults to this format. Another means to reduce paper use is to encourage the use of electronic readers instead of printing paper copies.

Paper may also be recycled, reprocessed, and used as a raw material in paper mills. However, a given paper source has a limited recycling life, as the paper fibers wear out after each use. Even so, paper is one of the most widely recycled constituents in MSW. It is estimated that about 60% of paper is recycled (Scott 2011).

2.4.5 Plastics

In the United States, plastics have become the preferred container material for beverages and food. Consequently, these materials make up a large fraction of MSW. There are many great opportunities for reducing plastic materials in wastes. A large sector of plastic bottle waste comes from the use of single use water bottles. Much of this use is due to the mistaken belief that bottled water is safer than tap water to drink, or to the convenience of easy-to-carry bottle water. In reality, tap water quality is more regulated and monitored than most bottled water. Educational programs can help to dispel the mistaken belief regarding the superior safety of bottle water. Installation of tap water filters can help to address concerns about particulates in water pipes. By providing convenient fill up sources, the use of reusable containers can be promoted.

Disposable shopping bags are another major source of waste plastic. People can be encouraged to use reusable bags.

Nonetheless, plastics are such a useful material they will remain in the waste stream. Once again, there are many opportunities for diversion if plastic materials are cleaned and separated. Technology has been developed to wash, disinfect, and reuse plastic bottles. It is not clear if this will become publically acceptable, but could be viable in some cases. However, plastics can be recycled. Polyester-based plastic containers and bags can be drawn into fibers, which can be used to make clothes, bottles, and other plastic products (Bartle 2011, Lettieri and Al-Salem 2011). Thermochemical treatments, such as gasification and pyrolysis, can be used to recover hydrocarbon chemicals from bottles and bags, which can be used as raw materials for new plastic production (Letteiri and Al-Salem 2011). Plastics are also excellent materials for WTE recovery, particularly if composed of non-chlorinated resins.

2.4.6 Rubber/leather/textiles

Rubber, leather, and textiles are organic materials that are highly resistant to degradation. Probably the largest source of rubber is used tires. Since these are usually changed at a service center, they are not commonly disposed as MSW. However, recycling opportunities abound for used tires: they may be retreaded to extend their useful “lives”; or processed for use as noise barriers, artificial reefs, fill, landfill cap material, insulation, sport and playground surfaces, or surfaces for industrial applications (such as non-slip floor mats); reduced to industrial powders; or shredded for use as a berm material for small arms firing ranges (Shulman 2011). Rubber is a good material for WTE production as well.

Textiles are primarily in the form of clothing, bedding, and draperies. In many cases, unwanted items are still functionally usable and can be reused (Bartle 2011). Consignment shops and charities will often find new users for these materials. These materials can also be cut up for other uses, such as art projects and quilting. Textiles can also be recycled or recovered by fiber recycling industries, although these can prove complex processes (Bartle 2011). Grinding fibers also yield products for beneficial reuse, such as insulation products. Dry textiles can be incinerated for energy recovery.

Like textiles, most leather products, such as clothes, furniture, and belts, can be reused. Leathers are particularly resistant to degradation and wear, and can be reconditioned in some cases.

2.4.7 Vegetation/yard waste

Beneficial reuse of vegetation/yard waste is feasible if these wastes are separated before disposal. Composting is a great approach to beneficially reuse these materials as a nutrient rich soil amendment. Large woody debris can be used for building, erosion control (Channell et al. 2009, Abbe and Montgomery 1996), playground equipment, wood chips for soil stabilization, and fireplace wood. Vegetation can also be ground and used as a feedstock for paper mills; this approach was used to recycle large amounts of vegetative debris in the aftermath of Hurricane Katrina (Brandon, et al. 2011). Dried, finely ground woody debris can be added to coal as a fuel source.

2.4.8 Food waste

Food waste is perhaps the most problematic of the major waste constituents found in MSW. Spoilage creates offensive odors and health risks that must be managed. Because food wastes are wet, they are not amenable to incineration, although they can be potentially dried. Food wastes may be concentrated, or mixed with paper and plastic service items.

The first step would be to reduce food wastes. This involves better planning so that the appropriate amount of food is prepared and used per meal. This may be accomplished with training courses. Since reducing food wastes also reduces spending, such training could assist military families to better manage their finances.

Once food waste is generated, diversion can be difficult. A key is good separation (Bernstad and la Cour Jansen 2012). Keeping food waste separate from other wastes eliminates the problem of separating actual food wastes from paper and plastic packing, containers, and utensils. This also reduces the overall amount of wastes in this category and simplifies further processing. Once separated, food waste can be composted, treated in an anaerobic digester to recover nutrients and generate energy, or food used as a raw material for biofuel generation.

2.4.9 Household hazardous waste (HHHW)

The Resource Conservation and Recovery Act (RCRA) defines hazardous waste. The definition exempts household wastes. Nevertheless, hazardous chemicals and materials in household waste can be very problematic (Slack and Letcher 2011). HHHW is a non-regulatory term used to describe unwanted household chemicals, such as cleaning chemicals, paints, and automotive chemicals, that would be considered hazardous wastes if they were in an industrial or commercial setting. The presence of these materials in MSW can greatly complicate resource recovery, making net zero more difficult.

Diversion is the key to eliminating these items in MSW. Many waste management organization are starting zero tolerance policies for HHHW. To do this, alternatives are needed to give customers outlets to safely dispose of unwanted HHHW. Periodic turn-in days can be valuable for this purpose. Collected materials in good condition could be sent to an exchange, where they can be offered at a low price or free of charge to other potential users. Other materials can be sent to recyclers. In some cases, some of the materials may need to be safely disposed.

2.4.10 Electronic waste (E-waste)

Electronic wastes (“E-wastes”) are disposed electronic goods. The rapid development of electronic technology has substantially increased the disposal of old goods as new replacement items are purchased. Studies have shown that metals in E-waste can be leached over time in landfill environments (Li et al. 2006). Fortunately, there are opportunities for diversion to reduce the need for disposal (Thibodeau 2002, Channell et al. 2009). Many unwanted electronic products still in good working order could be resold at used electronic stores or given away to charities and schools. E-waste recyclers accept a wide range of electronic items to recover batteries, electronic boards, and valuable metals.

2.4.11 Batteries

Batteries are specialty wastes commonly found in E-waste that could also be considered as HHHW. The development and increased use of mobile electronic technologies has increased battery use (Genaidy and Sequeira 2011). Batteries contain metals and acids that can become environmental contaminants if leached. Like HHHW, batteries mixed with MSW can complicate resource recovery.

Once again, separation and diversion are important. Better, “zero tolerance” disposal methods for MSW should be adopted, along with sufficient alternative turn-in sites to discourage illicit disposal. Since many electronic items are disposed in a useful state, batteries can be recovered and reused. In some cases, batteries can be reconditioned and reused. For many other batteries, useful metals (particularly lead) and constituents can be extracted for reuse (Genaidy and Sequeira 2011). If needed, batteries can be disposed of in an environmentally safe manner.

2.5 Disposal options

Disposal options may be categorized as primary, secondary (limited), and tertiary (very limited). Primary options are applicable to a broad range of possible waste types and could be used as a primary waste management process for all, or in some cases, most MSW. Secondary options are limited to a more limited set of wastes. Tertiary options have either very limited application; or technical, perception, or liability issues. By virtue of their "very limited" applicability, tertiary options may not be viable, or at best, may have limited possibilities.

A second consideration in all cases is whether a disposal application can generate energy as a usable by-product, in other words, whether the applications is a "WTE technology."

2.5.1 Landfill

Landfilling is still the most widely used means of solid waste disposal in the United States today. This approach involves transporting wastes to an MSW landfill, where it may first be processed (weighed, in which it may undergo some separation, possibly including some resource recovery or baling), then buried in a cell. MSW landfills are highly engineered facilities designed to minimize migration of contaminants that may be found in the wastes.

Landfilling is not considered a resource recovery or WTE approach. However, it has been found that biological reactions in the wastes can produce gases. If uncontrolled, these gases can be hazard, spreading foul orders and causing potential combustion hazards in basements of surrounding homes. However, if recovered, these gases, which contain methane, can be a resource a potentially useful fuel source. The gas usually requires processing to remove offensive elements like hydrogen sulfide, which is foul smelling, potentially toxic at very high concentrations, and can contribute to acid precipitation, and to concentrate the methane to commercially useful concentrations.

Over the past decade, the use of natural gas, which is also primarily composed of methane, has greatly increased in the United States (Ritchie 2012). In fact, new technologies and approaches that have allowed natural gas to be recovered from previously inaccessible formations, have created so much new production and new potential that some have expressed the belief that this fuels source could make the United States energy independent by 2030 (Mullaney 2012).

This abundance of natural gas availability could be affect the demand for biologically produced methane, such as that produced in landfills, either positively or negatively. The increasing use of gas-powered engines and other technologies could support the demand for biologically produced methane. On the other hand, if fossil sources of natural gas become relatively less expensive, biologically produced methane may not be competitive from a cost standpoint.

2.5.2 Incineration/combustion

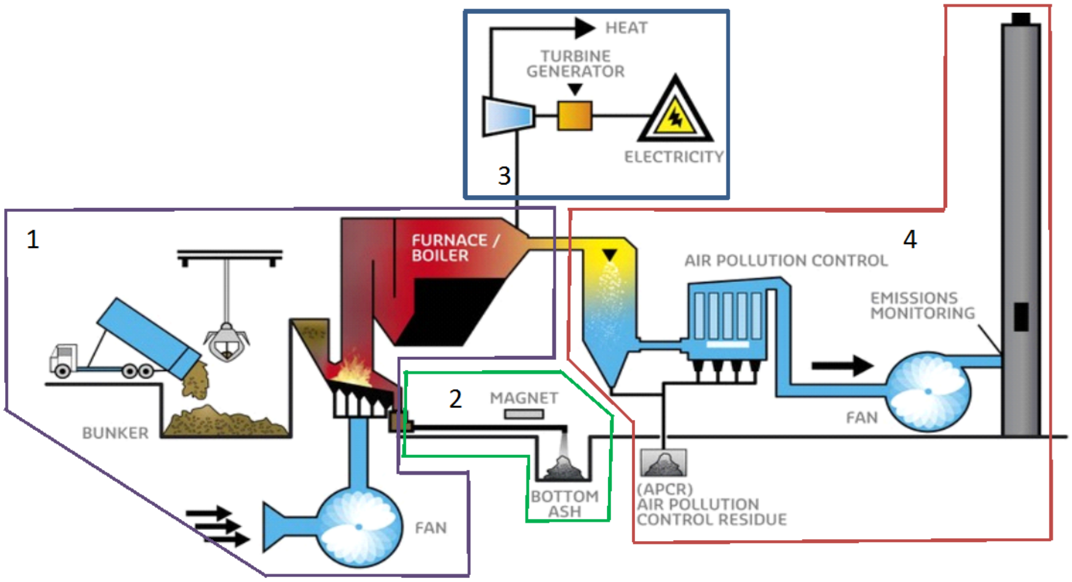
Incineration involves the combustion of organic waste portions at high temperature in a controlled reactor (Vallero 2011). Incineration can be operated as a WTE technology to provide energy from the combustion of wastes. This would require the wastes themselves to provide enough combustion energy to generate steam to drive an energy turbine. However, WTE is not always possible, because not all MSW waste streams are able to burn effectively. Additional energy may be needed to achieve appropriate combustion, particularly if waste streams contain wet materials. In some cases, this problem may be alleviated by using heat from the incinerator to dry the wastes before combustion.

Figure 2 shows a conceptual diagram of a solid waste incinerator with energy recovery and air pollution control with four general sub-processes:

1. Waste is deposited into a bunker where it can be fed into the incinerator.
2. After the waste is burned, the heavy, inorganic constituents exit the bottom of the unit and are landfilled accordingly.
3. Heat is recovered from the incineration process via a boiler. The steam created in the boiler can be used for heat, or to turn a turbine for electrical generation.
4. Air pollution controls clean the gases exiting the incinerator to ensure that emissions are within regulatory limits.

Wastes need to be fed into the reactor which requires energy. An additional energy input may be required for the reactor to reach and maintain sufficiently high temperatures to achieve effective destruction of the wastes. The heat from the reactor can then be used to drive a steam turbine reactor to generate electricity. At the end of the process, air pollution control equipment, which may also need energy for operation, may be needed to reduce air emissions to acceptable levels. Other WTE technologies, gasification, pyrolysis, and anaerobic digestion have similar process streams (Table 1).

While combustion (oxidation) of wastes for heat recovery is the most common commercial process, other processes are possible and under development in industry and government.



Source for process: http://www.sita.co.im/energy-recovery/the-energy-from-waste-process

Figure 2. Example schematic of an MSW incinerator with energy recovery and air pollution control.

Table 1. Comparison of combustion, gasification, and pyrolysis (Arena 2011).

	Combustion	Gasification	Pyrolysis
Aim of the process	To maximize waste conversion to high temperature flue gases, mainly CO_2 and H_2O	To maximize waste conversion to high heating value fuel gases, mainly, CO, H_2, and CH_4	To maximize thermal decomposition of solid waste to gases and condensed phases
Operating Conditions			
Reaction environment	Oxidizing environment, excess stoichiometric oxygen	Reducing, low oxygen	Zero oxygen
Reactant gas	Air	Usually air, could be oxygen enriched, or steam	None
Temperature	850 to 1,200 °C	500 to 1500 °C, depending on specific process	500 to 800 °C
Pressure	Atmospheric	Atmospheric	Slight positive
Process Output			
Produced gases	CO_2, H_2O	CO, H_2, CO_2, H_2O, CH_4	CO, H_2, CH_4, and other hydrocarbons
Pollutants / unwanted byproducts	SO_2, NO_x, HCl, PCDD/F, particulates	H_2S, HCl, NH_3, HCN, tar, particulates	H_2S, HCl, NH_3, HCN, tar, particulates

2.5.3 Gasification and pyrolysis

Gasification and pyrolysis are both technologies designed to recover energy from wastes (Malkow 2004, Vallero 2011). Both processes involve the interactions of high temperature with organic waste materials in low oxygen environments, low enough so that combustion does not occur. There is a small amount of oxygen in gasification, but no oxygen is present in pyrolysis.

Both technologies result in the degradation of the organic material coupled with the production of biological gases (primarily methane) or (in some cases using pyrolysis) liquids that can be used for fuel.

The advantage of these end products is that gas and liquid fuels can be stored and used when needed. Consequently, gasification and pyrolysis allow for a broader range of electrical generation technologies than does incineration/combustion. While incineration/combustion may be used to drive steam turbines, gasification and pyrolysis can generate fuels to power gas turbines or gas engines, or for heating.

2.5.4 Biofuels

Biofuels can be produced from a range of organic substrates (Fernando et al. 2006). Although most attention has been placed on developing biofuels from high value agricultural materials, oily grasses, and algae, some waste products may also provide useful substrates, particularly food and vegetative wastes. Biofuel substrate may be a limited application for waste disposal, but could be useful in some applications.

2.5.5 Composting

Composting is the controlled biological decomposition of organic material by successive microbial populations under both mesophilic and thermophilic conditions that results in a stable final humus-like material product that can be stored and applied to land without negative environmental effects (Iyengar and Bhave 2006, Tiquia and Honeyman 2002). Composting can be accomplished with worms (vermicomposting), in a vessel (in-vessel composting), or outside of a vessel in open air (in “Static Piles” or “Windrows”).

Static pile and windrow composting involve placing organic waste material in a pile or windrow with structural material added (such as waste wood chips) to encourage airflow. This allows for vigorous aerobic activity to occur while the waste itself provides insulation, which, in turn, increases the internal temperature and enables mesophilic or thermophilic reactions to occur. The increased temperature allows for relatively rapid partial degradation of organic constituents, which releases nutrients. This type of composting is easy to initiate, can be relatively inexpensive to operate, and can be applied to a combination of wet and dry materials.

In-vessel composting occurs when organic waste is fed into a vessel-type container. The vessel can be a drum, a silo, or a concrete-lined trench. The same biophysical composting activities that take place in static piles and windrows occur here except that in-vessel environmental conditions are more closely monitored. Aeration in-vessel is usually achieved through a mechanized turning device (USEPA).

Vermicomposting refers to composting that is facilitated by worms. According to the USEPA, red worms are the species of choice for this type of composting. The worms should be placed in a bin with the compostable organic material (USEPA), where they consume the organic waste and leave behind casts, which form the compost. Environmental conditions in the bin must be maintained to support the survival of the worms.

The ultimate goal of composting is to produce a residual that is amenable to land application as a nutrient source or soil amendment. Although technically a very wide range of organic materials can be successfully composted, aesthetic considerations must be considered as well. For example, a biodegradable plastic can undergo sufficient reactions in a compost pile, but still look like a plastic implement, such as a plastic fork. One way to address this is to grind the materials or the resultant compost so that partially degraded materials no longer look offensive after the composting reaction. Composting does not produce usable energy, so it is not a WTE approach.

Chapter 4 discusses more options on organics.

2.5.6 Anaerobic digestion

Anaerobic digestion is a treatment in which wastes are partially degraded in a low oxygen environment resulting in anaerobic respiration, which can allow for methane generation (Karagiannidis and Perkoulidis. 2009). The resulting residuals, like composting, are generally suitable for use as a soil amendment. The advantage of anaerobic digestion is that it can produce energy. However, anaerobic processes are slower than aerobic ones. Anaerobic digestion is considered by some to be particularly good for food wastes (Garcia-Pena 2011, Zhang et al. 2007, Bernstad and la Cour Jansen 2012) although its application could be broadened.

2.5.7 Animal feed

Organic fractions of solid wastes, such as food and vegetative wastes, can be used as animal feed. However, there are concerns that waste organic material may spoil, sicken animals, or indirectly spread diseases. Because of these concerns, animal feeding is seldom a part of modern day waste management. However, it may be possible to modify waste handling to allow animal feeding in some limited cases for food and vegetative wastes.

2.5.8 Open burning

Like animal feeding, open burning of solid wastes has been a historically important means of waste disposal and volume reduction. It is still used for disposal of vegetative materials in rural areas, or to dispose of large quantities of waste accumulated after large storms. However, in densely populated and urban environments, open burning is inefficient, illegal, and may produce severe air pollution issues.

2.6 Energy use factors for disposal options

Figure 3 shows a conceptual energy model for landfilling MSWs generated at an Army installation. The key energy inputs come from collection and transportation of the wastes, and energy needed to conduct landfill operations. Energy output comes from energy generated from the wastes themselves, in this case from recovered landfill gas. Essentially, all other waste management approaches have a similar energy configuration. All require energy pickup and transportation, all require a certain amount of operating energy, and all generate energy that can be recovered. Table 2 summarizes the energy required for collection and transport of wastes to a landfill, assuming a 2o-mile collection and disposal route.

Ozge Kaplan et al. (2009) summarized energy recovery per ton for several WTE options, as well as energy needs for startup, working temperatures, and solid residuals, for different WTE approaches (Table 3). This work reveals that the WTE approaches generate nearly the same amount of energy per ton and similar amounts of ash residue. The choice of the best approach will more likely focus on waste stream issues, capital costs, and the need for storable energy. For comparison, Table 4 lists the energy generated from landfill gas and from WTE. The data show that active WTE can generate 10 times more energy per ton of solid waste than landfill gas-to-energy.

2.7 Water use factors for disposal options

Water is used in the operation of MSW management. In landfills, water is needed for dust control on dirt roads and for application on soils used as daily cover to limit wind erosion. Water is also used in WTE applications. Table 5 lists potential water use in each WTE combustion sub-process. Table 6 lists estimated water uses for major MSW processes. As mentioned, the landfill water use assumes the primary water needs are dust control. Typical water use factors for dust control were obtained in discussion with a water truck company that specializes in dust control (Trauscht Undated). The water use for combustion, gasification, and pyrolysis assumes that the primary water use is associated with air pollution control and that the quantified ranges are based on information gained from discussion with an expert in air scrubber technology (Haley Undated).

Another possible water requirement associated with WTE use can be from stream generation. Table 7 lists makeup water needs with different steam turbine sizes (Flatton Undated). These numbers represent a worst-case scenario, assuming that there is no water condenser/recycle.

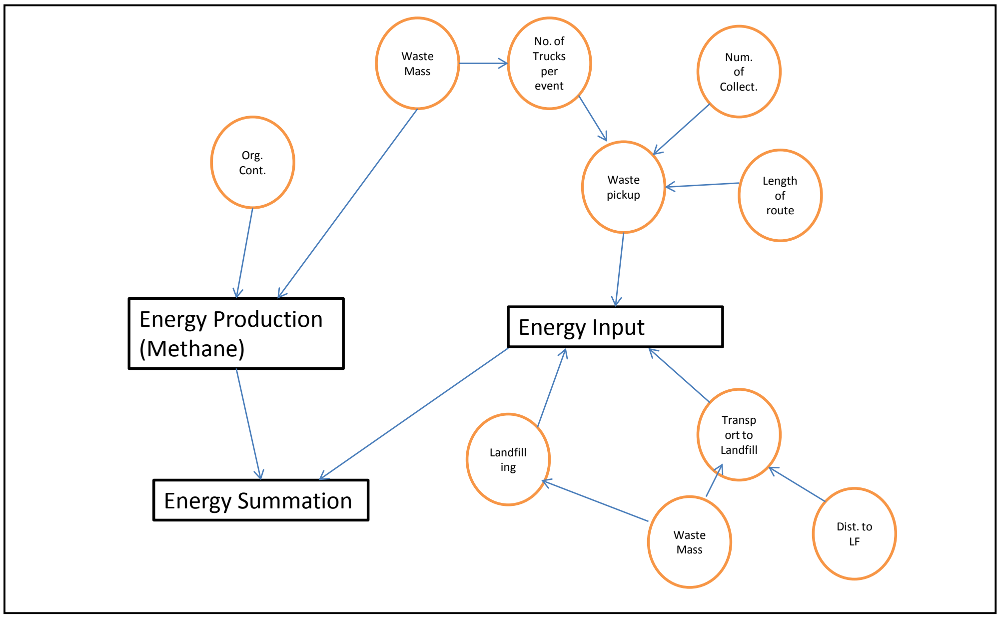


Figure 3. Energy model for landfilling wastes (Medina 2011).

Table 2. Energy estimates for waste collection (USEPA 2006).

Equipment	Diesel fuel consumed (gal/short ton MSW landfilled)
Collection vehicle	1.8
Landfill equipment	1.4
Total	3.2

Table 3. Energy per ton for WTE approaches (Ozge Kaplan, et al. 2099).

	Working temp. (°C)	Startup energy (kWh/ton)	Energy generated (kWh/ton)	Solid residue (kg/ton)
Combustion	850	77.8	544	180
Gasification	1000-1400	340	685	120
Pyrolysis	400-1000	340	685	120

Table 4. Electric power generated from landfilling and WTE (Zaman 2012).

Technology	Electric power generated from 1 ton of MSW (kWh)
Typical WTE	470-930
Landfill gas-to-energy	41-84

Table 5. Water use in WTE combustion.

Sub-Process	Water use
Waste handling	None
Ash handling	None
Heat recovery	This process will use up to 200 gal/min of water; 100% makeup water is needed for a boiler to create 100,000 pounds steam. If a condenser is used, less makeup water is required as the process water is recycled back into the system Water use scales linearly with waste throughput
Air pollution control	For a typical scrubber, 16 gal/1000 cfm combustion gas is usual.

Table 6. Water use in different disposal systems.

Landfill (gal/acre-day)	Combustion (gal/cfm gas)	Gasification (gal/cfm gas)	Pyrolysis (gal/cfm gas)
0 - 5281	0 - 0.016	0 - 0.016	0 - 0.016

Table 7. Makeup water needs for steam generation.

Steam Generated (lbs steam/hr)	Water needed (gal / min)
100,000	200
50,000	100
25,000	50

3 Training Wastes

Many wastes associated with training are exempt from net zero consideration. These include residuals from artillery firing and lead-affected berm materials from small arms training. However, some materials are affected, and these can be especially problematic. These wastes include field-generated wastes from training at simulated forward operating bases (FOBs), simulated villages, or maneuver training. These training wastes are among the costliest wastes for an installation to manage, often four to five times higher per unit mass or volume than wastes generated from other activities. For example, at Fort Polk, LA, field (training) wastes currently cost $484/ton to process and dispose, compared to $95/ton for other wastes.

Fort Polk was chosen as an ideal installation to study these kinds of wastes because it is the location of the Joint Readiness Training Center (JRTC), which conducts a broad spectrum of training. This includes the use of simulated FOBs, simulated villages, maneuver training, and small arms and artillery training. In addition to addressing the immediate needs of net zero waste, the development of better treatment approaches for these training wastes could yield improved approaches and technologies for use in actual contingency operations (Leaning 2000; Medina and Waisner 2011).

3.1 Dining facility (DFAC) wastes

The simulated FOBs at Fort Polk contain a DFAC facility, which is generally used to serve Soldiers’ breakfasts, lunches, and dinners. The DFAC serves many more breakfasts and dinners than lunches, since most personnel are conducting training missions in the field at midday.

There are two types of DFAC wastes. The first is left over food from the serving line, which is composed of virtually 100% food. At Fort Polk, this waste is currently composted. Other solutions could include using more sophisticated projection approaches to reduce the quantity of food prepared, donating the “leftovers” to local charities (if properly preserved, and liability issues have been addressed), feeding the waste to animal (assuming that potential liability issues can be overcome), or implementing other approaches applicable to wet organic wastes, such as anaerobic digestion.

The second form of DFAC wastes are those derived from serving Soldiers. This consists of a mix of food and service items, such as paper or plastic plates and plastic eating utensils. Composting is also a viable solution for these wastes, assuming that the installation would use compostable plastic serving items (and plastic disposal bags). This would allow the entire DFAC waste stream to be composted, or treated by anaerobic digestion.

3.2 Meals ready to eat (MREs) wastes

MREs are portable meals that are designed to provide nutrition to Soldiers during missions. In training, MREs are largely used to provide midday meals to Soldiers in field training. Hundreds are wasted during the average exercise. At Fort Polk, a plan was developed to donate unneeded MREs to local charities.

3.3 Other FOB wastes

The simulated FOBs generate a range of other wastes, including wastes associated with vehicle maintenance and general garbage associated with the living and office work. Among the most problematic of these are used communications (or “commo”) wires and concertina wire. These can be reused, but are often cut and left in place or pulled up and landfilled, at least one connex box worth per exercise.

Black and greywater are also key wastes. They are critical issues in FOB management (Medina and Waisner 2011, Waisner and Medina 2012). Approaches that deal with FOB solid wastes and greywater could be very valuable. (Note that contingency base policies already address wastewater and reuse of water.)

3.4 Training range (maneuver) wastes

Although artillery and small arms training are not part of the Net Zero program, wastes generated during maneuver training are affected by Net Zero. This includes wastes associated with simulated villages (particularly wastes from changing them), vehicles for training and target practices, and various targets. At Fort Polk, the current focus was on cleaning up several waste piles consisting of wastes of old villages (some dating back to the Vietnam War era). Some of these areas have become targets of uncontrolled dumping from the local community. Removing these piles should discourage this undesirable practice. Effective disposal is needed target materials, which may be effected by munitions constituents.

3.5 Class V material in wastes

Class V materials are munitions, such as bullets, mines, and grenades, and munitions simulants, such as blanks, pyrotechnic devices, and pieces of these that are inappropriately disposed in wastes. Over 180,000 Class V items were found in garbage associated with training at Fort Polk in 2011. This improper disposal results in very high disposal costs, four to five times higher than that of MSW disposal from the cantonment area of the installation. Currently, garbage associated with training is hand sorted by a contractor to remove the Class V items.

This issue is not a direct net zero issue in that during hand sorting, the contractors also recover recyclable materials. Resolving the problem, which may eliminate the hand sorting, would not necessarily reduce the amount of solid waste generation. However, the high costs associated with the location and disposal of Class V items detracts from other possible net zero initiatives.

An obvious solution could be to focus on improving mechanisms for proper disposal of Class V items, as well as an aggressive training process to discourage improper disposal. One by-product of this is that it may assist in training Soldiers on proper disposal of Class V materials in the field. It is believed that at least some improvised explosive device (IED) activity during Operations Enduring Freedom and Iraqi Freedom resulted from improper disposal in the field. Future research may address this problem with mechanical waste separation, sensing for Class V materials, and/or treatments for the Class V materials. Thermal treatment devices currently available for disposal of explosive munitions (Figure 4) could be adapted for this use.

Figure 4. Disposal system for small arms ammunition and small explosives.

4 Organic Wastes

4.1 Army processes and sources of organic wastes

The United States generates nearly 250 million tons of MSW annually (USEPA 2005; USEPA 2009). Of this, 34 million tons are classified as food waste and 16 million tons are classified as landscape wastes. Food and landscape wastes, therefore, represent nearly 20% of the total waste stream. Nearly 90% of landscape wastes are recovered and processed into soil amendments and organic fertilizers using simple composting technologies (Haug 1993, Renkow et al. 1994). Conversely, less than 3% of food wastes are recovered and recycled (Kim et al. 2008). The remainder, some 33 million tons, are thrown away and disposed of in landfills at considerable economic, environmental, and societal cost. Tipping fees in excess of $40.00/ton indicate that about $1.32 billion dollars are wasted on disposal alone, not to mention the value lost to individual purchasers from disposal of unconsumed food. When food waste is disposed in a landfill, it quickly decomposes and becomes a significant source of methane, a potent greenhouse gas with significantly greater potential for global warming than carbon dioxide gas (Komilis and Ham 2000, Chang and Hsu 2008). The USEPA estimates that more than 20% of all methane emissions can be attributed to landfills and decomposition of food and other organic wastes (USEPA 2009).

Each Army installation is similar to a small town or city, essentially a microcosm of a typical U.S. municipality. Landscape and food wastes produced at the installation level are likely to be very similar in proportion and amount to those cited in USEPA statistics (2009). Executive Order (EO) 13101 calls for the Department of Defense (DoD) to incorporate waste prevention and recycling into its daily operations. Compliance with this order is evident at nearly all DoD facilities. Installations typically have cantonment areas, greenspaces, and training ranges that generate landscape wastes. Most Army installations have landscape waste collection and recycling capabilities or contractual arrangements with nearby recyclers such that very little landscape waste is actually landfilled or incinerated, but rather composted to provide valuable soil amendments and fertilizers.

Like their municipal counterparts, Army installations also have food service providers (supermarkets, restaurants, schools, hospitals, and dining halls) and family housing areas where food waste is continually generated.

Unlike landscape waste, however, very little food waste is captured for recycling; most food waste ends up in a landfill (Kim et al. 2008). Several reasons for the disparity in the way food waste is handled (compared to landscape waste) are:

1. Most individuals, households, and other small-scale food waste generators are unaware of how much of the food they dispose of daily could be separated and collected for dedicated recycling.
2. Food waste separation and storage for later collection is often perceived as a relatively unsavory task due to unpleasant textures, odors, and the sheer bulk of the waste material.
3. Storage and collection of food wastes is often incompatible with that of typical MSW collection since it requires specialized handling and transport capabilities.
4. Facilities for disposal and processing of food wastes are not common although they are becoming more numerous given the potential value of finished food waste compost.
5. The economies of scale related to dealing with food waste suggest that economic payback is directly proportional to the amount of food waste available for processing (Renkow and Rubin 1998). In other words, the commonly believed that food recycling it is only economically feasible for large food waste generators. In fact, several lower cost options allow small- to medium-sized food waste generators to keep capital and labor costs at an economically manageable level (Bonhotal et al. 2011).

4.2 Materials and description

Landscape wastes are generated from a variety of sources including mowing, tree-trimming, gardening, and other weather-driven events such as windstorms, ice storms, snowstorms, and flooding. Because most installations have protocols, facilities, equipment, and/or contractual arrangements for the efficient collection, storage, and processing of landscape wastes, the following process description will be very brief.

Processing landscape wastes usually involves some type of pre-processing, such as grinding and screening, to produce a substrate with good particle size distribution (Adhikari et al. 2009). Following pre-processing, these materials are usually composted using aerated windrows that facilitate decomposition through a microbial process that produces significant amounts of heat, thereby destroying pathogens and producing stabilized compost that can serve as a soil amendment or fertilizer (Epstein 1997). Windrow composting is simple and has very low capital and labor costs. Periodic watering and mechanical turning are required to optimize the decomposition process and minimize the time to completion of finished compost.

Food wastes or residuals are defined as all pre- and post-consumer foods, and food byproducts (as well as organic items) that may accompany food. These byproducts include manufactured organics and soiled paper products (napkins, paper cups, cardboard, manufactured compostable serving ware) (U.S. Composting Council 2009). Food wastes are generated wherever people live and work and they take on many forms from pre-processed food waste (vegetable trimmings) to unsalable items (bruised fruit) to expired or spoiled items, to food scraps from a variety of venues (home, restaurant, hospital, cafeteria, school, dining hall, festivals).

The steps involved in food waste processing (diversion, collection, transport, pre-processing, and composting) are not always intuitive to those involved in food preparation. It requires significant awareness, training, and specialized equipment to minimize problems associated with the collection and diversion of food residuals at their source, i.e., in the home, cafeteria, and dining hall (Donahue et al. 1998). Training people in the concepts of food waste separation and diversion is probably the most difficult philosophical challenge in food waste recycling. From a practical standpoint, the most difficult challenge is associated with the high moisture content and the accumulated mass and volume of the food residuals. Suitable vessels that facilitate storage and subsequent transport are essential. Transportation costs to the processing facility are usually minimal compared to landfill tipping fees, especially considering that 100% of the food waste is diverted from landfill disposal. Technical aspects of the various food waste processing technologies are beyond the scope of this report. However, the following sections discuss management options for landscape and food waste recycling, including water and energy requirements.

4.3 Management options

Management options for recycling of landscape and food wastes nearly always include some type of formal collection, storage, and processing technology based on the science of composting (Haug 1993, Epstein 1998). Most of the food waste processing technologies rely upon availability of some type of high carbon content bulking material, usually in the form of landscape or lumber processing wastes, to optimize the composting process (Campbell et al. 1997). This requirement for bulking materials allows food waste processing to complement landscape waste processing. The two can often be conducted simultaneously at the same site.

Processing technologies range from very simple, on-site methods with limited throughput (e.g., vermicomposting, windrow composting, or in-vessel composting) to more complex and infrastructure intensive technologies involving anaerobic in-vessel composting or co-digestion with sewage sludge at under-used wastewater treatment facilities (USEPA 2006). Selection of the most appropriate technology is usually based on the amount of food and landscape waste generated and available for collection and processing that has been identified by a comprehensive landscape and food waste audit. The results of the audit will:

1. Highlight potential sources and anticipated volumes of recyclable landscape and food waste
2. Identify strengths and weaknesses in the waste diversion, separation, collection, storage, and transport chain
3. Identify opportunities for educational awareness training to facilitate efficient recycling efforts
4. Identify potential community partners to broaden the scope and share the costs of implementing landscape and food waste recycling programs
5. Provide guidance for selection of the waste recycling technology most appropriate for the set of circumstances identified in the waste audit.

Landscape and food waste processing technologies range widely in both complexity and cost. Nevertheless, processing technologies can be scaled to meet almost any set of waste generation and recycling scenarios. Simple waste processing technologies are characterized by:

1. Low capital startup and labor costs
2. Low energy, low-water (or no-water), and transportation requirements
3. Potential ability to construct, operate, and maintain the technology on-site
4. Limited amounts and throughput of waste materials
5. A limited geographic area of interest.

Complex waste processing technologies are characterized by:

1. High capital startup and labor costs
2. High energy, water, and transportation requirements
3. Little or no potential for on-site construction and use
4. Large amounts of waste materials from many different generators
5. A large geographic area of interest.

Windrow composting is among the simplest of landscape and food waste processing technologies (Haug 1993). A suitable site for windrow composting should be level, should have a concrete pad or lime stabilized surface for placing and mixing windrows, and should be of sufficient size to process the anticipated waste volume. Equipment requirements for windrow composting are minimal. They include a shredder/chipper/grinder, industrial screens, front-end loader, and a windrower. Many windrow composting facilities deal only with landscape wastes. However, more are beginning to accept food wastes into their composting programs because food wastes contain more moisture, have higher levels of nutrients to support microbial decomposition, require a high carbon content bulking agent , i.e., landscape or lumber processing wastes (Liang et al. 2006) to optimize decomposition, and result in a higher quality finished compost end product.

In windrow composting, the ground and screened landscape and/or food materials are placed in long windrows about 5 to 10 ft high, 10 to 20 ft wide, and up to 300 ft long. Windrows are periodically turned and watered as necessary to optimize the decomposition/composting process. After about 45 to 60 days, the windrows are deconstructed and moved to a different location for additional curing and drying before resale. The entire process takes from 6 to 8 months for landscape wastes and from 4 to 6 months for a mixture of landscape and food wastes (Komilis and Ham 2004). Throughput for windrow composting facilities varies widely and can range from 1,000 to 100,000 cu yd per year (Tables 8 and 9)

The size and complexity of different composting facilities are determined by the type of composting system in place and the amount and kinds of waste generated. In some cases, the composting system is determined by the space available for composting. As explained earlier, composting time varies depending on the system used, the materials composted, and the quality of compost required.

Municipal composting facilities service a range of populations and materials. For example, St. Louis Composting, in St. Louis. MO, annually services approximately 500,000 cu yd (135,000 tons) of mostly green material yard waste (St. Louis Composting 2012). The operation is comprised of five composting sites, the largest of which is a 52-acre windrow composting facility that processes green waste and waxed cardboard for a population of about 200,000 (Gavlick 2012) (Tables 8 and 9). Illinois State University manages a smaller windrow composting facility that processes food and yard waste for about 70,000 people, which includes the University and local population (Walker 2013).

4.4 Operating windrow and static pile facilities

The difference between the amounts of food processed by these two facilities is important in terms of the size of windrows necessary for proper composting, the heavy machinery required to move the different volumes of waste and the fuel usage needed for these tasks (Table 8).

The heavy machinery equipment used at the two facilities is the same, but the industrial strength levels of the machines (and the fuel consumption) are different. The Normal facility uses a pull-type of windrower and, thus, fuel use for windrowing at this facility is that of the front-end loader pulling the windrower, i.e., close to 6 gal. At the Normal facility the heavy machines are used 2 to 3 hrs a day during peak season and approximately 2 hrs a day during low season (Friend 2012). The compost produced at both facilities is of high grade and can be used as soil amendment (Tables 8 and 9). The main differences between the St Louis static pile and windrow facility is size (4 vs. 52 acres), and type of compost piles (stacked vs. rows).

Another example of a static pile system is the Aerated Static Pile System installed at Fort Lewis and manufactured by Green Mountain Technologies (2012). This system can be operational on less than 6 acres and can manage four zones independently using one blower. Each zone can to hold 5,400 cu yd for a period of 16 days accommodating a capacity of over 300 cu yd of compost per module per day. Twelve turns are required for compost-ready material.

Table 8. Specifications for composting facilities.

Facility	Material Composted	Size of Population	Dimensions (ft)				#Turns/ Moves	Compost Cycle	Quality
			Width	Height	Length	Between Rows			
St Louis Windrow	Weeds, Greens, Waxed-Cardboard	200,000	18	8	100-300	10	7 - 14	4 – 6 mo.	STA Certified Soil Amendment Garden Centers Wal-Mart
Normal Windrow	Food, Greens	50,000	10	4	200	15-30		2 mo.	Soil Amendment
St Louis Static Pile*	Leaves, Grass	200,000	45	25		10	3	9 – 12 mo.	STA Certified Soil Amendment Garden Centers Wal-Mart

* Gavlick (2012)

Table 9. Specifications for heavy equipment machinery.

Facility	Tub Grinder	hp	g/hr	Front-End Loader	hp	g/hr	Windrower	hp	g/hr
St Louis Windrower	Morbark[*] 6000	875-1175	35[†]	CAT 950	197-217[**]	5[†]	John Deere self-propelled D450	200[***]	5
Normal Windrower	Morbark 2600	200[*]	7–8[‡]	Bobcat S770	92[∞]	6	Pull – type windrower	Bobcat pulls it	6
St Louis Static Pile	Morbark 6000	875-1175	35	CAT 950	197-217	5	N/A	N/A	N/A

[*] Morbark (Undated); [**]Cat (2012); [***]John Deere (2012); [†]Gavlick (2012); [‡]Virginia Tech (Undated); [∞]Bobcat (2012)

According to the company, the time requirements for each task are: turning, screening, grinding and loading of compost. Each task takes less than 4 hrs a day, and site cleanup, daily equipment maintenance, and fueling takes less than 3 hrs per day. In addition, the system is described as easily managed by two full-time operators at a labor cost of less than $3/ton. Finally, the heavy machinery equipment recommended to run this system is a self-propelled windrower with 215 hp and a maximum fuel consumption of 12.1 gal/hr. This breaks down to composting that can be turned every 4 to 5 days for a total of 7 to 8 turns in 3 hrs of operator time (Tables 8 and 9).

4.5 In-vessel composting systems

Under circumstances where landscape and/or food waste collection and processing is limited by defined geographic or institutional boundaries (City, County, University, Army Installation), or where lack of space to accommodate windrow composting facilities or local regulations prohibit certain types of waste processing facilities, in-vessel aerobic composting is usually the preferred technology (Kim et al. 2008). In-vessel composting technology is promoted for managing food wastes with limited space. Compared to windrow composting systems, in-vessel composting technology and can range from the simple to relatively complex. More complex in-vessel systems require precise temperature, oxygen, moisture control, and high carbon content bulking agents (Liang et al. 2006), as well as skilled labor for system operation and maintenance. As such, capital expenses for an Army installation can be significant. However, many in-vessel manufacturers can customize systems to optimize anticipated waste volume with capital expenditure.

Common types of in-vessel aerobic composting systems include stationary, containerized, rotating drum and tub, and static pile systems. Regardless of type, ground and screened waste and bulking materials are mixed and placed inside the vessel where moisture content, oxygen, and temperature are controlled, thereby optimizing decomposition dynamics. Retention times for these systems generally vary from 1 to 6 weeks, depending on the system's complexity, the type of waste feedstock, and the waste volume processed. After the initial retention time is completed, the semi-composted material is moved to an off-site area for an approximate 6 to 8 weeks of curing. Throughput for the more complex in-vessel composting systems can vary widely, ranging from 1000 to 10,000 cu yd per year (Table 10).

In-vessel composting systems range from the operationally simple to the complex. A 1939 system used in Bangalore, India that is still in use today takes 5 -6 months, involves static piles in trenches layered with bulking agents, and mud-plaster dome covering (Gajalakshmi and Abbasi 2008). More complex systems include those currently installed at Fort Myer, VA and Fort Lewis, WA, and commercially sold by Ag-Bag and Green Mountain Technologies. These latter systems are scalable, able to handle several yards to several thousand yards of composting material, and offer varying levels of computerization, and operational efficiency (Tables 11 and 12).

Ag-Bag is a patented in-vessel type of system manufactured by Ag-Bag Company to service organic material. The system entails a hopper and long plastic bag–like-tunnels that the hopper fills with compostable material. This system uses one-third the area of windrow composting systems, with combined composting and curing times of 3 to 5 months (Ag-Bag 2002).

Table 10. General water and energy requirements for organic waste processing.

Processing Technology	Waste Type	Water Requirement	Energy Requirement	Input*	Output*	Processing Time	Landfill Diversion
Windrow	Landscape	25 gal/cy	45 kW h/cy	1 cy	0.35 cy	6-8 months	100%
Windrow	Food	15 gal/cy	240 KW h/cy	1 cy	0.44 cy	4-6 months	100%
In-vessel	Landscape	10 gal/cy	Fuel/electric	1 cy	0.45 cy	3-4 months	100%
In-vessel	Food	2 gal/cy	Fuel/electric	1 cy	0.58 cy	2-3 months	100%
Vermicomposting	Food	5 gal/cy	Fuel/electric	1 cy	0.66 cy	2-3 months	100%
Digester	Food	644 gal/cy	39 KW h/cy	1 cy	1.65 cy	2 days	100%
Pulper	Food	34 gal/cy	55 KW h/cy	1 cy	0.12 cy	8 hr	88%

* Input and output values are normalized based on inputting 1 cu yd of waste material into the system. For example, windrow composting of 1 cu yd of food waste produces 0.44 cu yd of finished compost, whereas digesting 1 cu yd of food waste produces 1.65 cu yd of food waste/water slurry.

Table 11. Specifications for in-vessel systems.

In-vessel Systems	In-vessel Size	Composting Capacity/yr	Composting Time	Curing Time/Cycle	Odors and Leachate	Materials Reusable	Materials Recyclable
Trench w/ mud-plaster covering	1 m deep x 1.5 -2.4 m wide filled to 30 cm above ground covered w/ 2.5cm mud-plaster	Small scale	5– 6 months			Yes	Yes
Ag-Bag	5 -10 ft x 200 ft	25,000 - 150,000+ tons	2 – 3 months	1 - 2 months	No	No	Yes
GMT: EFS	12 – 24 ft long x 8 ft 4 in wide	300 – 3,000 lbs/day	3 weeks	1 - 2 months	No	Yes	
GMT: CCS	23 ft, 8 in – 25 ft, 8 in. long 8 ft, 3 in. – 8 ft, 6 in. wide 8 ft, 6 in. x 9 ft, 5 in. high	2 -50 tons	3 weeks	3 weeks	No	Yes	
GMT: Aerated Earth Pile	Pneumatic pipes with wholes for airflow, temperature and water collection is computer-controlled and constructed in designated composting area. Pipes are exposed.	Scalable	Depends on compost materials	Depends on compost materials	Depends on materials and mgmt.	N/A	N/A
GMT: Aerated Earth Pad	– Pneumatic pipes with wholes for airflow, temperature and water collection is computer-controlled and constructed in designated composting area. Pipes are built w/in cement pad. – 1/3rd size of windrow systems	Scalable	Depends on compost materials	Depends on compost materials	Depends on materials and mgmt.	N/A	N/A

Table 12. Product and machinery requirements.

Systems	Recommendations	Computer System	#Employees	Tub Grinder: g/hr	Front-End Loader (g/hr)	Windrower
Trench w/ mud-plaster covering	Small scale, no electricity required	N/A	1 -2	97	N/A	N/A
Ag-Bag	Electricity must be present		1	7-8	6	N/A
GMT: EFS	Electricity must be present	Computerized control system	< than 2	7-8	6	N/A
GMT: CCS	Not cost effective for systems servicing > 35,000 tons compost per year or > 1 ton per day. –Electricity must be present –Garbage should be presorted	Ethernet cable to a desktop computer running Windows™ 98 or higher	Scalable	N/A	N/A	N/A
GMT: Aerated Earth Pile	Electricity must be present	Computerized control system	Scalable	7-8	6	N/A
GMT: Aerated Earth Pad	Electricity must be present	Computerized control system	Approx. 2 full-time employees	7-8	6	Vermeer CT1010TX with 215 hp engine and max. fuel consumption of 12.1 gal/hr

One acre of land can accommodate 11, 10-ft plastic tunnels. Over several cycles, the system can compost an approximate 22,000 acres per year. The heavy machinery required for this process is a tub grinder, front-end loader, a screener, and a hopper (sold with the Ag-Bag system). The plastic bag tunnels are recyclable, but not reusable (Ag-Bag 2012). This system can handle between 75 tons per 1 to 2 hrs to 3+ tons per minute, or 25,000 to 150,000+ tons annually (Ag-Bag 2002).

Other examples of in-vessel types of composting systems are the ones manufactured by Green Mountain Technologies that produces several categories of composting products with different models intended for larger populations (Green Mountain Technologies 2012). Four of note are the Earth Flow System (EFS), the Containerized Compost Systems (CCS), the Aerated Earth Pile system, and the Aerated Earth Pad. These systems are scalable and involve containers and integrated computer software technologies (Tables 11 and 12). They range from the smaller EFS, which has been installed at Fort Myer, VA to the larger CCS system. The EFS consists of one container with a built in mixer and computerized aeration system that can compost from 300 to 3,000 lb/day depending on needs.

The CCS system also consists of a computerized aeration system, but can be integrated with up to 50 airtight containers into a single composting unit. Because it is scalable, it can handle from 2 to 50 tons of sewage, septage, and green waste per day. The containers in the CCS system have a composting capacity that ranges in size from:

- Length: 23 ft, 8 in to 25 ft, 8 in.
- Width: 8 ft, 3 in. to 8 ft, 6 in.
- Height: 8 ft, 6 in. to 9 ft, 5 in. high.

This system is cost effective for facilities that service less than 35,000 tons a year. The entire CCS process, from start to finish, takes 6 weeks.

Both systems require that the site have electricity and both require tub grinders and front-end loaders. These composting systems use the same equipment as windrow systems (minus the windrower). Thus, depending on the scale of the containerized system in place, fuel usage for equipment would range from 5 to 35 gal/hr for the tub grinder and 5 gal/hr for the front-end loader.

The Aerated Earth Pile and Earth Pad systems involve pneumatic pipes with air vents built within designated composting areas. In the Aerated Earth Pile system, pipes are constructed in the open for direct placement of compost piles on top of pipes. (This system has been installed at Fort Lewis, WA.)

In the Earth Pad system, pipes are constructed within a cement base when composting on top of a pad is preferred. The Earth Pad system is designed to manage four zones independently with one blower on less than 6 acres. Each zone can to hold 5,400 cu yd for a period of 16 days, accommodating a capacity of over 300 cu yd of compost per module per day. Twelve turns are required for compost-ready material. According to the company, the time requirements for each task are:

- turning, screening, grinding, and loading of compost (less than 4 hrs/day per task)
- site cleanup, daily equipment maintenance and fueling (less than 3 hrs per day total).

In addition, the system is described as easily managed by two full-time operators at a labor cost of less than $3/ton. The heavy machinery equipment recommended to run this system is a self-propelled Vermeer CT1010TX (215 hp with a maximum fuel consumption of 12.1 gal/hr), which can move 2,000 cu yd per hour. This amount breaks down to composting that can be turned and re-watered every 4 to 5 days for a total of 7 to 8 turns in 3 hrs of operator time (Green Mountain Technologies 2012).

Both Ag-Bag Company and Green Mountain Technologies offer scalable solutions for composting. Ag-Bag systems achieve scalability through the use of plastic bag-like-tunnels that can be purchased in multiples, depending on the amounts of compost to be processes, a hopper for loading the plastic tunnels, and a minimum of computerization. The Green Mountain systems achieve scalability by integrating computer technology and containers designed to accommodate different amounts of compost, using technologically different types of composting systems.

Both companies claim that their products more cost effective, and require fewer employees, less space, and less time than more traditional windrow composting systems. However, systems from both companies still require the use of heavy equipment machinery (like tub grinders and front-end loaders) in conjunction with their commercial products. Ag-Bag also suggests the use of a screener to filter compost after it has cured.

4.6 Vermicomposting

Vermicomposting is the use of select earthworm species as a means to convert organic wastes into a compost material rich in worm casts (Garg et al. 2006, Nair et al. 2006, Suthar 2008). Worldwide, there is a growing realization that vermicomposting represents a simple, cost effective method of composting landscape and food wastes. Vermicomposting is especially suitable for certain specific situations. For example, in the United States, vermicomposting has been done on very small scales, often in conjunction with individual homeowners or as an educational outreach activity for elementary and secondary school science classes.

In other parts of the world, vermicomposting is operated on very large scales and has been shown to produce significant amounts of fertilizer that otherwise would be unavailable or far too expensive for small, family based farms (Nair et al. 2006; National Bank for Agriculture and Rural Development 2007). The basic requirements for vermicomposting are enclosure beds to house the food wastes and earthworms. The beds are maintained at 50% moisture and 80 °F. Finished compost is usually available in 2 to 3 months (Table 10). Throughput for vermicomposting varies widely depending on system complexity and size, and can range from as little as 1 cu yd per to as much as 10,000 cu yd yards per year.

4.7 Food waste digesters and pulpers

Availability of on-site food waste processing technologies suitable for small- to medium-sized generators is often desirable. Several manufacturers provide these technologies in the form of food waste digesters and pulpers. Fort Hood, TX is currently testing an Organic Refuse Conversion Alternative (ORCA) food waste digester at one of the dining halls.

Food waste digestion operates on the principal of accelerated decomposition in an environment optimized for moisture content, temperature, and aeration. Food wastes are separated and diverted to a digester housed in or near the kitchen, dishwashing, or food preparation area. Within the digestion unit, food residuals are constantly agitated in a solution of water and enzymes until the particle size is reduced to a size allowing disposal into a sanitary sewer system. This processed water may also be captured and used as “grey water” or “compost tea” for landscape irrigation (Note that this effluent has not been subjected to focused scientific research and may require additional treatment before such use is permitted.) Throughput for food waste digesters varies according to manufacturer, but typically ranges from 0.5 to 2 cu yd per day. Table 10.

Food pulpers operate similarly to food digesters, except that the water used to agitate and break down the food waste is recycled. The food waste particles are captured, dehydrated, compressed, and subsequently landfilled. Food pulpers are also marketed as on-site food waste processing units applicable for small- to medium-sized waste generators. These systems do not require the careful food waste separation and diversion steps that digesters require, and can process all food, paper, plastic, and Styrofoam wastes from a typical food service facility. The entire food waste stream is placed inside the pulper where constant agitation with water reduces particle size. The water/waste slurry is then transferred to a series of screens where the particles are captured, press dried, and bagged for landfill disposal. Food waste pulpers typically reduce waste volumes by 85 to 90% and can process from 1 to 2 cu yd per day (Table 10).

4.8 Future needs

Army installations have a clear need to better manage food waste. However, several shortcomings must be overcome before sufficient data will be available to make concrete recommendations to improve landscape and food waste management on installations:

1. There is a general lack of qualitative and quantitative data pertaining to landscape and food waste management at Army installations. Apparently, no comprehensive food audit has ever been conducted. Consequently, it is nearly impossible to make recommendations concerning options for complementary landscape and food waste recycling systems.
2. Once sufficient information is acquired to make sound food waste management recommendations, there will be a general need for training, specifically, to gain the ability to use the existing infrastructure and workforce to manage food waste processing technologies. Such training will involve a dedicated program to educate, to instill environmental awareness, and to acquire familiarity with the food waste recycling process and practical Army experience with recycling technologies.

These are typical issues that any user of a novel or new technology would experience and are not insurmountable given the proper exposure, education, and context. In the longer term, the Army has the infrastructure, the workforce, and the can-do attitude to become a leader in the management, recycling, and beneficial reuse of food and landscape wastes.

5 Construction Wastes

Installation experience and data in the SWARweb (Solid Waste Annual Reporting) system (DENIX 2012) show that waste materials from construction and demolition projects can comprise over half of total solid waste generated. However, waste modeling efforts and calculations of environmental impacts have historically focused on MSW. Therefore, little published information is available on modeling the environmental impacts of solid waste *including construction wastes*. The rise of the "green building" movement and adoption of Leadership in Energy and Environmental Design (LEED) standards (in the Army as well) has initiated a more systematic approach to data projection and collection efforts. The material in this chapter is based on some previous studies, and on ERDC-CERL experience in studying Army building types.

5.1 Army Construction and Demolition (C&D) material quantities

The C&D waste estimates in the following sections are based primarily on USEPA C&D waste characterization studies (performed in 1998 and updated in 2003 and 2010), on projections of Army C&D waste generation by Concurrent Technologies Corporation (2003), and on ERDC-CERL quantity "take offs" for C&D waste estimating purposes. Other sources from state and Federal solid waste surveys were also consulted. Residential buildings consist of family housing, the vast majority of which is now provided under the Army's Residential Communities Initiative program. These buildings resemble typical single family and townhouse-type housing communities. Non-residential buildings include the remaining Army building codes: operation and training, maintenance and production, supply, administrative, and housing and community (barracks and accompanying facilities).

5.1.1 Construction waste

The following average rates of construction waste generation were based on residential non-residential building types. Construction waste from residential buildings, single family and low rise multifamily is estimated to weigh 4.5 lbs/sq ft.

The composition of common residential building construction waste, by weight, is estimated to be:

- Wood: 45%
- Brick/block: 4%
- Roofing: 6% (asphalt shingles)
- Plastics: 3%
- Metals: 3%
- Drywall: 25%
- Other: 14%.

Construction waste from common non-residential building types is estimated to weigh 3.9 lbs/sq ft. This quantity was compared with selected Military Construction (MILCON) projects using construction diversion data recorded for LEED validation, and was found to be reasonably consistent as an average.

The composition of common non-residential building construction waste is estimated, by weight, to be:

- Wood: 38%
- Brick/block: 9%
- Plastics: 4%
- Metals: 13%
- Drywall: 21%
- Cardboard: 13%
- Other: 4%.

5.1.2 Demolition waste

Demolition waste from residential buildings, single family and low rise multifamily, is estimated to weight 115 lbs/sq ft. The composition of common residential building demolition waste is estimated, by weight, to be:

- Wood: 14%
- Brick/block:14%
- Roofing: 3% (asphalt shingles)
- Drywall: 17%
- Rubble: 51%
- Other: 1%.

Demolition waste from common non-residential building types is estimated to weigh 155 lbs/sq ft.

The composition of common non-residential building demolition waste is estimated, by weight, to be:

Wood:	3%
Brick/block:	6%
Roofing:	2%
Metals:	5%
Asphalt:	2%
Concrete:	80%
Other:	2%.

These data were based on Army standard designs for operation and training, maintenance and production, supply, administrative, and housing and community buildings.

The demolition debris-stream of some Army building types provides exceptions to the data provided above. Some notable exceptions are:

- Demolition of World War II-era wood barracks building will generate roughly 32 lbs/sq ft of debris, 58% of which is wood and 34% of which is concrete rubble.
- Demolition of WWII-era General Purpose warehouses will generate roughly 61 lbs/sq ft of debris, 45% of which is wood and 53% of which is concrete rubble.
- Demolition of barrack buildings built in the early 1950s to the standard Hammerhead design will generate roughly 225 lbs/sq ft of debris, 95% of which is concrete and masonry rubble.
- Demolition of motor pool buildings built in the early 1950s to the standard design of the time will generate roughly 350 lbs/sq ft of debris, 95% of which is concrete and masonry rubble and 5% of which is steel scrap.

5.2 On-post recycling opportunities

Most C&D materials can be recycled or reused. However, concrete and masonry rubble and wood debris are the only materials that, in practical terms, can be recycled on-post for use on-post. Concrete and masonry rubble can be crushed and applied on the installation for pavement base, erosion control, fill, and other similar uses. Wood debris can be shredded.

Current uses for shredded wood include mulch, erosion control, and compost. However, wood materials also have the potential to be used as a fuel source in a WTE application.

To determine the benefits of recycling concrete and wood, the inputs to the recycling process must be identified and quantified. Thus, they can be compared to the beneficial use of these materials to arrive at a total net benefit.

Recycling operations for concrete and wood debris are fundamentally similar, although the equipment itself varies. The steps would consist of:

1. Gather concrete or wood material at the construction or demolition site.
2. Transport concrete or wood material to the recycling site.
3. Load concrete material into a crusher, or wood material into a shredder.
4. Sort the resultant concrete or wood pieces according to size.
5. Convey the recycled concrete or wood material to pile or vehicle.
6. Transport the recycled concrete or wood material to a stockpile or the next application.

It is common practice among installation personnel to locate wood and concrete recycling operations at or near their landfills. Thus, the transportation requirements for recycling and landfill disposal are, for practical purposes, the same. Transportation of the recycled material from stockpile to the next application would likewise be the same regardless whether virgin aggregate or mulch were purchased or recycled on-post. For practical purposes, the crushing or grinding operations themselves would be the only input not required by landfill disposal. Inputs to these operations consist of energy to run the crushing or grinding equipment and water for dust suppression. Equipment may either be electrical or diesel fueled.

The following data are being solicited from C&D materials recycling businesses for both fixed and portable operations:

- output of recycled material on an hourly basis
- gallons of diesel fuel consumed on an hourly basis
- KW or electricity consumed on an hourly basis
- water consumed on an hourly basis.

From these data, the recycling energy and water use requirements can be calculated on a per-ton of recycled material basis. From that, the air emissions can also be calculated on a per-ton of recycled material basis.

6 Description of MSW-DST Model

The Municipal Solid Waste Decision Support Tool (MSW-DST) is a comprehensive modeling and planning system for local government units developed by the RTI and the USEPA Air Pollution Prevention and Control Division. The model predicts waste generation for a study location based on demographics and other basic measures. The waste generated can be managed via landfill, recycling, or a host of other user-configurable options. For each scenario, the model calculates cost, waste diversion, and many other environmental parameters. While cost is usually the paramount concern for selecting waste management options, MSW-DST can optimize the suggested options based on:

- cost
- CO_2 emissions
- electric power consumption
- NO_x emissions
- particulate matter emissions
- SO_2 emissions.

In addition to these factors, the model also tracks 23 other environmental factors and externalities resulting from waste management practices.

ERDC researchers plan to work with RTI to incorporate portions of the MSW-DST into the NZI-Optimization tool which includes energy and water tracking and optimization features. It is anticipated that the updated system will implement models of emerging WTE systems that are not common in municipal practice, but that may serve the waste management needs of Army installations.

7 Conclusion

This work has characterized MSW, specifically as the term pertains to waste generated on Army installations:

- mixed wastes (Chapter 2, p 2)
- training wastes (Chapter, p 20)
- organic wastes (Chapter 4, p 23)
- construction wastes (Chapter 5, p 36).

For each type of waste, this work has described disposal options, with particular emphasis on the processes and technologies that may be integrated to support a NZW installation. Those processes and technologies include:

- recycling (pp 6-11, 38)
- gasification and pyrolysis (p 14)
- biofuels generation (p 15)
- composting (pp 15, 28)
- anaerobic digestion (p 16)
- animal feeding (p 17)
- vermicomposting (p 34)
- food waste digestion (p 34)
- WTE (pp 8, 9, 13, 17, 18).

Special attention was given to the treatment of food wastes, which are a common source of organic waste that is currently landfilled, but that is a primary candidate for composting.

A short discussion of the Municipal Solid Waste Decision Support Tool (p 40) describes how the MSW-DST may be used to model emerging WTE systems that are not common in municipal practice, but that may serve the waste management needs of Army installations.

Acronyms and Abbreviations

Term	Definition
BTU	British Thermal Unit
CEERD	U.S. Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CO	Carbon Monoxide
DC	District of Columbia
DFAC	Dining Facility
ERDC	Engineer Research and Development Center
FOB	Forward Operating Base
FY	Fiscal Year
HHHW	Household Hazardous Waste
JBLM	Joint Base Lewis-McChord
MILCON	Military Construction
MRE	Meals Ready To Eat
MSW	Municipal Solid Waste
MSW-DST	Municipal Solid Waste Decision Support Tool
NHTSA	National Highway Traffic Safety Administration
RCRA	Resource Conservation and Recovery Act
RTI	Research Triangle Institute
SF	Standard Form
TR	Technical Report
URL	Universal Resource Locator
US	United States
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
WTE	Waste to Energy
WWW	World Wide Web

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14. ABSTRACT

Today's Army faces significant threats to our energy and water supply requirements both home and abroad. Addressing energy/water security and sustainability is essential to mission accomplishment. The Army's goal is to manage "net zero installations" (NZI), i.e., installations that operate not only on a net zero energy basis, but net zero water and waste as well. A net zero waste installation reduces, reuses, and recovers waste streams, converting them to resource values with zero landfill over the course of a year. This work outlines a plan for U.S. Army Engineer Research and Development Center (ERDC) researchers to support the Army NZI vision by developing an NZI-Optimization tool that includes energy and water tracking and optimization features. This preliminary stage of work was undertaken to characterize Municipal Solid Waste (MSW), and describe the processes and technologies that may be integrated to support a Net-Zero Water (NZW) installation.

15. SUBJECT TERMS
net zero waste, municipal solid waste (MSW), sustainable practices, net zero installations (NZI)

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