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14. ABSTRACT
This is the publicly releasable abridged version of a report that provides analysis of characteristics of solid waste at five medium-to-large forward bases (contingency bases or CBs) in Kuwait and Afghanistan based on data collected by a deployed U.S. Army Logistics Innovation Agency and contractor team in Feb-Mar 12. Based on extensive manual waste sample characterization guided by ASTM D5231-92 (2008), the team found that energy is likely recoverable from at least 85% of CB solid waste and significant potential for power generation (0.8-16MW) by waste-to-energy systems. The three most prevalent types of solid waste by weight were food, wood, and plastics.

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USARCENT AOR CONTINGENCY BASE WASTE STREAM ANALYSIS

An Analysis of Solid Waste Streams at Five Bases in the U.S. Army Central (USARCENT) Area of Responsibility

UNLIMITED DISTRIBUTION VERSION

U.S. ARMY LOGISTICS INNOVATION AGENCY

MARCH 2013

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US Army Central (USARCENT) Area of Responsibility (AOR) Contingency Base Waste Stream Analysis (CBWSA)

Unlimited Distribution Version

March 2013

Prepared by the U.S. Army Logistics Innovation Agency

Report Background and Disclaimer

This is the publicly releasable version of a final project report prepared by the United States Army Logistics Innovation Agency (USALIA), headquartered at Fort Belvoir, Virginia. USALIA provided overall project management for both data collection and report preparation with contractor support as noted below. This report is made available for general information only and is not intended to substitute or serve as the primary reference for cost-benefit, engineering, or related analyses and decisions on any specific technology or system.

USALIA's mission is to provide innovative capabilities and solutions for logistics readiness. USALIA is the field operating agency of the Headquarters Department of the Army Deputy Chief of Staff for Logistics (HQDA DCS, G-4).

Pacific Northwest National Laboratory (PNNL) performed data collection and provided an initial draft report for the US Department of Energy under Contract DE-AC05-76RL01830. PNNL subcontractors CAPE Environmental Management Inc. and Cascadia Consulting Group supported PNNL with data collection and analysis and/or report preparation.

The report team extends special thanks to our many sponsors and supporters in and out of theater who made possible the data collection effort at the core of this report.

Cleared for public release by the Department of Defense Office of Security Review under case number 13-S-1427.

The front cover images depict project data collection activities in Afghanistan in Feb-Mar 2012. The landscape background comes from U.S. Army photograph 130128-A-ZQ422_0106a by SGT Jon Heinrich.

Executive Summary

Report Overview

This is the publicly releasable abridged version of the final report of the United States Army Logistics Innovation Agency (USALIA) Contingency Base Waste Stream Analysis (CBWSA) project. The project objective was to obtain waste stream data needed to inform requirements for and evaluate waste-to-energy (WTE) and other waste management systems for medium-to-large contingency bases (CBs) [>3000 residents]. The project consisted of characterization and analysis of the solid waste streams of five CBs located in the US Army Central (USARCENT) Area of Responsibility (AOR).

The project's principal finding is that the solid waste stream at medium-to-large CBs has significant potential for power generation or other useful energy conversion and is likely to support a variety of waste treatment technologies.

Key findings from data collection and analysis include:

- The three most prevalent types of solid waste are food (19.1% by average sample weight), wood (18.9%), and plastics (16.0%) based on analysis of bases in Afghanistan.
- Energy could be recovered from over 85% of materials in solid waste streams studied.
- Treatment of medium-to-large base solid waste could generate up to 0.8-16.8 megawatts of electrical power (assuming at least 70 tons per day of waste treated).

The waste stream at the medium-to-large CBs studied could potentially support up to large-scale WTE or incineration systems and a variety of treatment technologies. However, feasibility based on the waste stream alone does not ensure that a WTE or other technology is a viable or appropriate solution for a base. Section 3 of this report provides suggested criteria for base-specific system evaluations.

The report data and analysis are intended to support development of waste treatment system requirements and evaluation of system suitability for medium-to-large CBs. Data may also be of relevance to CB planners, staffs, and others with interest in CB sustainment. This report is intended to support, not substitute for a cost-benefit, engineering, or related analysis on any specific technology or system.

Report Outline: This report consists of an executive summary, three sections, and four appendices. The executive summary provides an overview of report contents. Section 1 provides an overview of project background and activities. Section 2 provides general waste stream data and analysis results. Section 3 discusses general implications of analysis for waste management technology and provides suggested criteria for base-specific system evaluations. Appendix A lists acronyms and abbreviations. Appendix B lists references. Appendix C details research design and methodology. Appendix D provides additional waste characterization data.

Overview of Data Collection Activities and Findings

The project data collection team deployed to a total of five CBs in Afghanistan and Kuwait (as listed in Table ES.1) in February-March 2012. At each base, the team collected data through manual sorting of samples of mixed, non-hazardous solid waste guided by a waste management industry method[1]; interviews with base personnel; and observation of base waste collection activities. The team supplemented field data with additional data from research and post-collection analysis. Data collected and analyzed include municipal solid waste[2] (MSW) generation rates and composition and content of ash, heat, moisture, and volatiles. The team analyzed data for each base individually and in aggregate for the Afghanistan bases.

Table ES.1. Examples of General Characteristics of Data Collection Sites

Base	Location	Approximate Population Group (# Residents)	Estimated MSW Generated (tons/day)	MSW Generated Per Capita[a] (lb/person/day)
CB #1	Kuwait	5-10K	106[b]	-
CB #2	Afghanistan	>10K	-	20.0
CB #3	Afghanistan	5-10K	-	21.5
CB #4	Afghanistan	>10K	255	-
CB #5	Afghanistan	3-5K	16	9.2

Dashes indicated data not included or available.
[a]Calculated from base-provided population and MSW generation data.
[b]MSW generation rate for CB #1 calculated assuming an average MSW generation rate based on CB #2, CB #3, and CB #4.

Figure ES.1 and Table ES.2 show the waste component category (waste types) percentages by weight at all five CBs studied as well as the average of the four Afghanistan bases (indicated in Figure ES.1 by the thick brown lines within the brown-shaded boxes). The shaded box indicates the 90% confidence interval, meaning there is 90% probability that the true value falls within the interval shown. Food and wood wastes are the largest components of the average waste stream (both at ~19% by weight), followed by plastic (16%), cardboard (14%), and mixed paper (13%). Potentially energy-generating (combustible) materials comprise 93% of the average solid waste stream based on data collected with an average waste moisture content of 27.6% and heat (energy) content of 9.6 MMBtu/ton. For comparison, US domestic MSW has an average heat content of approximately 11 MMBtu/ton.[3]

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[1]ASTM International (ASTM) D5231-92 (Reapproved 2008), "Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste."
[2] In this report, municipal solid waste (MSW) refers to solid wastes and residues generated at CBs, unless noted. MSW is a term commonly used in the waste management industry for typical solid wastes of mixed composition from residences, businesses, and institutions. The team only analyzed composition of non-hazardous MSW, rather than other waste streams including construction and demolition, hazardous, bulk liquid (e.g. black and gray water), and medical.
[3] Energy Information Administration 2007.

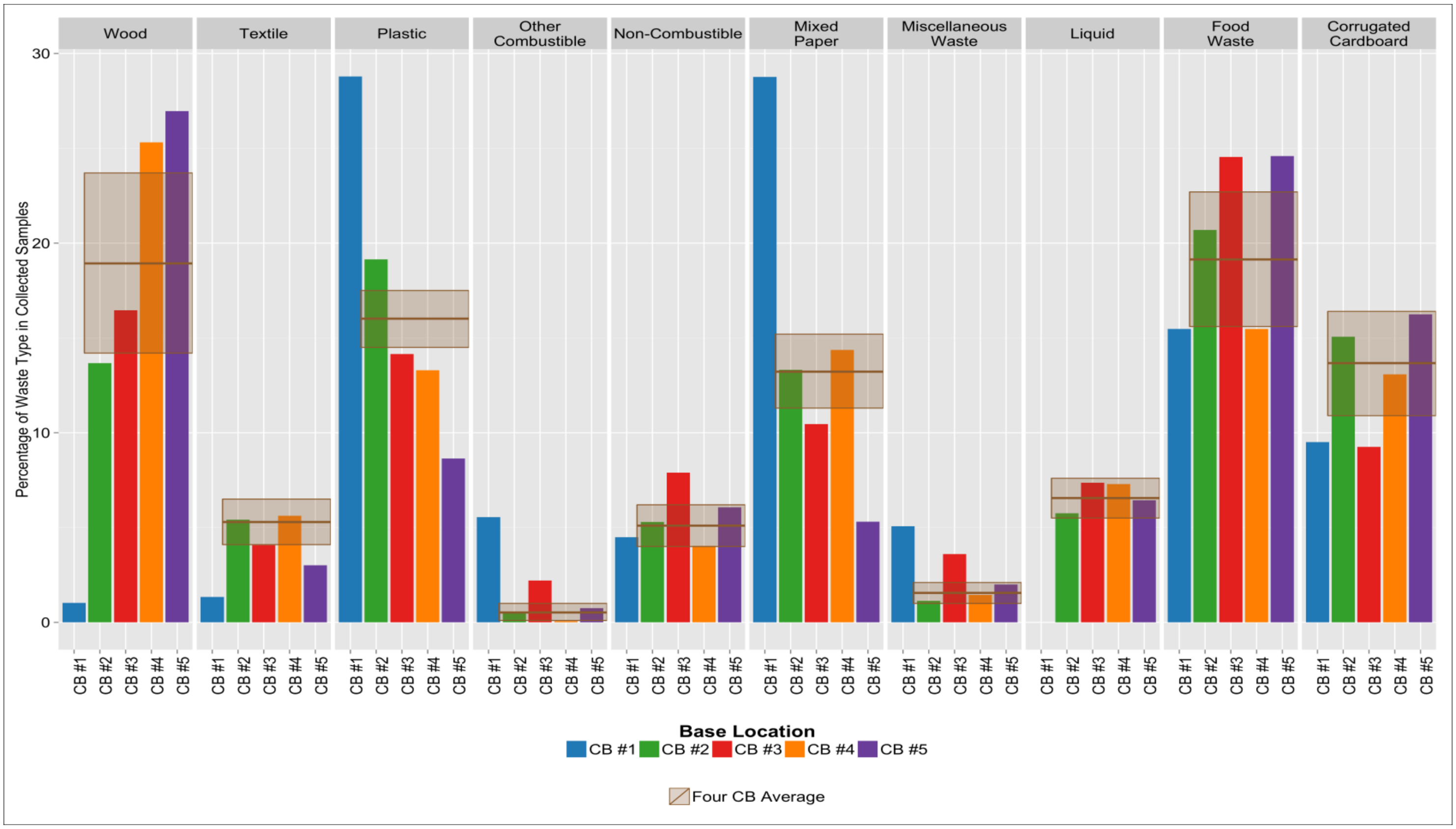

Figure ES.1. Waste Composition (MSW, Percent by Weight) for Individual Bases and Afghanistan (Four CB) Average

Table ES.2. Individual and Average Base Waste Composition (MSW, Percent by Weight)[a]

Waste Component	CB #1	CB #2	CB #3	CB #4	CB #5	Afghanistan Average (weighted)[b]	Afghanistan Standard Error
Corrugated Cardboard	9.5%	15.1%	13.1%	9.3%	16.2%	13.7%	1.6%
Food Waste	15.5%	20.7%	15.5%	24.5%	24.6%	19.1%	2.1%
Liquid	NR[c]	5.8%	7.3%	7.4%	6.4%	6.6%	0.6%
Miscellaneous Waste[d]	5.1%	1.1%	1.5%	3.6%	2.0%	1.6%	0.3%
Mixed Paper	28.8%	13.3%	14.4%	10.5%	5.3%	13.2%	1.2%
Non-Combustible	4.5%	5.3%	4.0%	7.9%	6.1%	5.1%	0.7%
Other Combustible	5.5%	0.5%	0.1%	2.2%	0.8%	0.5%	0.3%
Plastic	28.8%	19.1%	13.3%	14.2%	8.6%	16.0%	0.9%
Textile	1.3%	5.4%	5.6%	4.1%	3.0%	5.3%	0.7%
Wood	1.0%	13.7%	25.3%	16.5%	27.0%	18.9%	2.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	-

[a]Due to rounding, some percentages different from some other tables and figures and some totals do not add up to 100%. Percentages generally rounded to nearest tenth of a percent.
[b]Averages for Afghanistan bases weighted in proportion to the base total weight of waste processed annually. Refer to appendix C for more information (page C.9).
[c]Liquid waste was not measured at CB #1. Liquid waste is not a separate liquid waste stream but rather liquids that were entrained in the MSW stream (such as beverage bottles with liquid contents).
[d]Miscellaneous wastes are items identified as potentially unsuitable for standard sorting and/or waste treatment such as personal medical and hygiene items.

Table ES.3 summarizes the solid waste stream characteristics for each base sampled and the Afghanistan average. In addition to waste composition, the team obtained specialized waste characteristic data, including moisture content (measured during sampling using a portable moisture meter) and published heat, ash, and volatiles content (refer to Appendix D for more information). These data are intended to assist system developers with design requirements.

Table ES.3. Summary of Specialized Waste Stream Characteristics for Sampled Bases

	Moisture Content (% by weight)	Heat Content (MMBtu/ton)[a]		Ash Content (% by weight)		Volatiles Content (% by weight)	
		wet	dry	wet	dry	wet	dry
CB #1	12.0	13.8	15.1	9.6	10.8	70.9	80.1
CB #2	28.7	9.9	12.8	10.0	12.4	54.1	71.7
CB #3	31.7	8.8	12.0	12.5	15.2	49.1	68.0
CB #4	28.6	9.2	11.8	9.6	11.7	53.3	69.8
CB #5	23.5	9.6	11.9	12.0	14.0	54.5	67.5
Afghanistan Average	27.6	9.6	12.3	10.3	12.5	54.2	70.4

[a]MMBtu/ton means a heat content equivalent 1,000,000 British Thermal Units (Btus) per ton. A Btu is the amount of energy required to increase the temperature of 1 pound of water by 1 degree Fahrenheit, at normal atmospheric pressure.
1 MMBtu/ton = 500 Btu/lb. 1 MMBtu = 1.06 gigajoules (GJ) = 293 kWh.

Waste Treatment Options

There are many waste management options for a variety of purposes, including waste disposal (elimination), volume reduction, and resource or energy recovery. Based on data collected, waste streams on medium-to-large bases could likely support a variety of waste treatment technologies and processes.

Based on high-level analysis, treatment of waste from medium-to-large CBs could produce up to 0.8-16.8 megawatts of electrical power, depending on the amount and energy content of the waste, the conversion process employed, electrical generator and infrastructure performance, parasitic loads, and other factors.[1]

Based on the waste stream data collected, waste treatment technologies for CBs are not expected to require significantly different features from those intended for similar municipal or commercial applications. Based on observations of CB #5's estimated 16 ton-per-day (TPD) solid waste stream, smaller CBs will likely only be able to effectively support incinerators and small-scale WTE systems. Given construction time and infrastructure requirements, facility-sized or other large-scale WTE systems may only be cost-effective if able to operate for several years at a relatively well-developed base.

Not all types of waste can be effectively treated for energy recovery. Some wastes common at medium-to-large bases are unlikely to be effectively processed in large quantities by WTE systems and most incinerators. Further, some waste treatment technologies can only process a few types of waste and accordingly may require considerable waste sorting and other pre-treatment.

[1] Potential electrical power generation is a high-level estimate based on average study-derived wet basis heat contents, 10-30% technology efficiency range, and 90% system capacity factor. Net output will vary depending on actual conditions.

Each technology has different requirements and capabilities. Given variation in real world bases, the most appropriate waste treatment options for each CB should be determined by base-specific conditions and requirements. Feasibility based on the waste stream alone does not ensure that a WTE or other technology is a viable or appropriate waste management solution for a CB. Decision-makers will likely need to assess trade-offs between various potential solutions to determine the best option(s). Section 3 provides high-level suggested criteria for base-specific system design and evaluation.

To ultimately be effective, any CB waste management solution must be able to meet the demands of operational conditions. Many types of waste are continuously generated at real world bases with non-hazardous solids often mixed for expediency of collection and disposal. Systems that frequently require intensive maintenance, special parts and other items potentially not easily supplied, or considerable waste pre-sorting or other special pretreatment may not be practical for CB waste management in an austere environment or remote location.

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1.0 Introduction

1.1 Background and Project Objective

Energy security and waste management are challenges for military bases, particularly in austere environments. Reducing dependence on liquid fuels is a priority for the Army and other Services. Management of the waste continuously generated at austere bases is also vital. Waste-to-energy (WTE) and other advanced waste treatment technologies may be an effective solution to both of these challenges by converting wastes into useful energy while reducing waste management impacts on contingency bases.

The U.S. Army Logistics Innovation Agency's (USALIA, referred to here as LIA) mission is to provide innovative capabilities and solutions for logistics readiness. LIA is the field operating agency of the Headquarters Department of the Army Deputy Chief of Staff for Logistics (HQDA DCS, G-4).

In the summer of 2011, LIA obtained funding to conduct a waste stream analysis project to support U.S. Army Central (ARCENT) and other DoD efforts to develop and evaluate improved waste management systems for CBs. ARCENT Environmental was the overall project sponsor. United States Forces-Afghanistan (USFOR-A) Environmental and Area Support Group-Kuwait (ASG-KU), in coordination with U.S. Central Command (CENTCOM) Environmental, provided theater sponsorship for data collection activities.

The purpose of this project was to collect and analyze waste stream data needed to inform requirements for and evaluate WTE and other improved waste management systems for medium-to-large CBs (>3000 residents). This project is the first known to have conducted systematic waste characterization studies at several CBs in the ARCENT area of responsibility (AOR).

1.2 Summary of Project Activities

From February to March 2012, the project data collection team (LIA, Pacific Northwest National Laboratory [PNNL], and PNNL subcontractor Cape Environmental Management Inc. with CONUS-based support from PNNL subcontractor Cascadia Consulting Group) conducted waste characterization studies at five contingency bases in the ARCENT AOR. The team collected data through manual sorting of samples of mixed, non-hazardous solid waste guided by a waste management industry method; interviews with base personnel; and observation of base waste collection activities.

For data integrity, the project team developed a Data Collection Plan (DCP) based on a waste management industry-accepted method of waste characterization, ASTM International (ASTM) D5231-92 (Reapproved 2008), "Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste." This DCP guided activities at each base, with some modifications necessary due to situations encountered in the field.

The data collection method consisted of collecting a statistically significant number of random samples of MSW weighing at least 200 pounds per ASTM (2008) for manual sorting into waste component material categories (e.g., food waste, plastic, paper). After sorting a sample, the project team measured weight, volume, and moisture content of each component material. The team also collected information on waste generation rates from base staff. Other data were collected as necessary from published sources to estimate energy contents and other waste characteristics relevant to waste treatment technology development. Appendices C and D provide additional information about the post-data collection analysis.

The data collection team visited these bases according to the schedule listed in Table 1.1.

Table 1.1. Sampling Schedule

Base	Arrival Date (2012)	Departure Date (2012)	Number of MSW Samples Collected
CB #1	21 February	23 February	9
CB #2	23 February	02 March	26
CB #3	03 March	09 March	32
CB #4	09 March	16 March	32
CB #5	16 March	20 March	32

"Samples collected" refer to samples collected for manual waste composition sorting. Out of 131 samples collected, 126 yielded data suitable for incorporation into the analysis (no less than 26 each for CBs #2-5).

2.0 Waste Stream Data and Analysis

This section provides an overview of data collected and findings from post-collection analysis.

2.1 General Base Data and Waste Generation Rates

To support the analysis, the sampling team collected general information as available on each base, including:

- Approximate population
- General base mission and functions (e.g. major theater airbase, regional support base)
- Waste generation rates (as available from base staff)
- General waste collection and disposal methods

Table 2.1 summarizes the population and solid waste generation rates provided by respective base staff and provides examples of estimated per capita solid waste generation rates.

Based on site-provided populations and waste generation rates, per capita solid waste generation rates varied from 9.2 pounds per person per day to ~20-25 pounds per person per day. The average per capita solid waste (MSW) generation rate across all bases studied was 19.7 lbs/day. CB #5 residents generated the least amount of waste per person at 9.2 pounds per person per day. The team observed fewer supporting activities at CB #5 (e.g. motor pools and supply support activities [SSAs]), which likely influenced the lower per capita generation. At time of data collection, CBs #2 through #4 all had more extensive infrastructure (e.g. Dining Facilities [DFACs], Post Exchange (PX), supply and maintenance facilities) and regional support missions, which may have contributed to higher waste generation rates.

Table 2.1. Data Collection Site Population and Examples of Estimated MSW Generation Rates

Base	Location	Approximate Population Group (# Residents)	Estimated MSW Generated (tons/day)	MSW Generated Per Capita[a] (lb/person/day)
CB #1	Kuwait	5-10K	106[b]	-
CB #2	Afghanistan	>10K	-	20.0
CB #3	Afghanistan	5-10K	-	21.5
CB #4	Afghanistan	>10K	255	-
CB #5	Afghanistan	3-5K	16	9.2

Dashes indicate data not included or available.
[a]Calculated from base-provided population and MSW generation data.
[b]MSW generation rate for CB #1 calculated assuming an average MSW generation rate based on CB #2, CB #3, and CB #4.

These population and waste generation rate data were provided by base personnel, typically through interviews. Both of these quantities are difficult to measure precisely in an operational environment, so per capita generation rates are only general estimates.

In particular, precise calculation of waste generation rates is also difficult in an operational environment. Site constraints, including lack of truck scales, variable recycling and segregation practices, and general unavailability of construction and demolition (C&D) waste generation estimates may affect the data provided to the sampling team. Time constraints and other factors prevented independent validation of the base-provided waste generation rates. See section 2.2.2 (page 2.4) for more information on potential data constraints.

Table 2.2 summarizes the waste collection and disposal methods at each base at the time of data collection. Waste collection and disposal methods varied base to base. The team had to modify the data collection plan in some cases to accommodate base-specific conditions. Appendix C provides more detailed information.

Table 2.2. Waste Collection and Disposal Methods

Base	Material Separation	Waste Collection Methods
CB #1	Separate collection bins for plastic water bottles, cardboard, mixed paper, wood, and metals.	MSW collected in 6-m^3 dumpsters and emptied two to three times per day by a local contractor in compactor type garbage trucks. Wood, construction and demolition waste, and similar materials collected in 20-m^3 dumpsters and emptied periodically.
CB #2	Plastic water bottles, metals, glass, electronics, and mattresses manually sorted from small percentage of total MSW waste stream.	MSW collected in 6-, 15-, 22-, and 30-m^3 dumpsters. 6-m^3 dumpsters are emptied once during the day and once at night by three contractor-operated compactor trucks. Dining facility dumpsters are emptied two to three times during the day and two to three times at night. Dumpsters in other areas are emptied up to two times during the day and up to two times during the night.
CB #3	Separate collection bins for wood and metals.	MSW collected in 1.5-m^3 dumpsters and usually emptied twice per day by a contractor.
CB #4	Separate collection bins for aluminum cans and plastics. Separated materials sometimes consolidated into MSW dumpsters by contractors	MSW collected in 1.1- and 5.5-m^3 dumpsters, and serviced by compactor trucks operating on routes that service a variety of facility types. Dining facility dumpsters are emptied five times per day while all others are emptied two times per day.
CB #5	No formal activities noted.	MSW collected in 1.1 m^3 dumpsters, which are emptied twice per day by two contractor-operated compactor trucks.

2.2 Waste Composition Data Collection

The team collected detailed solid waste composition data through manual sorting of nearly 130 samples of non-hazardous MSW[1] across the five bases, most weighing at least 200 pounds, subject to waste availability. At sites with centralized waste collection areas, the team drew samples from waste collection truck deliveries. At sites without regular centralized deliveries, the team drew samples from dumpsters throughout the base.

[1]In this report, municipal solid waste (MSW) refers to solid wastes and residues generated at CBs, unless noted. MSW is a term commonly used in the waste management industry for typical solid wastes of mixed composition from residences, businesses, and institutions. The team only analyzed composition of non-hazardous MSW, rather than other waste streams including construction and demolition, hazardous, liquid (e.g. black and gray water), and medical. Out of 131 samples, 126 yielded data suitable for the final analysis. Report data likely captures most types of MSW that could be treated for energy recovery, but due to CB operational and project constraints, some non-combustible and other solid wastes may be underrepresented. Refer to Section 2.2.2 for more information.

2.2.1 Overview of Waste Composition Data Collected

For each sample, the team manually separated materials into waste component categories[1] and recorded several measurements for each component. The data recorded by the team for each sample included:

- Originating activity category (where possible): Administrative (admin), Dining Facility (DFAC), General[2], Life Support Area (LSA), Motor Pool, Supply Support Activity (SSA)
- Total weight of sample
- Weight, volume, and moisture content of each waste component category

The team manually sorted waste samples into the following component categories:

- Corrugated Cardboard
- Food Waste
- Liquids (e.g. contents of beverage containers)
- Miscellaneous Waste[3]
- Mixed Paper
- Non-Combustible
  - Ferrous Metal
  - Non-Ferrous Metal
  - Glass
  - Concrete, rocks, soil, and similar materials
- Other Combustible[4]
- Plastic
  - #1 - Polyethylene terephthalate (PET)
  - #2 - High-density polyethylene (HDPE)
  - #3 - Polyvinyl chloride (PVC)
  - #4 - Low-density polyethylene (LDPE)
  - #5 - Polypropylene (PP)
  - #6 - Polystyrene (PS)
  - #7 - Other (Plastic #7)
- Textile[5]
- Wood

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[1] Waste component categories (shortened as waste components) is the term used in the ASTM D5231-92 standard used to guide the project's waste sorting for composition analysis. In this study, waste components are designated categories for types of waste in the solid waste stream, such as food, plastic, and wood. Refer to Appendix C for more information.

[2] General waste areas included areas with a mix of activity types, and areas other than the five primary categories (Admin, DFAC, LSA, Motor Pool, and SSA). Many Post Exchange (PX) and Morale, Welfare, and Recreation (MWR) facilities were located in areas classified as general.

[3] Miscellaneous waste is the standard term used in this report for items encountered potentially unsuitable for standard sorting and/or waste treatment such as personal medical and hygiene items. The term is used to avoid confusion with segregated hazardous and regulated medical waste that is not part of the MSW stream and which the team did not sort or analyze. Miscellaneous wastes were occasionally found in small quantities during sampling activities as is expected for any manual MSW waste sorting activity.

[4] Other combustibles primarily consist of rubber (usually tires or tire scraps). For purposes of this study, categories of combustible materials are cardboard, food waste, liquid, mixed paper, other combustibles plastic, wood, and textiles. Liquids entrained with solid waste (e.g. in beverage containers) are included in the general combustible materials category because they unlikely to be efficiently removed. Further, the analysis takes liquid content in account when calculating waste heat (energy) content. Non-combustibles and some miscellaneous wastes are likely to be more easily segregated from the mixed solid waste stream.

[5] Textiles include bedding, carpet, clothing, rope and webbing, and other items composed of textiles.

2.2.2 Data Collection Constraints and Assumptions

As with any real world data collection activity, the project team faced several constraints that may impact the analysis. The team made best effort to work through these issues and mitigate their impact where possible as noted below and in Appendix C. The following discussion summarizes key issues.

- Sampling conducted during a single 3-5 day period at each base and may not capture waste stream variations from population, seasonal, and other changes that may occur over longer periods.
- Team made best effort to collect representative samples at each base. In some cases, base-specific constraints such as low waste volumes and inaccessible or segregated materials (see points below) the team to adjust the data collection plan. Appendices C and D detail data collection and analysis methods.
- As noted in section 2.1, this report's data may under-represent certain waste types due to common waste collection and segregation practices. Waste composition findings are based on waste available for sampling. This is certain to affect C&D wastes (such as concrete) which are generally not included in standard solid waste collection and to at least some extent, other common non-combustible wastes and tires which are generally segregated from the MSW stream and likely under-represented in samples sorted. However, this report's data likely account for the majority of waste likely to be effectively treated for energy recovery by WTE and other waste treatment technologies.
- Based on team experiences during data collection, not all waste generation rates are measured uniformly or consistently, particularly wastes other than MSW, black and gray water. Use of truck scales to record weights of collection vehicle loads is one potential solution to better track quantities of wastes generated, particularly C&D.
- Because of the relatively small number of bases that LIA was able to sample and the inherent variations between real world bases, waste characterization findings and associated treatment recommendations cannot be extrapolated to other bases with certainty. However, data may be useful for estimates and as a baseline for comparison.

2.3 Waste Characterization Analysis

The data collected at each base was analyzed individually and in aggregate as detailed in Appendix C. The field-recorded composition and moisture content data were used to determine more waste characteristics, including heat, ash, and volatiles content as detailed in Section 2.4 and Appendix D.

2.3.1 Findings for Individual Bases

This section summarizes the solid waste stream analysis for each base individually. The project team only handled, sorted, and analyzed standard non-hazardous solid waste (MSW).

Many factors could influence waste generation rates, including frequent population changes and other nearly continuous variations in base activities. Many factors likely influence variations between bases, including level of infrastructure (such as number of DFACs or usage of flush toilets versus chemical toilets) and base forces and functions (such as population of residents who rarely leave the base compared to population of transients and residents who frequently go on multi-day missions outside the base).

Waste Composition by Weight

Table 2.4 and Figure 2.1 summarize the waste component percentages by weight for each base. Food waste was the largest component at CB #2 and CB #4 and the second largest component at CB #3 and CB #5. Wood was the largest component at CB #3 and CB #5. Based on data collected, materials that could produce useful energy when treated by WTE systems range from 88%-94% of the total MSW waste stream. Non-combustible materials encountered include metals and small amounts of glass. Liquids (such as in beverage bottles) entrained with most waste samples reduce heat content, but would be difficult to completely remove without specialized equipment or intensive manual sorting. Figure 2.2 shows waste component percentages for each base overlaid with 90% confidence intervals.

Table 2.4. Solid Waste Composition for Individual Bases (MSW, Percent by Weight)

Waste Component	CB #1	CB #2	CB #3	CB #4	CB #5
Corrugated Cardboard	9.5%	15.1%	9.3%	13.1%	16.2%
Food Waste	15.5%	20.7%	24.5%	15.5%	24.6%
Liquid	NR[a]	5.8%	7.4%	7.3%	6.4%
Miscellaneous Waste	5.1%	1.1%	3.6%	1.5%	2.0%
Mixed Paper	28.8%	13.3%	10.5%	14.4%	5.3%
Non-Combustible	4.5%	5.3%	7.9%	4.0%	6.1%
Other Combustible	5.5%	0.5%	2.2%	0.1%	0.8%
Plastic	28.8%	19.1%	14.2%	13.3%	8.6%
Textile	1.3%	5.4%	4.1%	5.6%	3.0%
Wood	1.0%	13.7%	16.5%	25.3%	27.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Due to rounding, some differences from other tables and figures and some column totals do not equal 100%. [a]NR indicates data not recorded.

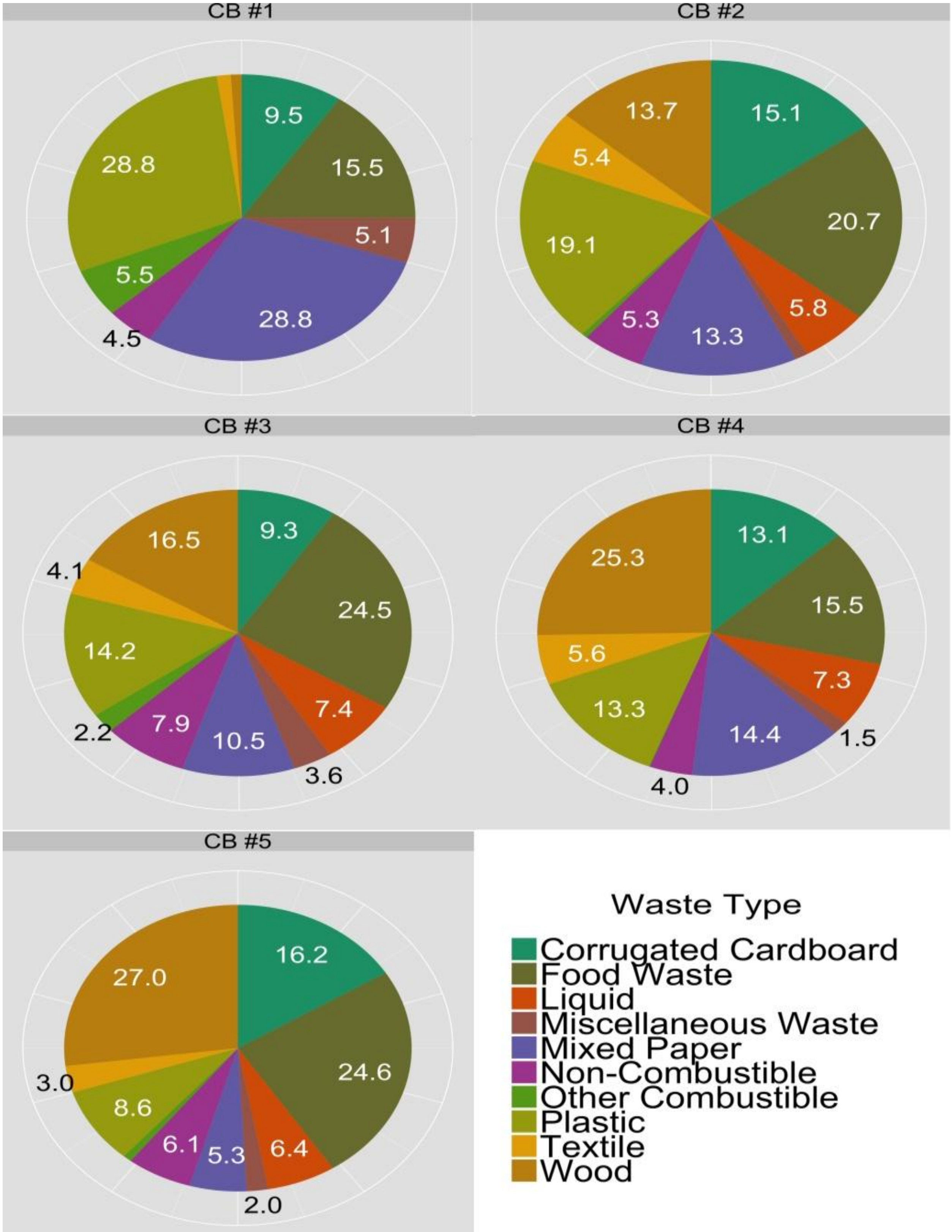

Figure 2.1. Solid Waste Composition for Individual Bases (MSW, Percent by Weight)

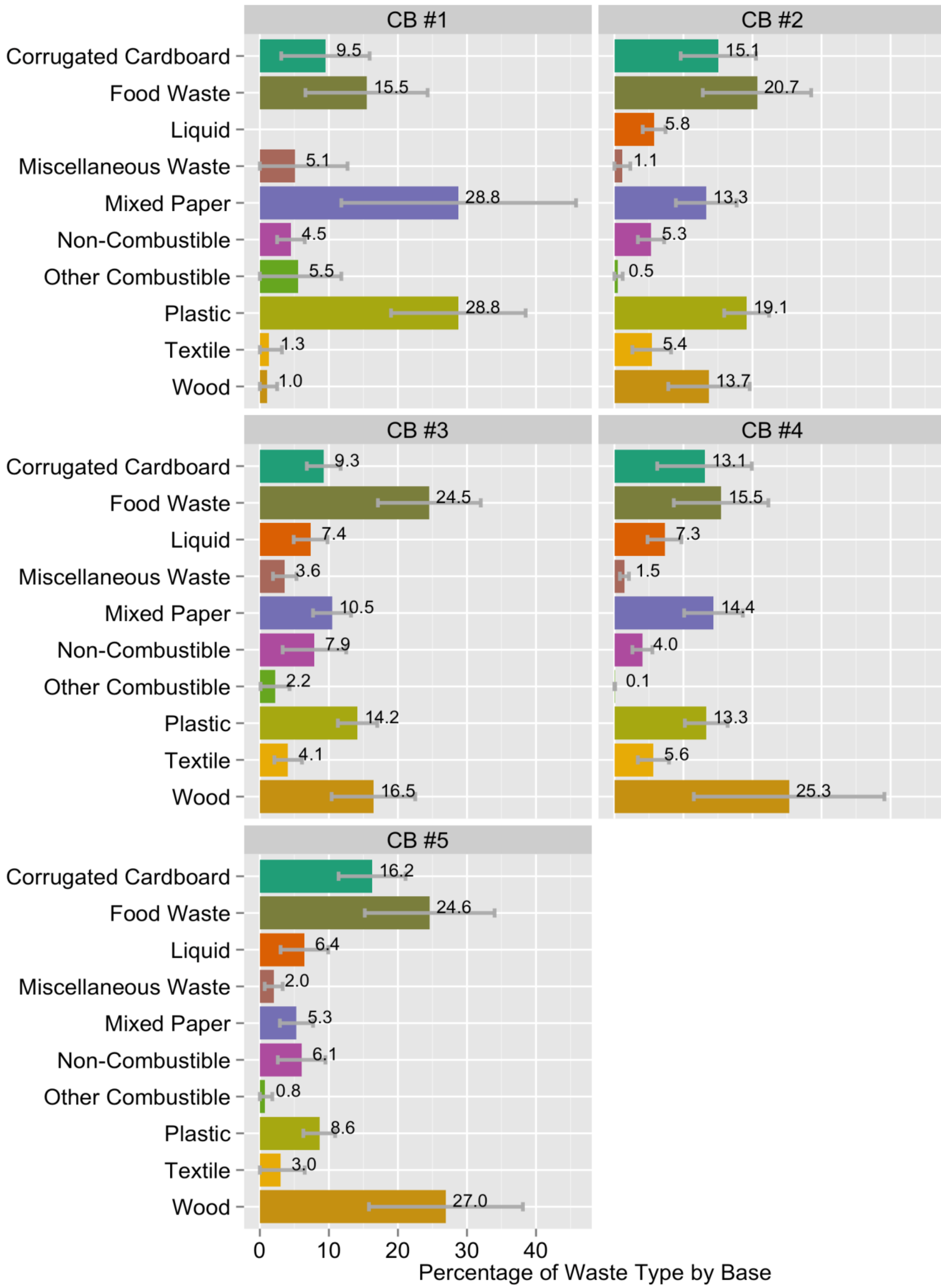

Figure 2.2. Solid Waste Composition for Individual Bases with 90% Confidence Intervals (MSW, Percent by Weight)

Table 2.5 shows the waste composition in more detail, including plastic and non-combustible sub-categories.

Table 2.5. Detailed Solid Waste Composition by Base (MSW, Percent by Weight)

Waste Component		CB #1	CB #2	CB #3	CB #4	CB #5	Afghanistan Avg (Weighted)[b]
Corrugated Cardboard		9.5%	15.10%	9.3%	13.1%	16.2%	13.7%
Food Waste		15.5%	20.70%	24.5%	15.5%	24.6%	19.1%
Liquid		NR[b]	5.80%	7.4%	7.3%	6.4%	6.6%
Miscellaneous Waste		5.1%	1.10%	3.6%	1.5%	2.0%	1.6%
Mixed Paper		28.8%	13.30%	10.5%	14.4%	5.3%	13.2%
Non-Combustible	Ferrous Metal	1.2%	3.30%	5.7%	2.4%	3.5%	3.2%
	Non-Ferrous Metal	2.3%	1.80%	2.0%	1.4%	1.1%	1.6%
	Glass	1.0%	0.20%	0.2%	0.2%	0.7%	0.2%
Other Combustible		5.5%	0.50%	2.2%	2.2%	0.8%	0.5%
Plastics	#1- PET	10.6%	7.00%	5.5%	6.1%	3.2%	6.4%
	#2 - HDPE	5.0%	5.40%	4.2%	1.6%	1.6%	3.7%
	#3 - PVC	4.4%	0.70%	0.8%	0.5%	1.2%	0.7%
	#4 - LDPE/LLDPE	1.3%	2.80%	1.9%	3.1%	1.0%	2.8%
	#5 - PP	0.1%	0.20%	0.3%	0.2%	0.1%	0.2%
	#6 - PS	7.3%	2.20%	1.0%	1.2%	1.0%	1.6%
	#7 - other	0.1%	0.70%	0.4%	0.6%	0.5%	0.6%
Total Plastic (All Types)		28.8%	19.00%	14.1%	13.3%	8.6%	16.0%
Textile		1.3%	5.40%	4.1%	5.6%	3.0%	5.3%
Wood		1.0%	13.70%	16.5%	25.3%	27.0%	18.9%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

[a]Due to rounding, some percentages different from some other tables and figures and some totals do not add up to 100%. Percentages generally rounded to nearest tenth of a percent.
[b]Averages for Afghanistan bases weighted in proportion to the base total weight of waste processed annually. Refer to appendix C for more information (page C.9).

Estimated Waste Composition by Base and Generating Activity Category

The activity area(s) where each sampled load originated was identified and recorded at all bases, except CB #4 where the waste origin could not be reliably determined because waste trucks delivered mixed loads from a variety of activities to a central location and detailed truck route information was unavailable. Due to limited number of samples collected, CB #1 is also excluded from this analysis by activity category. For analytical purposes, the waste generation activities across the CBs studied were categorized as:

- Administrative Area (Admin): areas primarily for offices and staff activities
- Dining Facility (DFAC): facilities for preparation and serving of meals
- General[1]: areas with mixed functions
- Life Support Area (LSA): housing areas with tents, barracks, latrines, and other residential facilities

[1] General waste areas included areas with a mix of activities and/or those other than the five primary activities (Admin, DFAC, LSA, Motor Pool, SSA). For example, dumpsters adjacent to Admin, DFAC, and LSA activities receiving waste from all three locations. Many Post Exchange (PX) and Morale, Welfare, and Recreation (MWR) or equivalent facilities were located in areas classified as general.

- Motor Pool: areas primarily for vehicle and equipment maintenance and repair facilities
- Supply Support Activity (SSA): areas primarily for receipt, distribution, and/or storage of supplies

The team assigned generating activities to samples within the constraints of information available, so compositions by activities are only general estimates. Unlike for most other waste composition analyses in the report, the team did not collect sufficient sample data by generating activity type to achieve a high statistical confidence level due to time and sample availability constraints.

Figure 2.3 shows the estimated waste composition by generating activity for CB #2, CB #3, and CB #5. Activity data was more limited at CB #3 and CB #5, but some could be extracted for comparison.

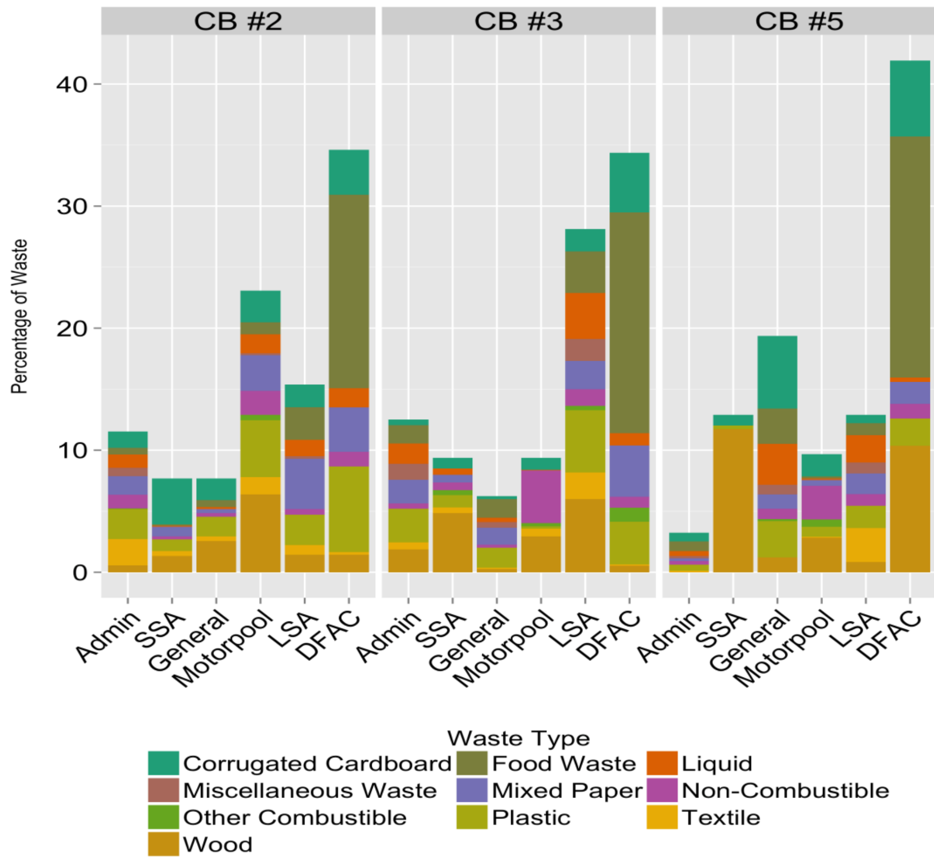

Figure 2.3. Estimated Waste Composition by Generating Activity (Percentage of Total Base MSW)

2.3.2 Aggregate Waste Composition Analysis

This section provides aggregate analysis of the waste stream data of the four Afghanistan bases studied. Data from CB #1 was not included in the aggregate analysis since it differed in several respects from other bases, including unusually frequent waste collection which limited availability of sufficiently-sized samples.

Average Waste Composition for Bases Studied in Afghanistan

Figure 2.4 shows the weighted solid waste composition average for the four bases studied in Afghanistan. This average is weighted in proportion to the base's total estimated waste generation rate (see Appendix C for more information). Food waste is the largest primary component at 19.1% of the waste stream, followed by wood (18.9%), plastic (16.4%), cardboard (13.7%), and mixed paper (13.2%). Combustible (potentially energy-yielding) materials comprise approximately 93% of the average waste stream based on sample data.[1]

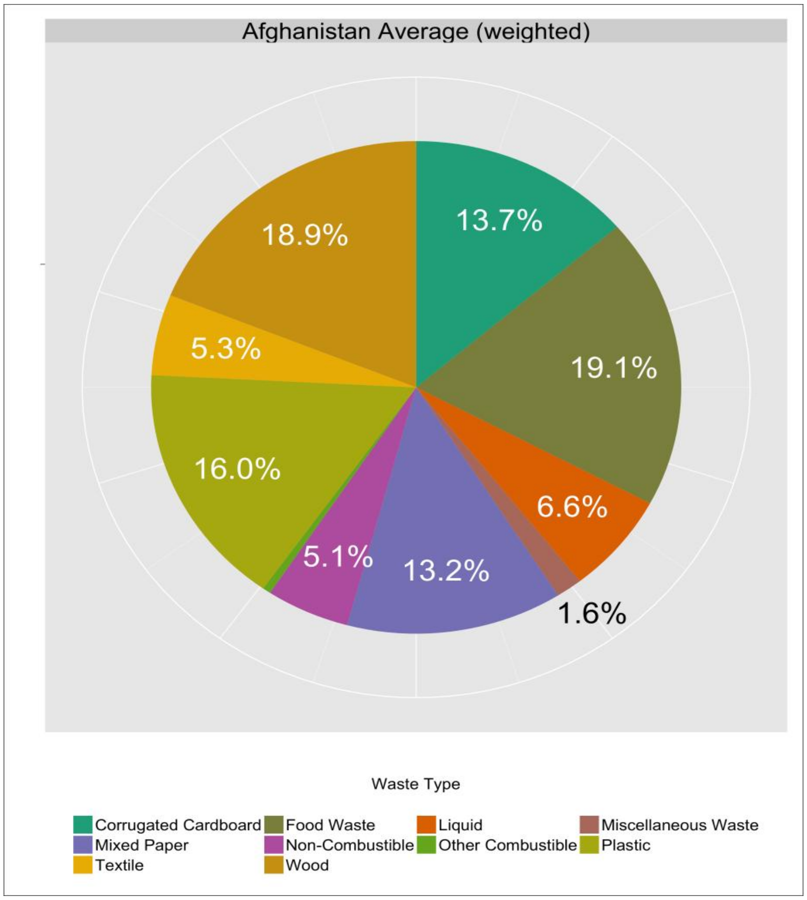

Figure 2.4. Average Solid Waste Composition for Afghanistan Bases (MSW, Percent by Weight)

Figure 2.5 shows the measured waste composition by base with confidence intervals. The solid brown lines indicate the weighted average for Afghanistan bases for each waste component. The brown box on each waste component is the estimated range (with 90% statistical confidence) within which the actual component percentage average lies. The process used to calculate this 90% confidence interval is documented in Appendix C.

[1] For purposes of this study, categories of combustible materials are cardboard, food waste, liquid, mixed paper, other combustibles, plastic, textiles, and wood. Liquids entrained with solid waste (e.g. often in beverage containers) are included in the general combustible materials category because they unlikely to be efficiently removed. Further, the analysis takes liquid content in account when calculating waste heat (energy) content. Non-combustibles and some miscellaneous wastes are likely more easily segregated from the mixed solid waste stream. Miscellaneous wastes constitute a variety of materials and energy contents, so the category is excluded from calculations of a base's percentage of combustible waste. Some miscellaneous wastes encountered in small quantities, such as personal hygiene items would likely be combustible.

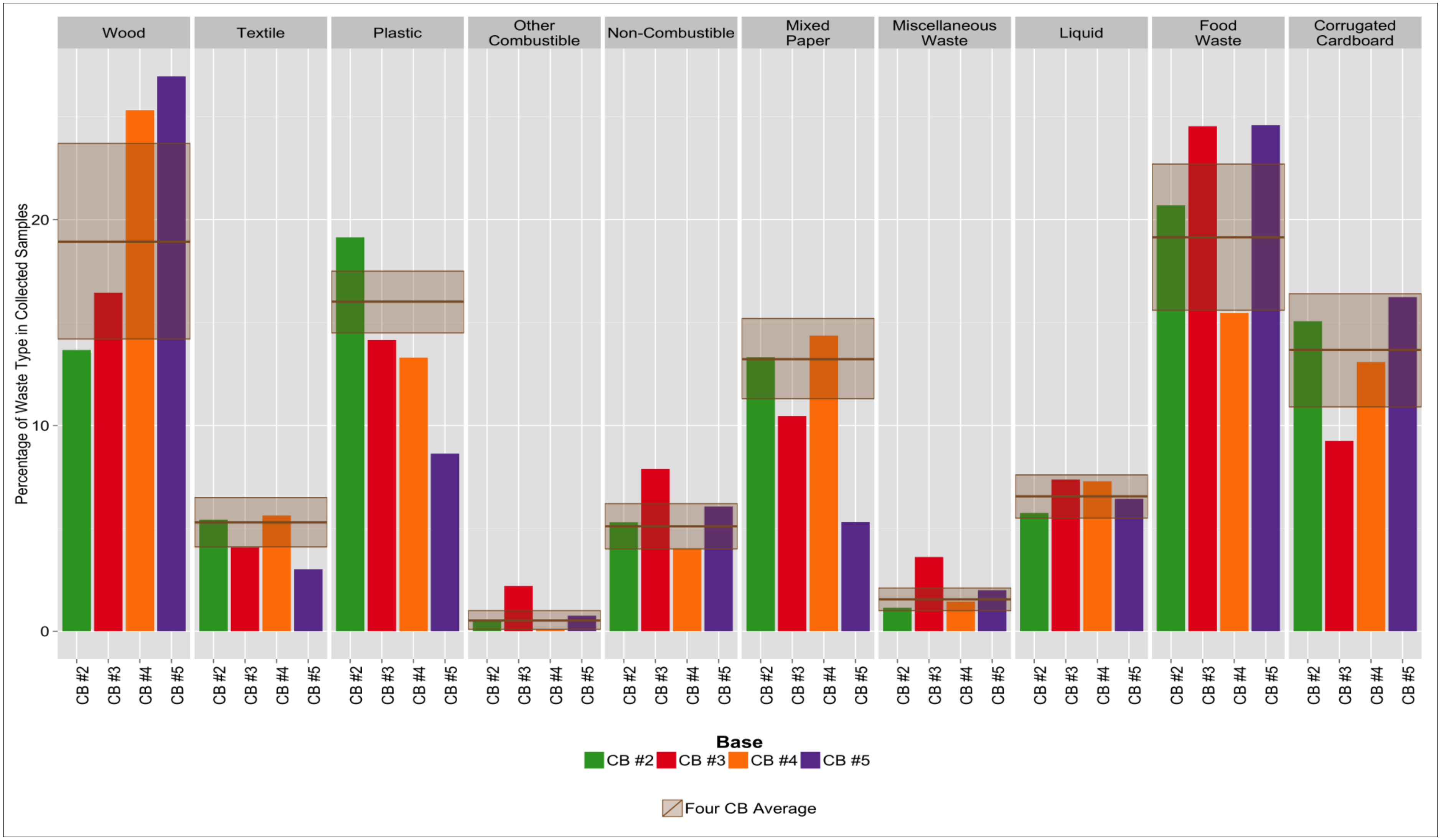

Figure 2.5. Solid Waste Composition for Afghanistan Bases (MSW, Percent by Weight)
(Shaded boxes indicate 90% confidence interval for the category average indicated by the dark horizontal lines)

Table 2.6. Solid Waste Composition for Afghanistan Bases (MSW, Percent by Weight)

Waste Component	CB #2	CB #3	CB #4	CB #5	Afghanistan Average (weighted)	Afghanistan Standard Error
Corrugated Cardboard	15.1%	9.3%	13.1%	16.2%	13.7%	1.6%
Food Waste	20.7%	24.5%	15.5%	24.6%	19.1%	2.1%
Liquid	5.8%	7.4%	7.3%	6.4%	6.6%	0.6%
Miscellaneous Waste	1.1%	3.6%	1.5%	2.0%	1.6%	0.3%
Mixed Paper	13.3%	10.5%	14.4%	5.3%	13.2%	1.2%
Non-Combustible	5.3%	7.9%	4.0%	6.1%	5.1%	0.7%
Other Combustible	0.5%	2.2%	0.1%	0.8%	0.5%	0.3%
Plastic	19.1%	14.2%	13.3%	8.6%	16.0%	0.9%
Textile	5.4%	4.1%	5.6%	3.0%	5.3%	0.7%
Wood	13.7%	16.5%	25.3%	27.0%	18.9%	2.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	-

[a]Due to rounding, some differences from other tables and figures and some column totals do not equal 100%.

Estimated Average Waste Composition by Generating Activity Type

Limited data obtained on sample waste generating activities enabled the team to estimate solid waste composition by activity type. As noted above, activity types were assigned to samples within the constraints of the information available.

Figure 2.6 illustrates the estimated average waste composition by activity type for the combined CB #2, CB #3, and CB #5 data for which generating activities were available. The gray bars on each waste component note the 90% confidence interval for the actual waste stream component percentage based on data collected. The process used to calculate the confidence interval is documented in Appendix C.

DFAC waste consisted mostly of food with significant cardboard, mixed paper, and plastic. Motor pool waste has a higher percentage of non-combustible waste (metals and glass), wood, and plastic. SSA waste had a high percentage of cardboard and wood from shipping materials. The admin, general, and LSA waste generation activities had a more evenly distributed waste composition.

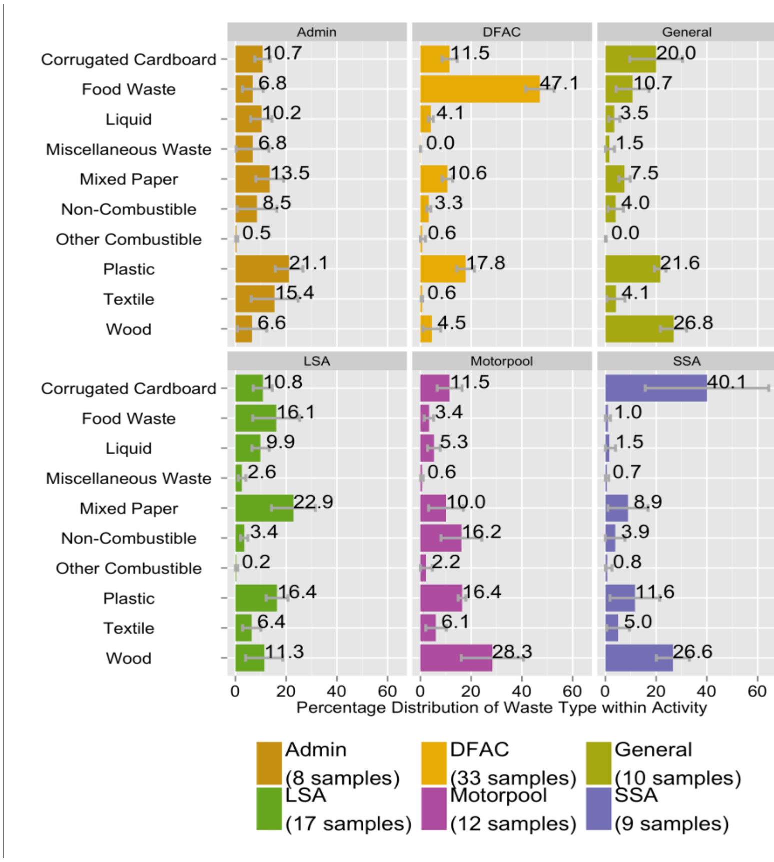

Figure 2.6. Estimated CB Average Solid Waste Composition by Generating Activity with 90% Confidence Intervals (MSW, Percent by Weight)

2.4 Specialized Waste Stream Characteristics

Specialized waste stream characteristics such as heat, moisture, ash, and volatiles content are intended to assist developers with requirements for system configuration as well as design elements such as auxiliary heating and moisture handling.

- The exact heat, or energy, content value is needed to estimate the amount of energy that could be recovered from treating the waste. For energy generation purposes, waste streams with higher heat content materials are preferred.

- The moisture content affects overall heat content and can determine the need for pre-drying the waste stream or help identify suitable waste treatment system types, as described above.

- Lower ash content should result in better system performance. Any ash that is part of the feedstock composition will not produce energy and could cause buildup in the system that reduces efficiency and increases maintenance needs.

- Volatiles from materials in the feedstock will become part of the system gas product or stack emissions in the conversion process and inform any necessary cleanup steps in the treatment process. Common volatiles are carbon dioxide, carbon monoxide, and chlorine.

These characteristics were calculated for the base waste streams studied, based on the percentage of each component in the waste streams, published dry-basis values for the various materials, and the field measured moisture contents. Dry-basis values are based on materials dried to 0% moisture content and are consistent for all materials of the same composition. Wet-basis values take into consideration the in-situ moisture content as measured during sampling.

Table 2.7 compares the waste characteristics for the CBs studied to published values for typical MSW streams. Appendix D provides additional data, including wet-basis values. Potentially energy-generating (combustible) materials comprise 93.3% of the average solid waste stream based on data collected with an average waste moisture content of 27.6% and heat (energy) content of 9.6 MMBtu/ton (wet basis). For comparison, US domestic MSW waste has an average heat content of approximately 11 MMBtu/ton.[1]

The four largest bases studied were estimated to generate sufficient waste to support a wide range of technologies, from small containerized units to large-scale systems and facilities. Based on high-level analysis and data collected, treatment of waste from medium-to-large CBs could produce up to 0.8-16.8 megawatts of electrical power, depending on the amount and energy content of the waste, the conversion process employed, electrical generator and infrastructure performance, parasitic loads, and other factors.[2]

Table 2.7. CB and Typical Published Municipal Solid Waste Stream Characteristics

	CB #1	CB #2	CB #3	CB #4	CB #5	Afghanistan Average	Published Range[a] for typical MSW	Published Average[b] for typical MSW
Heat Content, wet basis (MMBtu/ton)	13.8	9.9	8.8	9.2	9.6	9.6	5.8 - 30.6	12.4
Heat Content, dry basis (MMBtu/ton)	15.1	12.8	12.0	11.8	11.9	12.3	9.4 - 31.5	17.1
Moisture Content (% by weight)	12.0%	28.7%	31.7%	28.6%	23.5%	27.6%	2.9% - 38.7%	27.3%
Ash Content, dry basis (% by weight)	10.8%	12.4%	15.2%	11.7%	14.0%	12.5%	4.4% - 44.2%	20.8%
Volatiles Content, dry basis (% by weight)	80.1%	71.7%	68.0%	69.8%	67.5%	70.4%	62.3% - 82.2%	71.5%

[a]Valkenburg et al. 2008 [b]Phyllis 2012

While there is a wide range of published values for MSW characteristics, the values found for the ARCENT AOR CB waste streams all fall within these ranges as shown in Table 2.7. Variations in published values are usually explained by differences in waste composition assumptions in the sources.

[1] Energy Information Administration 2007. MMBtu/ton means a heat content equivalent 1,000,000 British Thermal Units (BTUs) per ton. A BTU is the amount of energy required to increase the temperature of 1 pound of water by 1 degree Fahrenheit, at normal atmospheric pressure. MMBtu/ton = 500 Btu/lb. 1 MMBtu = 1.06 GJ = 293 kWh. Under certain conditions, 1 MW could power up to 1000-1200 U.S. homes.
[2] Potential electrical power generation is a high-level estimate based on average study-derived wet basis heat contents, 10-30% technology efficiency range, and 90% system capacity factor. Net output will vary depending on actual conditions.

Table 2.8 compares the Afghanistan average waste composition to domestic composition as identified in the US Environmental Protection Agency's (EPA) 2010 US MSW characterization report. While the CB data represent only 3-5 days of waste generation, the CB and typical US domestic waste streams appear similar in composition (with exception of much less glass and no yard waste encountered at CBs studied).

Given waste stream data collected, it is not expected that waste treatment technologies for CBs will require significantly different features from those intended for similar municipal or commercial applications.

Table 2.8. Comparison of Afghanistan CB and US MSW Composition

Waste Component (EPA Categories)	Afghanistan CB Average (% by weight)	US EPA Average (% by weight)
Food Waste	19.1%	13.9%
Glass	0.2%	4.6%
Metals	4.8%	9.0%
Other	8.4%	3.4%
Paper Products[a]	26.9%	28.5%
Plastics	16.4%	12.4%
Rubber, Leather, and Textiles[b]	5.8%	8.4%
Wood	18.9%	6.4%
Yard Trimmings	0.0%	13.4%

[a]Includes mixed paper and corrugated cardboard categories from CB waste analysis.
[b]Includes textiles and other combustibles from CB waste analysis.

3.0 Waste Management Technologies

This section provides a high-level general discussion of potential CB waste treatment technology options considering waste stream data and characteristics of the bases analyzed. This discussion is not a substitute for a cost-benefit, engineering, or related analysis or an endorsement of any specific technology or system.

3.1 Overview

There are many waste management options for a variety of purposes, including waste disposal (elimination), reduction, and resource or energy recovery. Depending on the intended purpose(s), options are as varied as composting, incineration, field-expedient methods, landfilling, waste-to-energy, and primarily non-technical activities such as reduction policies and reuse or recycling.

Based on the waste stream data collected, waste streams on medium-to-large bases could support a variety of waste treatment technologies. Given the large amounts of waste that they generate, these bases could potentially support WTE or incineration facilities and large fixed units, but would need numerous smaller systems to process all or most of their solid waste.

To ultimately be effective, any stand-alone CB waste management solution must be suited for the demands of operational conditions. Many types of waste are continuously generated at real world bases with non-hazardous solids usually combined for expediency of collection and disposal. Systems that frequently require intensive maintenance, changes of specialized components, and extensive waste pre-sorting or other special pretreatment may not be practical in an austere environment or remote location.

Every technology has different requirements and capabilities. Given the variations in real world bases, the most appropriate waste treatment options for a CB should be determined by base-specific conditions and requirements. Feasibility based on the waste stream alone does not ensure that a WTE or other technology is a viable solution for a specific base. Section 3.3 suggests additional criteria to evaluate suitability of a waste management technology for a CB.

3.2 General Implications of Waste Stream Analysis for CB Waste Treatment Technology Evaluation, Design, and Operation

3.2.1 Implications for Technology Evaluation

Since technologies have various trade-offs, feasibility based on waste stream data alone is unlikely to determine the best option for a base. For most medium-to-large bases, there are many waste management options based on available waste streams, so decision makers should evaluate desired capabilities and tradeoffs carefully.

Based on those studied, medium-to-large CBs generate sufficient waste to support a variety of waste treatment technologies. Waste generation rates for bases studied ranged from 16 to >250 tons per day (TPD). Based on analysis of CB #5's 16 TPD solid waste stream, smaller CBs will likely only be able to support small-scale systems. Larger bases may be able to support facilities and other large-scale systems, but would likely require a large number of small systems to process most or all of their waste.

CBs should especially consider waste treatment technologies that can effectively handle a range of moisture contents and a variety of solid wastes, including combustibles. Based on data collected, combustible (potentially energy-yielding) materials and entrained liquids overall comprise approximately 93% of the average MSW stream.

Given construction time and infrastructure requirements, facility-sized or other large-scale WTE systems may only be cost-effective if able to operate for several years at a relatively well-developed base. Particularly for any large energy recovery system, a base will likely require significant infrastructure to be able to effectively use any energy the system is able to export.

Not all types of waste can be effectively treated for energy recovery. Some types of waste common at medium-to-large bases are unlikely to be effectively processed in large quantities by WTE systems and most incinerators. Further, some waste treatment technologies can only process a few types of waste and accordingly may require considerable waste sorting and other pre-treatment.

3.2.2 Implications for System Design and Operation

Bases may have high variability in composition of waste loads, such as bases analyzed here with wider confidence intervals for some waste components. Waste loads as delivered to a treatment system are not likely to be consistently mixed. For example, food waste is mostly concentrated at DFACs, so some loads may have mostly food waste while other loads have little to none. Waste treatment technologies must be able to handle this variability or will likely require waste pre-mixing, sorting, or other treatment.

The CB MSW stream contains some non-combustible and potentially undesirable materials for energy recovery including metals, entrained liquids (e.g. contents of beverage bottles), and a small amount of glass. For most efficient treatment of the solid waste stream as observed, CB systems should be able to tolerate un-segregated MSW of varying materials and moisture contents, including plastics, food wastes, incidental non-combustibles such as cans, utensils and small tools, and small quantities of liquids. Given large quantities of diverse wastes generated on medium-to-large CBs, removing most or all desired or undesired items from mixed waste would likely be difficult, especially without specialized equipment or intensive manual sorting. The entrained liquids, often in beverage bottles and other containers, could not easily be separated and do contribute to the overall waste stream moisture content.

Unless unusually stringent manual or automated waste segregation are possible at the points of waste generation, CB solid waste treatment systems should be able to handle at least small amounts of diverse materials, because various non-combustibles or other potentially undesirable wastes will almost certainly remain comingled with other solid waste. For example, some bases provided containers for segregation of recyclables including plastic and metals (such as beverage cans), but quantities of these materials were inevitably still found in the MSW stream. Systems with low tolerance for diverse waste types will likely require a mechanical or manual waste sort at the front end of the treatment process. CBs will need to assess any energy demand, labor, or other impacts for any waste pre-treatment, such as segregation or drying. Waste treatment options vary in amount of waste handling necessary. The simplest solution would likely be treating unsorted solid waste as received in one or a few large systems, but other options could be feasible subject to technology- and base-specific requirements.

3.3 Suggested Criteria for CB Waste Management System Evaluation

This report is intended to provide waste stream data to support design and evaluation of CB waste management technologies for medium-to-large CBs. However, it is not intended to be the sole or primary basis for any design, decision, or other activity. The following section recommends several criteria to consider before selecting a WTE or other waste management system for a specific CB.

CBs will need to assess their specific infrastructure before selecting a technology, particularly a WTE system, for ability to provide sufficient waste of acceptable composition and distribute power, water, and other resources as necessary to and from the system.

This section suggests several general criteria potentially applicable to many CB waste management system efforts. However, these are not inclusive of all possible factors and may not be applicable to all potential waste management solutions.

1. Intended function of system. For example, waste disposal, electricity generation, liquid fuel generation, heat recovery, etc.

2. Capital cost.

3. Operations and Maintenance (O&M) cost.

4. Technology/system actual operational experience under realistic conditions.

5. Types of waste to be treated.

6. Variability of base waste stream. Potential probability, nature, and frequency of changes in base population and/or activities which may impact the waste stream.

7. System reliability. Given the nearly continuous waste generation at CBs, any effective systems must be reliable under the demands of operational conditions.

8. Ability to integrate any system energy output with base infrastructure.

9. Other infrastructure or supply chain requirements. For example, supplies of consumable components such as filters, water or other resources required for system operation.

10. Ability to site system on base. The system should be located where adequate waste can be conveniently delivered and pretreated as needed.

11. Ability to transport technology. The system or system components must likely be able to be transported efficiently to remote locations, ideally in standardized shipping containers or modules. Facility construction may be feasible depending on base-specific requirements.

12. Ability to operate technology. Any specialized technical knowledge and skills required for operation. In addition, labor, infrastructure, and energy for waste preprocessing such as sorting, shredding, and drying.

13. Ability to maintain technology. This includes the knowledge and skills to perform scheduled preventative maintenance as well as troubleshooting and repairs and the cost and feasibility of obtaining replacement parts.

14. Regulations and policy, including environmental requirements.

15. Ability for technology requirements to fit within current base practices. This may include any special waste handling, waste pre-treatment, or other special requirements to use the technology.

16. Ability to dispose of treatment byproducts and wastes unsuitable for the waste treatment technology.

17. Alternative or supporting waste management requirements. Cost and requirements for any backup or alternative systems and/or processes required in event of failure or downtime of system under consideration.

18. System procurement and installation lead times.

19. System closure/retrograde requirements.

Appendix A

Acronyms and Abbreviations

Appendix A: Acronyms and Abbreviations

Admin	administrative area
AOR	area of responsibility
ARCENT	U.S. Army Central (abbreviated form)
ASG-KU	Area Support Group-Kuwait
ASTM	ASTM International (formerly American Society for Testing and Materials)
C&D	construction and demolition
CB	contingency base
CBWSA	Contingency Base Waste Stream Analysis (Project)
CENTCOM	(U.S.) Central Command
CONUS	Continental United States
DCP	data collection plan
DFAC	dining facility
DoD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
GJ	gigajoules (billions of joules)
HDPE	high-density polyethylene
kJ	kilojoules
kW	kilowatt
kWe	kilowatt electrical
kWh	kilowatt-hour
LDPE	low-density polyethylene
LIA	(U.S. Army) Logistics Innovation Agency
LLDPE	linear low-density polyethylene
LSA	life support area
MMBtu	million British thermal units
MSW	municipal solid waste (definition of usage in this report on page iii)
MW	megawatt
MW_e	megawatt electrical
MWR	morale, welfare, and recreation
NR	not reported
O&M	operations and maintenance
PET	polyethylene terephthalate
PM	project manager
PNNL	Pacific Northwest National Laboratory
PP	polypropylene
PPE	personal protective equipment

PS	polystyrene
Psig	pounds per square inch gauge (relative to atmospheric pressure)
PVC	polyvinyl chloride
PX	post exchange
QA	quality assurance
RC	Regional Command
SSA	supply support activity
TPD	tons per day (1 ton = 2,000 pounds)
USFOR-A	United States Forces-Afghanistan
USALIA	U.S. Army Logistics Innovation Agency
USARCENT	United States Army Central
WTE	waste-to-energy

Appendix B

References

Appendix B: References

This appendix provides several sources reviewed for or referenced in the report, but is not all inclusive.

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Appendix C

Research Design and Methodology

Appendix C: Research Design and Methodology

This appendix details the project research design, including methods of data collection and analysis. Sections C.1-C.2 provides an overview of data collection methods and activities. Section C.3 discusses the analysis methods.

C.1 Data Collection Overview

To guide field activities, the project team developed a Data Collection Plan (Solana et al. 2012) based on a uniform, industry-accepted method of waste characterization. This plan was based on ASTM D5231-92 (2008), "Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste" (ASTM 2008) modified for project-specific conditions and to collect additional specialized data for waste treatment technology requirements as provided in Appendix C. This ASTM standard is widely used by the waste management industry for commercial and municipal waste characterization studies.

The Data Collection Plan designated food waste as the primary (governing) waste stream component, based on previous research on CB waste streams, both personal (by PNNL personnel) and published (SERDP 2010, RDECOM 2004). The minimum number of samples required was 26 in accordance with ASTM (2008), using a 90% confidence level and a precision of 10% and food as governing component. Wood was found to be the primary component in other studies (e.g. Gerdes and Jantzer 2006) and at CB #3 and CB #5, but it was not feasible for this project to collect the 271 samples required at this level of confidence and precision for wood as the primary component per ASTM (2008). To account for the possibility of a governing component of plastic and to gain additional samples in event some sample data was unusable, the team attempted to collect 32 samples at CB #3, CB #4, and CB #5. Based on data collected, the most prevalent types of MSW by weight at each base were: food (CB #2 and CB #4), plastic/mixed paper (CB #1 based on 9 samples), and wood (CB #3 and CB #5).

The following summarizes the three principal data collection tasks completed at each CB based on the Data Collection Plan, discussed in more detail in section C.3 below.

1. Document the methods of waste collection used at each base, including location and frequency of collections, through discussions with base staff and obtaining any available relevant data. Obtain any available data on waste generation rates from base staff and, as possible, team observations.

2. Obtain a reasonably representative sample of base non-hazardous MSW for sampling in accordance with ASTM (2008). This generally consisted of at least 26, 200-pound mixed samples per base, with some variations due to local conditions. While the team collected generation data on various waste streams as available, only non-hazardous MSW was manually sorted and analyzed.

3. Manually sort and characterize waste samples by category in accordance with ASTM D5231-92 (2008) with modifications as outlined in the Data Collection Plan. The team supplemented the ASTM standard to include collecting and analyzing moisture content and other specialized data relevant to WTE and other CB waste treatment system design. At bases without a suitable central waste collection area, the team used a modified methodology to collect samples from individual or groups of waste collection containers throughout the base.

C.2 Data Collection Process

At each base, the data collection team collected waste composition and characteristic data through manual sorting of samples, generally consisting of 200+ pounds of mixed solid waste from collection vehicle loads or dumpster(s) contents. When sorting each sample, the data collection team separated waste materials into baskets according to type (component categories[1]) and then measured various attributes for each component. Before sorting each sample, the team assessed each location for hazards and used appropriate personal protective equipment and safety procedures. The team typically used standardized containers (5-liter plastic baskets) to sort waste by type. The waste composition data was collected according to the categories below:

- Corrugated Cardboard
- Food Waste
- Liquid[2]
- Miscellaneous Waste[3]
- Mixed Paper
- Non-Combustible
  - Ferrous Metal
  - Non-Ferrous Metal
  - Glass
- Other Combustible
- Plastic
  - #1 - Polyethylene terephthalate (PET)
  - #2 – High-density polyethylene (HDPE)
  - #3 - Polyvinyl chloride (PVC)

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[1] Waste component categories (shortened as waste components) is a term used in the ASTM D5231-92 standard used to guide the project's waste composition studies. In this study, waste components are designated categories for types of waste in the solid waste stream, such as food, plastic, and wood.

[2] Liquid waste is not a separate liquid waste stream (such as gray water) but rather liquids that were entrained in the solid waste stream (such as beverage bottles with liquid contents).

[3] Miscellaneous wastes are items identified as potentially unsuitable for standard sorting and/or waste treatment such as personal medical and hygiene items.

- #4 - Low-density polyethylene (LDPE)
- #5 - Polypropylene (PP)
- #6 - Polystyrene (PS)
- #7 - Other (Plastic #7)

- Textile
- Wood

The measurements taken for each waste component in each sample are briefly described below:

- Weight – The most carefully controlled measurement, which is used for all the proportion (percentage) calculations shown in this report. Values were recorded in pounds using a portable calibrated scale. The sample weight measured before separation and the sum of the separated component weights sometimes varied by a few pounds due to sampling conditions (e.g., wind and losses of small amounts of materials) and the difficulty in measuring the entire sample before separation. All report calculations were based on the more precisely recorded sum of the separated components.
- Moisture – The moisture content of the material in each category was measured in percent by weight using a portable, battery operated, handheld moisture meter.
- Volume – Recorded in liters. Volume was much more difficult to reliably measure than weight, but it was measured or estimated for most waste components found in each sample.

In addition to waste sample sorting, the team also gathered base-specific information to support post-data collection analysis. Through observations and interviews with base staff, the team collected data on local waste collection practices and waste generation rates for solid waste as well as some other waste streams as possible. However, the team only sorted and analyzed non-hazardous solid waste.

Figure C.1. Example of Collection of a >200lb Mixed Waste Sample

Figure C.2. Example of Manually Sorting a Sample by Waste Type (Component Categories)

Figure C.3. Example of Field Measurements of Waste Component Characteristics
(Note the portable scale and the black and yellow moisture meter on top of the basket in foreground)

Team employed various quality assurance practices throughout data collection and analysis, including:

- Analysis methods were derived from appropriate statistical techniques and waste management industry standards. Refer to section C.3 below for in-depth discussion.
- Samples were weighed and recorded before separation. Individual component weights were compared with sample weights before separation to confirm all component weights were included.
- Sorting was always done on a relatively clean surface. Pavement, where available, was swept or scraped to remove debris and materials from previous samples. Where pavement was not available, the samples were sorted on large plastic tarps. Tarps were swept or shaken out to clear debris between samples and were replaced frequently or when they became coated with hard-to-remove debris.
- The data collection team member with the most expertise in a waste component category (e.g., plastic) made final decisions on appropriate component designation to maintain consistency. Individual bins were cross-checked by team members for consistency before weighing and recording.
- Waste component distributions and characteristics for each sample were examined for potential inaccuracies, resulting in five samples disqualified for incorporation into the report analysis.

CB #2 provided the most complete waste generation and collection information, so it was used to validate the assumption that the samples collected were representative of the overall waste stream. Table C.3 shows the distribution of samples collected by activity category as compared to the estimated total base waste disposal capacity (calculated by multiplying the number of base dumpsters by the volume and the frequency emptied). Samples were assigned to activities based on site-provided information on waste collection vehicle load origins.

Table C.3. Distribution of Samples and Waste Disposal Capacity for CB #2 Activities

Activity Type	Percentage of Sample Data	Base-Wide Daily Waste Disposal Capacity
Admin	10.9%	6.0%
DFAC	38.5%	34.7%
General	8.6%	14.2%
LSA	11.8%	18.7%
Motor pool	23.0%	14.7%
SSA	7.2%	11.7%

C.3 Analysis Methods

All estimates derived in this report are based on the statistical properties of ratio estimation (Thompson 2002) and are the industry standard tools for waste characterization analysis (Cascadia 2006). The following section discusses the assumptions and equations associated with using ratio estimators.

The traditional ratio estimator has some standard assumptions which waste stream data generally follow. The relationship between the total amount of collected waste (x) from a particular base and the total amount of specific waste components (e.g. plastic or food) (y) are assumed to have a strong linear relationship. As is the case with waste characterization, it is also necessary to assume that as the amount of total waste generation goes to zero the specific waste components also go to zero (i.e. if no waste is generated, then no plastic waste is generated either).

A waste characterization study involves random sampling of a representative subsample of the total generated waste, which is then used to make inference to the entire waste stream. Constraints unique to each base made this challenging, but the team made best efforts to collect representative samples of the waste stream. Because the sampling constraints were unique at each base and the waste characteristic findings from the Afghanistan bases still generally aligned, it appears that the modified methodologies were unbiased. Therefore, the statistical methods described below can be applied to the sample data. Each sample consisted of approximately 200 pounds of waste, the target weight in accordance with ASTM Standard D5231-92 (ASTM 2008). As listed previously, proportion estimates were derived for each of the different waste components. When estimating the ratio of one specific waste component (reported as percentage in the document, which is $100 \times ratio$), the overall waste weight (x) is recorded for each of the n equal-sized samples as well as the weight of the waste component (y). More specifically:

$$x_i = weight\ of\ the\ i^{th}\ sample$$
$$y_i = weight\ of\ unique\ waste\ component\ in\ the\ i^{th}\ sample$$

If the complete waste stream were separated into equal sized parts for sampling, the total number of parts (N) would be the population from which a representative sample is desired. If all the equal sized parts could be measured, the true ratio (R) would be calculated as

$$R = \frac{\sum_{i=1}^{N} y_i}{\sum_{x=1}^{N} x_i} = \frac{\mu_y}{\mu_x},$$

where μ_y and μ_x are the population means for *x* and *y*. However, only a sample (*n*) of the total population (*N*) is observed. The sample ratio (*r*) is calculated as

$$r = \frac{\sum_{i=1}^{n} y_i}{\sum_{x=1}^{n} x_i} = \frac{\bar{y}}{\bar{x}},$$

where $\bar{y}$ and $\bar{x}$ are the sample means for *x* and *y*. This sample ratio is then used to make inference to the general true ratio (*R*), where the variance of *r* is

$$\widehat{Var}(r) = \frac{1}{\bar{x}^2} \times \frac{s_r^2}{n} \ \ where \ \ s_r^2 = \frac{1}{n-1} \sum_{i=1}^{n} (y_i - r x_i)^2.$$

The standard error (SE) columns on the percentages estimates in the tables throughout this report are $100 \times \sqrt{\widehat{Var}(r)}$. Then the approximate confidence interval for *R*, based on the normal approximation, is

$$r \pm t_{n-1}(\alpha/2)\sqrt{\widehat{Var}(r)}.$$

For the analysis in the report, $\alpha = 0.1$ was used with the t-distribution with *n-1* degrees of freedom, which resulted in 90% confidence intervals.

If the true ratio of a specific waste component was known, then the known total annual waste generation (τ_x) could be used to calculate the total annual amount of a specific waste component (τ_y) with the following relationship:

$$\tau_y = R\tau_x$$

As *R* is not known, the estimate, *r*, from the sample will be used with the known annual waste generation, τ_x, to estimate the total amount of a specific waste component generation, $\hat{\tau}_y = r\tau_x$. Accounting for the need to estimate an annual waste component total, the approximate confidence interval would be

$$\hat{\tau}_y \pm \tau_x t_{n-1}(\alpha/2)\sqrt{\widehat{Var}(r)}.$$

While the goal during the data collection was to keep each sample at the same total weight of 200 pounds, the sample weights differed due to waste availability. See Figure C.4 for a distribution of the sample weights across the five bases. As shown in the figure, most samples were at least 200 pounds with a few samples varying significantly. If there were only one waste generation activity at each base, these differences would not be influential in the calculations listed above. However, there were multiple waste generation activities (see Table C.3), and the waste component percentages generally varied according to activity, so some adjustments were necessary to arrive at representative base ratio estimates.

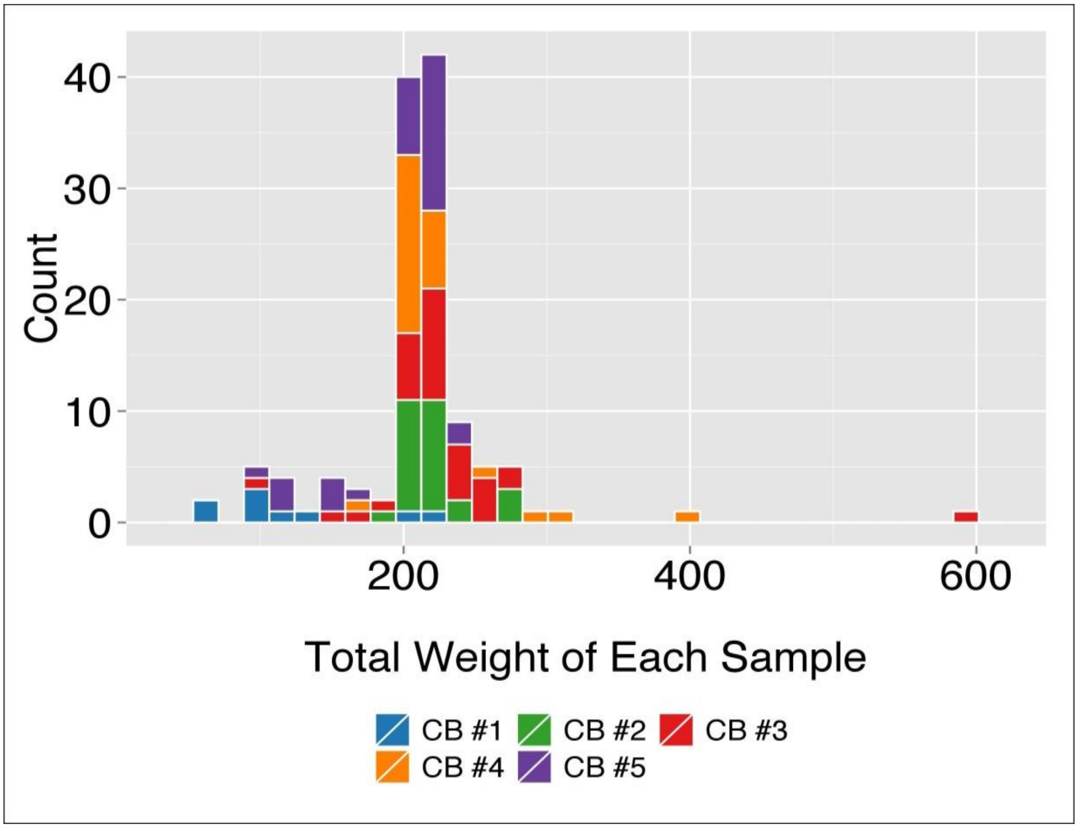

Figure C.4. Sample Weight Distributions for the Five Bases Studied

This adjustment was done in a similar manner to the work that Cascadia documented (Cascadia 2006). The analysis of CB #2's available data (see Table C.1, sufficient data was not available at other sites to complete a similar comparison) supports the assumption that the proportion of samples collected from each waste activity represented the contribution of the waste activity to the total waste generated. As the average expected sample weight was 200 pounds, all samples were standardized to this value to minimize over- or under-representing a specific waste type component. For example, the 600-pound sample collected at CB #3 was mostly metal and wood from a motor pool area. Including this sample at the full 600 pounds would have been equivalent to including three additional motor pool samples, which would have overrepresented the amount of motor pool waste containing large amounts of wood and metal. The adjustment described below was repeated for each waste component at all five bases.

The adjustment was completed by assuming that each sample was 200 pounds ($x_i' = 200 \; for \; i = 1, \ldots, n$) and all the waste component weight values (y_i) were transformed using the following equation:

$$\frac{y_i}{x_i} \times 200 = y_i'$$

The four Afghanistan bases were combined to determine an average estimate of the waste ratios that might be expected for other bases similar to the four studied. Data from CB #1 was not included in the aggregate analysis since it differed in several respects from other bases, including unusually frequent waste collection which limited availability of sufficiently-sized samples. A weighted average was used, where each base's weight was proportional to the total weight of waste processed annually. Table C.4 lists the estimated total annual solid waste generation values (tonnage) from each of the four Afghanistan bases. These tonnage values were used in the following equations to establish the statistical weighted Afghanistan variance ($\hat{\sigma}_A^2$) and ratio average ($\hat{\mu}_A^2$) for each waste component.

$$\hat{\mu}_A^2 = \frac{\sum_{j=1}^{4} w_j r_j}{\sum_{j=1}^{4} w_j} \; and \; \hat{\sigma}_A^2 = \sum_{j=1}^{4} w_j^2 \widehat{Var}(r),$$

where w_j is the tonnage from the j^{th} Afghanistan base. To arrive at the weighted variance listed above, it was assumed that variance estimate at each base was uncorrelated.

Table C.4. Examples of Annual Waste Generation Values Used in the Calculation of the Afghanistan Weighted Average

	CB #4	CB #5
Tons per Year	92,710	5,850

Appendix D

Specialized Waste Stream Characteristics

Appendix D: Specialized Waste Stream Characteristics

Specialized waste stream characteristics including heat, moisture, ash and volatile material contents and elemental composition inform waste treatment system designs. The waste heat content is important to determine system burner size and estimate the amount of useful energy that could be recovered. For energy export purposes, waste streams of higher heat contents are preferred. The moisture content affects overall heat content and can determine need for any pretreatment drying of the waste stream or suitable waste treatment system types. Lower ash content will generally result in better system performance. Ash that becomes part of the feedstock composition will not produce energy and could cause buildup in the system that reduces efficiency and increases maintenance requirements. Volatiles in the feedstock will become part of the gas product or stack emissions in the treatment process and may indicate necessary cleanup steps in the process. The waste's elemental composition provides additional data to assess potential energy output and emissions control requirements.

These characteristics are determined through proximate and ultimate analyses. Proximate analyses determine ash, heat, moisture, and volatile content and fixed carbon of a sample using general field or laboratory equipment, such as moisture meters or calorimeters. Ultimate analyses require more specialized equipment to determine the chemical elemental composition of a sample, focusing primarily on carbon, hydrogen, oxygen, nitrogen, and sulfur. On a dry basis, waste component materials are expected to have the same proximate and ultimate analysis findings. This study used both published data and the waste components measured during sampling to calculate overall waste stream characteristics.

Published data from proximate and ultimate analyses for various components are shown in Table D.1 and Table D.2. Average moisture content for each waste component as measured in the field samples is listed in Table D.3.

Table D.1. Proximate Analysis Findings for Primary Waste Component Categories[a]

Category		Heat Content (MMBtu/dry ton)	Ash Content (weight % dry basis)	Volatiles Content (weight % dry basis)
Corrugated Cardboard		17	5	78
Food Waste		13	14	41 - 141
Liquid		0	0	0-20
Miscellaneous Waste		20	5	95
Mixed Paper		7	8	66 - 83
Non-Combustible	Ferrous Metal	0	96	1
	Non-Ferrous Metal	0	96	1
	Glass	0	97	0
Other Combustible[b]		27	10	84
Plastic	#1- PET	21	2	98
	#2 – HDPE	19	2	98
	#3 – PVC	17	2	98
	#4 - LDPE/LLDPE	24	2	98
	#5 – PP	38	2	98
	#6 – PS	36	0	98
	#7 – other	21	2	98
Textile		14	16	84
Wood		10	10	68

[a] Based on published sources, data not measured in the field (Arsad et al. 2006, CEMP-ET 1997a, Ding et al., EIA 2007, EPA 1994, Qudiah et al., Valkenburg 2008)

[b] Based on tires, the primary material of this category

Table D.2. Ultimate Analysis for Primary Waste Combustible Categories[a]

Category		Elemental Composition (% by Dry Weight)					
		C	H	O	N	S	Cl
Cardboard		41.8	6.1	50.6	0.4	0.1	ND[b]
Food Waste		48.1	5.9	40.7	0.7	0.04	0.03
Mixed Paper		39.9	5.9	45.4	0.01	0.04	0.05
Plastic	#1- PET	86.1	13.0	0.9	ND	ND	ND
	#2 - HDPE	62.2	4.2	32.9	ND	ND	0.03
	#3 - PVC	38.4	4.8	ND	ND	ND	56.8
	#4 - LDPE/LLDPE	85.7	14.2	0.1	0.05	ND	ND
	#5 - PP	85.5	14.3	0.2	ND	ND	ND
	#6 - PS	92.7	7.9	ND	ND	ND	ND
Wood		51.6	6.3	36.6	1.5	0.2	ND

[b]ND indicates not detected

The box plots in Figure D.1 shows the moisture contents measured for the various components of each sample, excluding liquid waste components. The box plot shown for each waste component depicts the overall distribution of moisture measurements. The median moisture content (indicated by the horizontal dark gray line) for each waste component were calculated using the overlaid points shown for each waste component. The white shaded boxes indicate the range for the middle 50% of measurement values (interquartile range). The dark vertical line bisecting the boxes indicates the range of moisture contents within1.5x higher or lower than the interquartile range.

Figure D.1. Moisture Content Readings by Waste Component Category

Table D.3. Average Moisture Contents of Waste Components (as measured during sampling)

Waste Component		CB #2	CB #1[a]	CB #3	CB #4	CB #5	Average Field Measurement	Published Value[b]
Corrugated Cardboard		17.1	2.5	10.7	16.9	6.3	12.6	5.2
Food Waste		52.8	35.1	59.8	52.2	47.0	53.6	60.0
Liquid		100.0	100.0	100.0	100.0	100.0	100.0	100.0
Miscellaneous Waste		8.6	16.1	53.6	96.7	45.0	57.8	Varies with contents
Mixed Paper		36.9	17.8	31.9	40.0	27.1	34.1	5.5
Non-Combustible	Ferrous Metal	0.0	0.0	0.0	0.0	0.0	0.0	3.0
	Non-Ferrous Metal	0.0	0.0	1.4	0.0	4.3	1.3	3.0
	Glass	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Other Combustible		0.0	0.0	6.2	0.0	6.2	6.4	1.2[c]
Plastic	#1- PET	0.0	0.3	0.0	0.3	0.0	0.0	0.2
	#2 - HDPE	11.4	0.0	3.6	0.0	3.6	9.6	0.2
	#3 - PVC	11.4	0.2	4.8	0.2	4.8	6.7	0.2
	#4 - LDPE/ LLDPE	20.2	6.3	7.9	6.3	7.9	14.4	0.2
	#5 - PP	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	#6 - PS	8.7	0.0	7.5	0.0	7.5	7.2	0.2
	#7 - Other	0.0	0.0	6.2	0.0	6.2	1.6	0.2
Textile		22.4	7.5	25.2	7.5	9.2	21.9	10.0
Wood		12.6	16.0	7.1	16.0	5.7	7.9	20.0

[a]Values shown are for measurements taken; sample moisture contents were not all consistently measured at CB #1
[b]CEMP-ET 1997a, CEMP-ET 1997b
[c]Based on tires, the primary material of this category

Based on this data and the waste component percentages identified during sampling, Table D.4 shows estimated overall waste stream characteristics for each CB and for the Afghanistan average. The moisture contents were calculated using a weighted average of the individual component moisture contents and used to determine the wet-basis values. The dry basis values were also calculated using a weighted average of the individual components.

Table D.4. Summary of CB Solid Waste Stream Characteristics

	Moisture Content (% by weight)	Heat Content (MMBtu/ton)[a]		Ash Content (% by weight)		Volatiles Content (% by weight)	
		wet	dry	wet	dry	wet	dry
CB #1	12	13.8	15.1	9.6	10.8	70.9	80.1
CB #2	28.7	9.9	12.8	10	12.4	54.1	71.7
CB #4	28.6	9.2	11.8	9.6	11.7	53.3	69.8
CB #3	31.7	8.8	12	12.5	15.2	49.1	68
CB #5	23.5	9.6	11.9	12	14	54.5	67.5
Afghanistan Average	27.6	9.6	12.3	10.3	12.5	54.2	70.4

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