State University System of Florida
Florida Center for Solid and Hazardous Waste Management
PROJECT SUMMARY

TITLE: **Generation and Composition of Construction and Demolition Waste in Florida**

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RATIONALE: The management of construction and demolition (C&D) debris is a growing concern. Historically, C&D debris has not been well characterized. The U.S. EPA did recently publish the results of a study performed to estimate the generation of building-related C&D debris in the U.S. These results may not, however, be representative of C&D debris generation in Florida. Florida is one of the most rapidly growing states in the nation and does not have the aging infrastructure typical of other locations. Florida-specific C&D debris generation and composition information provides the solid waste industry and policy-makers a more accurate picture of the true state of C&D debris in Florida.

OBJECTIVES: Researchers gathered information on the generation and composition of C&D debris in Florida based on the following objectives. 1) Apply the methodology used for the national C&D debris study, modifying as necessary, to estimate the amount of building-related C&D debris produced in Florida. 2) Use the generation estimation method along with actual C&D debris composition studies to provide information on the typical composition of C&D debris in Florida. 3) Evaluate techniques for conducting composition studies on C&D debris. 4) Provide an indication of the potential for recycling C&D debris in Florida via traditional C&D debris materials markets.

METHODOLOGY: Data relating to construction and demolition actives were collected from sources such as the census bureau and along with information from the literature on project-specific C&D debris composition were used to estimate the generation of C&D debris in Florida. Composition studies were performed at C&D debris landfills and recycling facilities. All C&D debris loads were visually characterized, with some loads also being characterized by component weight. Photogrametric techniques were evaluated as well. The results of the composition work were used to make recommendations for conducting C&D debris composition studies.

ACCOMPLISHMENTS: C&D debris generation and composition literature was summarized. The amount of building-related C&D debris produced in Florida was estimated. Data on the typical composition of C&D debris in Florida were presented. Methods for conducting C&D debris composition studies were examined and recommendations were made.

Generation and Composition of Construction and Demolition Debris in Florida

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EXECUTIVE SUMMARY

Construction and demolition (C&D) debris represents one of the larger components of the solid waste stream in Florida. C&D debris consists of materials such as wood, concrete, asphalt, metal, gypsum drywall, cardboard, soil, and a number of other items in smaller amounts. Historically, C&D debris has not been tracked as a waste stream in the same fashion as municipal solid waste (MSW) from households and commercial establishments. MSW disposal and recycling facilities are equipped with scales that operators use to weigh and record the amount of incoming solid waste. Counties are required to conduct periodic waste composition studies. Thus, the solid waste industry and the policy-makers have a relatively clear picture of the amount, composition, and disposition of MSW in Florida.

Less is known about Florida's C&D debris stream. Facilities that accept and process or dispose of mixed C&D debris (as opposed to single component waste streams such as asphalt or concrete) are required to submit annual reports to the Florida Department of Environmental Protection (FDEP). Based on these reports, as well as other information supplied by individual county solid waste coordinators, it is known that the majority of mixed C&D debris produced in Florida is disposed in landfills, though in some areas of the state, recycling is common. C&D debris composition studies are not required. Composition information is available from the literature, including a few studies in Florida. But as a whole, characterization of Florida's C&D debris stream is limited. Better estimates of the amount, composition and disposition of Florida's C&D debris stream would be a benefit to the solid waste industry and the policy makers.

The U.S. Environmental Protection Agency (U.S. EPA) recently sponsored and published the results of a study conducted to estimate the amount of building-related C&D debris produced in the U.S. (in 1996). A similar approach was used by the researchers in this study to estimate the generation of building-related C&D debris in Florida. Information from the literature regarding the amount of debris produced from defined C&D activities (e.g. residential construction) was used in combination with activity data for those sectors (e.g. number of new housing starts) to predict the amount of C&D debris produced in Florida in 2000. A total of 4.1 million tons of building-related C&D debris were estimated for Florida in 2000. The per capita generation rate (1.4 lb per person per day) was less than that of the U.S. The sector contributing the most debris was the new construction sector. This differs from the U.S. where demolition is the largest sector and can be attributed to the rapid construction activity currently underway in Florida and the lack of aged infrastructure that requires demolition (as might be required in other areas of the country). Residential construction debris contributed 24.4% of the C&D debris stream, followed by residential renovation (23.1%), nonresidential demolition (21.8%), nonresidential construction (12.8%), nonresidential renovation (11.7%), and residential demolition (6.3%).

Composition data for Florida C&D debris were gathered in two different manners. First, C&D debris materials composition was estimated using the same approach used for the generation estimate. The underlying approach and assumptions used to estimate the amount of debris produced from a given C&D activity (e.g. lbs of debris per ft^2 of residential construction) could also be used to estimate the composition (e.g. lbs of wood per ft^2 of residential construction). The resulting composition by weight was 54.2% concrete, 13.6% wood, 11.4% drywall, 6.9% roofing, 2.8% metal and 11.2% miscellaneous materials. Secondly, the composition of various loads of C&D debris was evaluated at C&D debris landfill and recycling facilities. All loads were evaluated for composition using a visual method. Hand sorts were performed on some of these loads to determine the true weight composition. A set of conversion factors (analogous to bulk densities) were develop to estimate the weight composition of all of the loads inspected. While the composition varied (as expected) for different C&D activities, an average composition (by weight) was calculated using the average composition results for each sector and the relative contribution of each sector from the generation estimate. The following composition (by weight) resulted; 32.4% concrete, 14.8% wood, 11.7% drywall, 6.1% roofing, 5.4% metal and 29.7% miscellaneous materials.

The study also focused on the methods used for conducting composition studies on C&D debris. Performing a composition study on C&D debris poses several challenges not encountered when characterizing household and commercial MSW. The materials are often much bulkier and harder to separate. One truck load of C&D debris might represent only a fraction of one project, thus many loads of material must be characterized to obtain an accurate reflection of the true composition. While weight-based sorts were the most accurate method, visual sorts were found to much more efficient with respect to time. Photogrametric techniques were evaluated and found to be effective, but not more so than the less time-consuming visual sorting methodology.

Finally, the potential markets for the majored recovered materials in C&D debris were evaluated and compared to the predicted generation rates. Markets were estimated from available statistical information such as industrial demand (e.g. gypsum in cement production, concrete aggregate in road construction) and existing market capacity (e.g. capacity of wood fuel consumption in industrial boilers). Concrete was found to have the largest recycling market capacity (as crushed stone in road base). Neither gypsum wall board nor asphalt shingles are recycled at any great extent at the present moment, but do have potential market capacity for a large amount of the materials that could be reclaimed from C&D debris. Wood is currently recycled to some extent, but its market capacity is most limited and as such deserves attention for market development.

ABSTRACT

Construction and demolition (C&D) debris represents one of the larger components of the solid waste stream in Florida. C&D debris consists of materials such as wood, concrete, asphalt, metal, gypsum drywall, cardboard, soil, and a number of other items in smaller amounts. Historically, C&D debris has not been tracked as a waste stream in the same fashion as municipal solid waste (MSW) from households and commercial establishments. MSW disposal and recycling facilities are equipped with scales that operators use to weigh and record the amount of incoming solid waste. Counties are required to conduct periodic waste composition studies. Thus, the solid waste industry and the policy-makers have a relative clear picture of the amount, composition, and disposition of MSW in Florida.

Less is known with respect to Florida's C&D debris stream. Facilities that accept and process or dispose of mixed C&D debris (as opposed to single component waste streams such as asphalt or concrete) are required to submit annual reports to the Florida Department of Environmental Protection (FDEP). Based on these reports, as well as other information supplied by individual county solid waste coordinators, it is known that the majority of mixed C&D debris produced in Florida is disposed via landfills, though in some areas of the state, recycling is common. C&D debris composition studies are not required. Composition information is available from the literature, including a few studies in Florida. But as a whole, characterization of Florida's C&D debris stream is limited. Better estimates of the amount, composition and disposition of Florida's C&D debris stream would be a benefit to the solid waste industry and the policy makers.

In 1996, the U.S. Environmental Protection Agency (U.S. EPA) sponsored and published the results of a study conducted to estimate the amount of building-related C&D debris produced in the U.S. A similar approach was used by the researchers in this study to estimate the generation of building-related C&D debris in Florida. Information from the literature regarding the amount of debris produced from defined C&D activities (e.g. residential construction) was used in combination with activity data for those sectors (e.g. number of new housing starts) to predict the amount of C&D debris produced in Florida in 2000. A total of 4.1 million tons of building-related C&D debris was estimated for Florida in 2000. The per capita generation rate (1.4 lb per person per day) was less than that of the U.S. The sector contributing the most debris was construction. This differs from the U.S. where demolition is the largest sector and can be attributed to the rapid construction activity currently underway in Florida and the lack of aged infrastructure that requires demolition (as might be required in other areas of the country). Residential construction debris contributed 24.4% of the C&D debris stream, followed by residential renovation (23.1%), nonresidential demolition (21.8%), nonresidential construction (12.8%), nonresidential renovation (11.7%), and residential demolition (6.3%).

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Finally, the potential markets for the major recovered materials in C&D debris were evaluated and compared to the predicted generation rates. Markets were estimated from available statistical information such as industrial demand (e.g. gypsum in cement production, concrete aggregate in road construction) and existing market capacity (e.g. capacity of wood fuel consumption in industrial boilers). Concrete was found to have the largest recycling market capacity (as crushed stone in road base). Neither gypsum wall board nor asphalt shingles are recycled to any great extent at the present moment, but do have potential market capacity for a large amount of the materials that could be reclaimed from C&D debris. Wood is currently recycled to some extent, but its market capacity is most limited and as such deserves attention for market development.

SECTION I

INTRODUCTORY MATERIAL

1.0 INTRODUCTION

Construction and demolition (C&D) debris includes concrete, asphalt (pavement and shingles), wood, gypsum drywall, and metal. These are primary construction materials. C&D debris also includes a smaller amount of material such as packaging (paper, plastic, buckets), carpet scraps, and insulation. While not in the strict regulatory definition of C&D debris, materials such as municipal solid waste (originating from worker and neighbor waste) and hazardous waste (e.g. lead flashings, fluorescent lamps) also are present in C&D debris. C&D debris is generated from many sources and the waste varies as a function of these sources (e.g. building vs. road construction, construction vs. demolition, residential construction vs. commercial construction).

1.1 MOTIVATION

The management of C&D waste is a growing concern. C&D waste represents a large fraction of the waste generated from municipal activities. It is most often disposed in unlined landfills, but many of the components are easily recycled. Recent recognition of the potential for diversion from the landfills of more and more waste components has led to C&D waste becoming a target of interest for recycling. Despite the interest, our understanding of the C&D waste stream is not nearly as complete as other components in municipal solid waste. In 1998, (Franklin and Associates, 1998a) the U.S. EPA published an estimate of C&D generation rates on a national basis. The results were based on a combination of a materials flow approach and technical literature reporting direct generation measurements. These results may not, however, be representative of C&D waste generation in Florida. Florida is one the most rapidly growing states in the nation and does not have the aging infrastructure typical of other states.

The U.S. EPA estimated C&D debris generation rates using a combination of Bureau of Census data on C&D expenditures in the US and results of previous C&D waste composition and generation studies (U.S. EPA, 1998). The C&D debris stream was divided into six categories: 1) Residential Construction, 2) Residential Renovation, 3) Residential Demolition, 4) Nonresidential Construction, 5) Nonresidential Renovation, and 6) Nonresidential Demolition. The amount of waste generated from each category was estimated. The total of all building-related C&D debris was estimated as 136 million tons for 1996. This figure corresponds to 2.8 pounds per capita per day.

The national C&D debris estimate, while a valuable contribution, does have limitations, especially when relating the estimate to specific geographic locations such as Florida. Florida is one of the fastest growing states in the U.S. In some parts of the state, different construction materials are beginning to be more commonly used because of possible high wind conditions or more favorable economics (e.g. concrete block, metal frame structures). The national estimate did not include C&D materials generated from the construction of roads and bridges, something else that can be included in a Florida-specific study. Another example of national data that may not apply to Florida is the comparison between residential new construction and renovation. The national C&D debris estimate indicates that the waste produced in 1996 from kitchen renovations was greater than the amount of waste produced in all new construction. In addition, while a total generation was reported, a composition of the waste stream was not included. Thus, a Florida-specific estimation of C&D generation and composition would be a valuable contribution to the solid waste community in Florida.

1.2 PROJECT OBJECTIVES

The objectives of the research were to:

1) Apply the methodology used for the national C&D debris study, modifying as necessary, to estimate the amount of building-related C&D debris produced in Florida.

2) Use the generation estimation method along with actual C&D debris composition studies to provide information on the typical composition of C&D debris in Florida.

3) Evaluate techniques for conducting composition studies on C&D debris.

4) Provide an indication of the potential for recycling C&D debris in Florida via traditional C&D debris materials markets.

1.3 ORGANIZATION OF REPORT

This report consists of thirteen chapters organized into four major sections. Section I provides introductory material, including a review of the literature with respect to C&D debris generation and composition, and a brief discussion of C&D debris management in Florida. Section II provides the methods and results of the Florida C&D debris generation estimate. Section III presents several chapters relating to the composition of C&D debris, including discussions of methods available for conducting C&D debris composition studies and the results of composition estimates made for Florida C&D debris. Section IV includes a chapter that addresses the potential recyclability of the major components of Florida C&D debris (from a market capacity perspective) and a chapter with conclusions for all of the research presented in the report. A list of referenced literature is presented at the end of the report.

The research presented in this report was the result of a two-year study by a collaboration of researchers from three universities. A preliminary annual report was published after the first year of work on the project (Reinhart et al. 2001). Much of the content of this report was derived from the Master's Degree theses of three students. Cochran (2001) used a similar approach as the EPA-sponsored prediction of the 1996 U.S. building-related C&D debris generation (Franklin and Associates 1998a) to predict the amount of building-related C&D debris generated in Florida in 2000. Cochran (2001) also expanded the generation study to predict Florida C&D debris composition and conducted a study to evaluate the market capacity of the major recyclable C&D debris components in Florida. Chakrabarti (2002) reported the results of many composition studies on loads of C&D debris (using visual and hand-sorting techniques) and summarized the composition of several C&D debris sectors. Medeiros (2001) evaluated the use of photogrametry as a tool for conducting composition studies of C&D debris. At times in this report, these theses are referenced as sources of raw data and additional information. Portions of this research were also presented at national meetings during the course of the project (Cochran et al. 2001, Heck et al. 2002).

2.0 REVIEW OF LITERATURE: C&D DEBRIS COMPOSITION

Waste characterization and composition studies have been performed by various organizations in the United States as well as other countries. The data from these studies can be averaged together to use as a general waste stream composition for that particular job activity. The sections below describe each composition study and how it relates to this study.

2.1 RESIDENTIAL CONSTRUCTION WASTE COMPOSITION STUDIES

2.1.1 METRO Study 1 (1993)

The METRO Solid Waste Department in Portland, Oregon awarded a grant to Palermini & Associates to perform waste audits on residential new construction. Waste audits were conducted on the waste from the construction of three single-family homes in 1992 (Palermini & Associates, 1993). All of these houses were 2,200 to 3,000 square foot homes with wood frames.

The first home was a 2,200 square foot home with a wood shingle roof. It had a sale price of $150,000. The total waste that was generated was 8,234 pounds (4.12 tons), 87 percent of which was recycled. Therefore, the waste generation rate was 3.74 pounds per square foot. Wood composed 57 percent of the total waste, three percent of which was treated lumber. Drywall was the second largest component of waste, composing 25 percent of the waste. Each of the rest of the components fell under five percent of the waste. The land clearing debris collected consisted entirely of stumps. The composition of the waste from Home 1 is depicted in Figure 2.1.

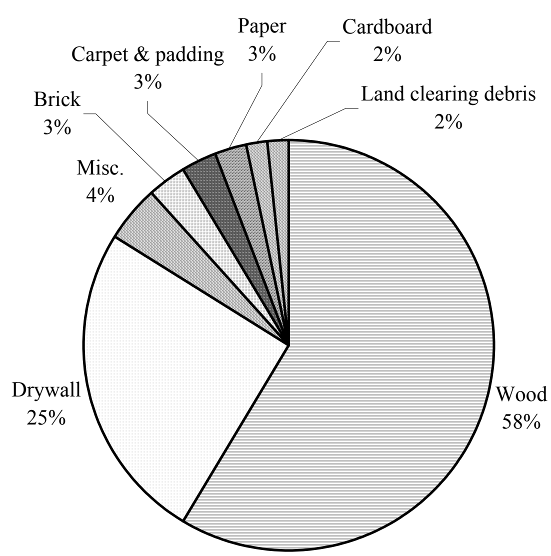


Figure 2.1. Composition of Residential Construction Waste; Portland Site 1 (Palermini & Associates, 1993).

The second house was a 2,900-square-foot home with a wood roof. It had a sales price of $249,940. The total amount of waste generated was 11,799 pounds (5.90 tons), 97 percent of which was recycled. Therefore, the waste generation rate was 4.07 pounds per square foot. Wood represented 79 percent of the waste. Drywall, the second largest component, represented 28 percent of the total waste stream. Figure 2.2 depicts the waste from Home 2.

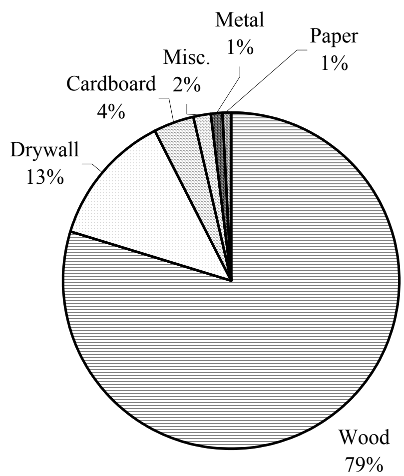


Figure 2.2. Composition of Residential Construction Waste; Portland Site 2 (Palermini & Associates, 1993).

The third and final home in this study was a 3,000-square-foot home with a concrete roof. It had a sales price of $265,000. The total amount of waste generated from the construction of this home was 13,776 pounds (6.89 tons). Therefore, it had a waste generation rate of 4.59 pounds per square foot. Mostly due to the roof type, this house had much less wood waste per square foot than the other two. Concrete was the third major component in the waste. This composition was significantly different from the other two houses, as they did not have much, if any, concrete waste. Figure 2.3 depicts the composition of the waste from Home 3.

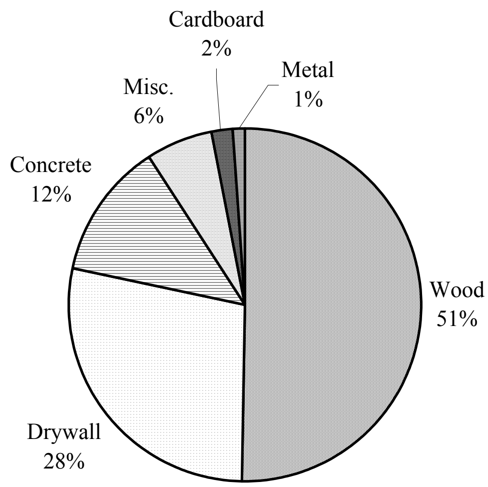


Figure 2.3. Composition of Residential Construction Waste; Portland Site 3 (Palermini & Associates, 1993).

2.1.2 NAHB Research Center

A study entitled "Residential Construction Waste Management Demonstration and Evaluation" was performed by the National Association of Homebuilders (NAHB) Research Center in cooperation with the U.S. Environmental Protection Agency (NAHB 1995). This study was performed to identify the barriers for new construction waste recycling. In order to facilitate this, waste characterizations were performed on homes in different regions of the country, Maryland, Oregon, and Michigan.

Although all homes are located in wide-ranging locations in the U.S., they are all in northern areas. As such, the researchers did not examine the differences that homes in the southern portion of the United States may have with northern homes. There were differences, however, in the selected homes' exteriors, two were built with a brick façade (Maryland), another with wood siding (Oregon), and the third with vinyl siding (Michigan). This difference did not have much of an impact on the waste composition and neither did the fact that one of the builders was a large company, whereas the other two were relatively small.

Seventy to 80 percent of the waste stream, by volume or by mass, was represented by wood, drywall, and corrugated cardboard. Engineered wood comprised as much as 50 percent of the total wood waste. The amount of drywall that was generated followed the industry standard of one pound per square foot of living space. The amount of cardboard that was generated depended on the materials selected and proximity of the vendor.

The researchers collected all of the waste from the three homes. The waste was collected in weather tight containers, roll-off containers with tops or tarps to cover them when construction activity was not taking place. The waste sort was performed on a solid, covered surface. All of the materials were separated and weighed individually on the tipping scale (if there was a significant amount) or on a bathroom scale. The results of the waste sorts are illustrated in Figures 2.4 through 2.6.

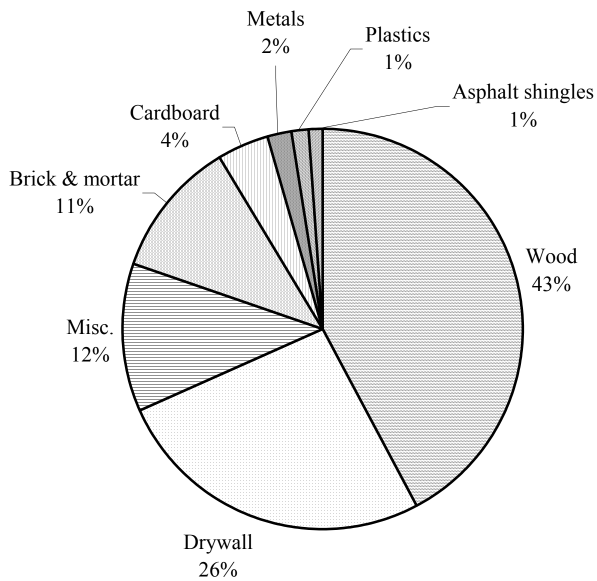


Figure 2.4. Debris Composition (By Weight) from the Construction of a Home in Largo, Maryland. (NAHB 1995).

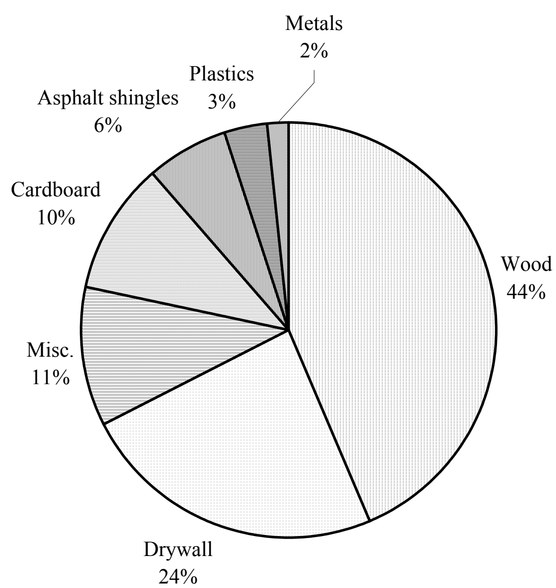


Figure 2.5. Debris Composition (By Weight) from the Construction of a Home in Grand Rapids, Michigan (NAHB 1995).

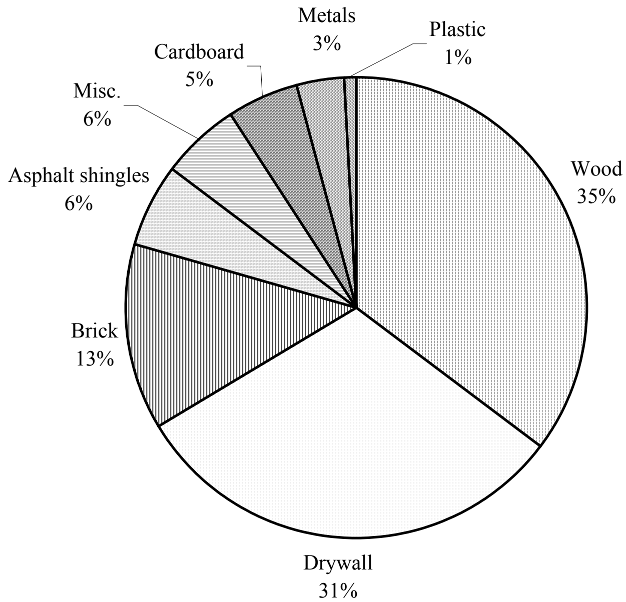


Figure 2.6. Debris Composition (By Weight) from the Construction of a Home in Anne Arrundel County, Maryland (NAHB 1995).

2.1.3 METRO Study 2

A second study was performed for the METRO Solid Waste Department in Portland, Oregon in 1993 (McGregor et al. 1993). The objective was to determine the amount and composition of waste from residential and nonresidential construction projects in the Portland, Oregon area. A second objective was to determine how hazardous components of C&D waste were managed. To accomplish the first goal, waste audits were performed on a series of residential and nonresidential new construction projects as well as two nonresidential renovation projects. The new residential construction projects will be discussed in this section. The nonresidential construction project will be discussed in Section 2.2.2.1. The two nonresidential renovation projects will be discussed in Section 2.2.4.1.

The project team performed audits on the waste from four single-family new homes. All of the homes were built with wood frames. The different characteristics of each house are listed in Table 2.1. The compositions of the waste from each house are depicted in Figures 2.7 through 2.10.

Table 2.1. Characteristics of the Four Residential Construction Projects (Evaluated in McGregor et al. 1993).

	House 1	House 2	House 3	House 4
Area (ft^2)	1,500	1,765	1,810	3,521
Value	$125,000	$134,900	$149,900	$246,000
Waste weight (lbs)	6,921	7,950	6,869	14,408
Waste generation (lbs/ft^2)	4.61	4.5	3.7	4.09

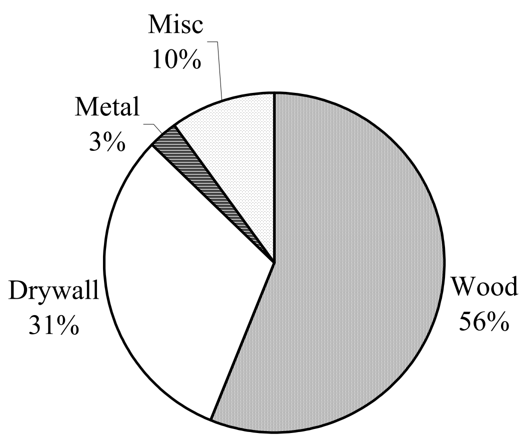


Figure 2.7. Debris Composition from a 1,500 Square-foot Home in Portland, Oregon (McGregor et al. 1993).

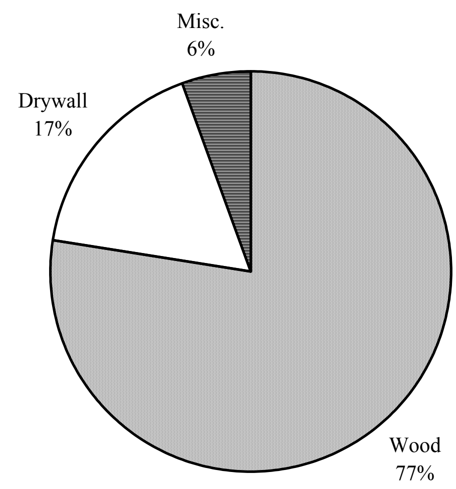


Figure 2.8. Debris Composition from a 1,765 Square-foot Home in Portland, Oregon (McGregor et al. 1993).

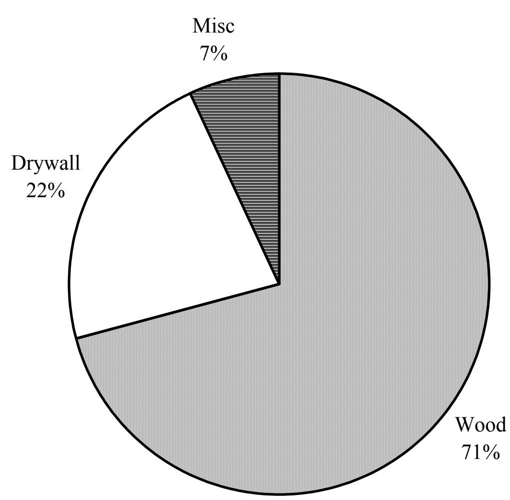


Figure 2.9. Debris Composition from a 1,810 Square-foot Home in Portland, Oregon (McGregor et al. 1993)

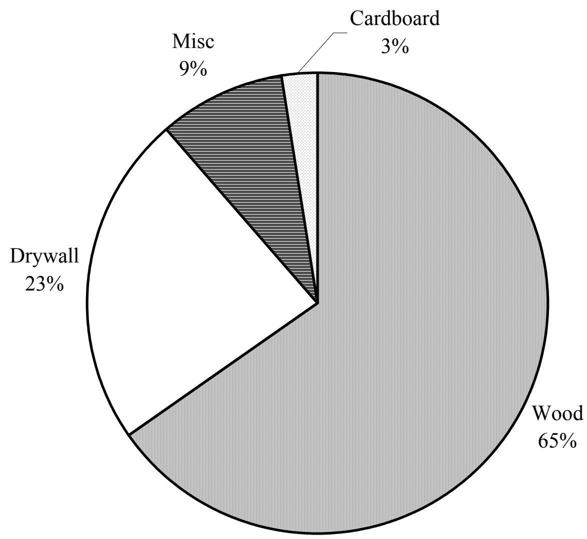


Figure 2.10. Debris Composition from a 3,521 Square-foot Home in Portland, Oregon (McGregor et al. 1993).

The project team also audited waste from two multi-family new construction projects. The first was an eight-unit complex called "Nevada Street Rowhouses." The average area per unit was 1,100 square feet and the average weight of waste per unit was 3,405 lbs, giving a waste generation rate of 3.0 lbs/sq ft. The total amount of waste generated during the entire project was 27,239 pounds. Figure 2.11 depicts the composition of the waste from the Nevada Street Rowhouses.

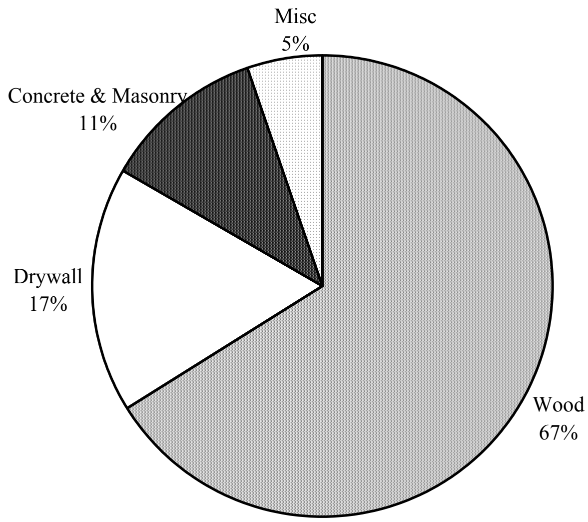


Figure 2.11. Composition of the Debris from the Nevada Street Rowhouses in Portland Oregon (McGregor et al. 1993).

The second project was the Rystadt Apartments, a 17-unit complex. The average area of each unit was 800 square feet. The wood that arrived on site for framing was pre-cut and, hence, wood waste was drastically reduced. The average weight of waste per unit was 1,672 pounds or 2.0 lbs/sq. ft. The total amount of waste was 28,434 lbs. The composition of the waste from the complex is depicted in Figure 2.12.

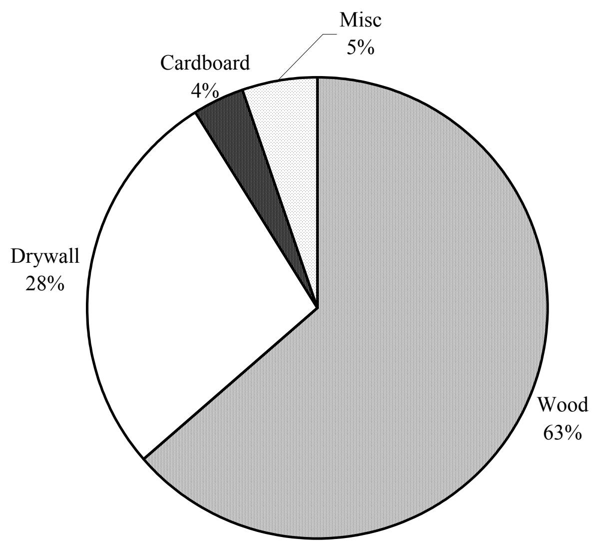


Figure 2.12. Composition of the Debris from the Rystadt Apartments in Portland, Oregon (McGregor et al. 1993).

2.1.4 University of Florida (1998 a)

The University of Florida conducted a study to determine the composition of waste from two homes in Alachua County, Florida (Townsend 1998). The project team characterized the waste from two 1,750 square-foot, wood-frame homes. The project team also conducted studies on the waste from other construction and demolition sites (discussed in later sections). The waste from these houses consisted mostly of wood. Drywall was the second largest component and roofing materials was the third largest component. There was a total of 17,720 pounds of waste from the two homes. Figure 2.13 depicts the composition of the waste.

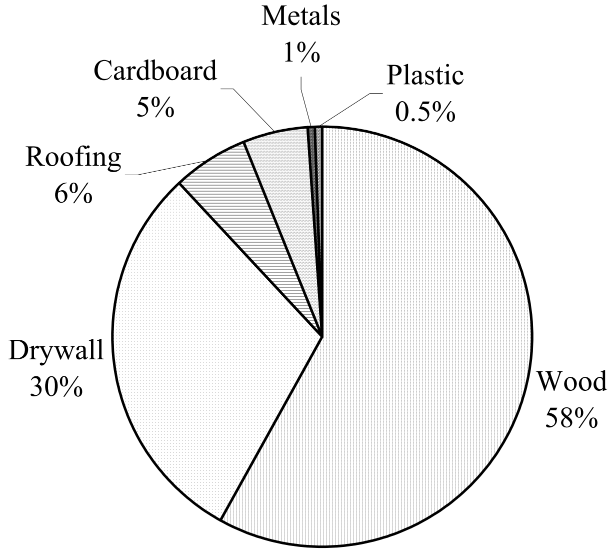


Figure 2.13. Debris Composition from Two Wood-Frame Homes in Alachua County, Florida (Townsend 1998 a).

2.1.5 Summary of Residential Construction Waste Composition Studies

Each of these studies was used to determine an average composition of the waste from residential construction projects. Table 2.3 summarizes the composition of each home. The composition studies are labeled in the table by the state in which they were located and then by the order in which they are presented in this chapter. For instance, OR_1 through OR_3 are from the first METRO Solid Waste Department composition study discussed in Section 2.1. MD_1, MD_2, and MI are from the NAHB study. OR_4 through OR_7 are from the second METRO Solid Waste Department composition study. Finally, FL_1 is from the University of Florida study. A waste mass amount per square foot was calculated for each component. These numbers were then averaged to estimate a weight per square foot for each component of residential construction.

Table 2.2. Summary of Waste Composition from All Residential Construction.

Component	OR_1	OR_2	OR_3	MD_1	MD_2	MI	OR_4	OR_5	OR_6	OR_7	FL_1
Wood	4,728	9,080	6,798	4,305	3,319	5,310	3,997	6,160	4,800	9,336	10,278
Drywall	2,025	1,447	3,806	2,680	2,940	2,900	2,217	1,350	1,500	3,354	5,316
Cardboard	149	443	280	420	478	1240	0	0	0	374	876
Metal	97	131	138	215	316	283	210	0	0	81	98.6
Plastic	62	23	65.5	135	67	409	0	0	0	0	88.6
Miscellaneous	576	177	837	1195	532	1197	707	440	469	1,263	0
Asphalt roofing materials	0	32	0	120	544	780	0	0	0	0	1,063
Brick	249	0	0	1,140	1,240	0	0	0	0	0	0
Paper	206	93	65	0	0	63	0	0	0	0	0
Concrete	14	14	1,698	0	0	0	0	0	0	0	0
Land Clearing Debris	125	0	87	0	0	0	0	0	0	0	0
Total	8,231	11,440	13,775	10,210	9,436	12,182	7,131	7,950	6,769	14,408	17,720
Area (ft^2)	2,200	2,900	3,000	2,200	2,450	2,600	1,500	1,765	1,810	3,521	3,500

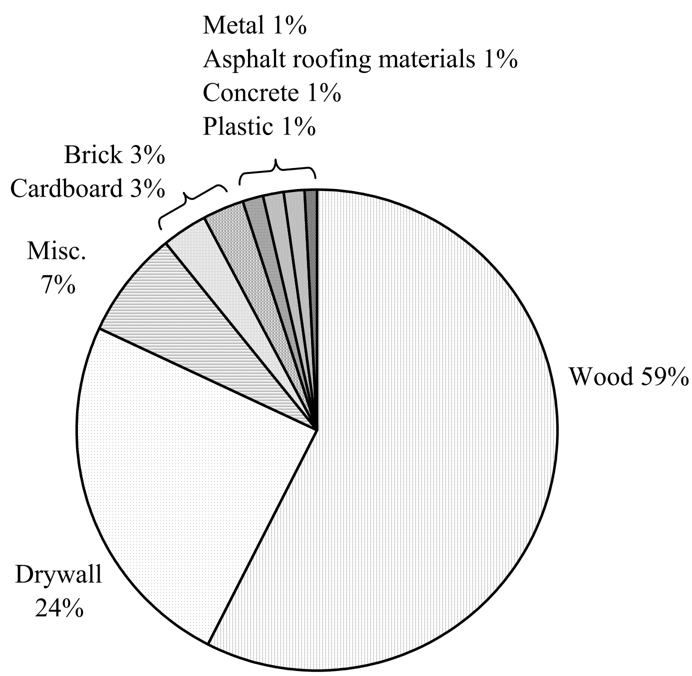


Figure 2.14. Summary Composition of Debris from All Residential Construction Composition Studies (by weight).

2.2 NONRESIDENTIAL CONSTRUCTION WASTE COMPOSITION STUDIES

2.2.1 Oregon Study

As part of the METROC study discussed in Section 2.1.3 (McGregor et al. 1993), an audit of nonresidential construction waste was also performed. The project team audited the waste from one nonresidential construction project, an Applebee's Restaurant. The building had an area of 5,000 square feet and the weight of the waste was 12,344 pounds, therefore the waste generation rate was 2.46 pounds per square foot. Figure 2.15 describes the composition of the waste from this audit.

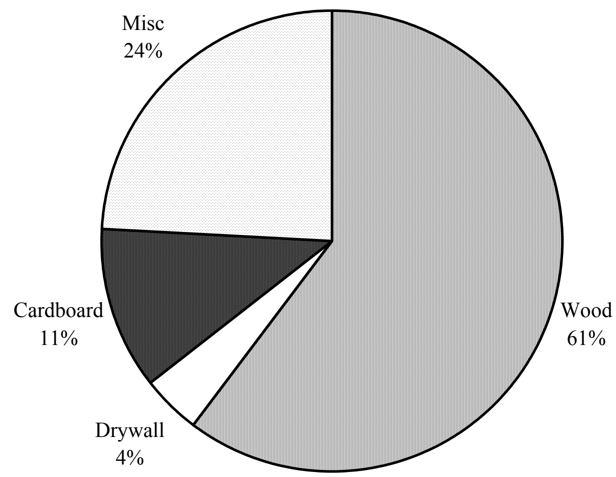


Figure 2.15. Debris Composition from Construction of a Restaurant. (McGregor et al. 1993).

2.2.2 University of Florida

The University of Florida conducted a study on the feasibility of job-site recycling at the construction site of a 15,505 square-foot building with a concrete block frame in Alachua County (Townsend 1998 b). The waste was sorted for recycling and weighed accordingly. The total amount of waste from the construction of this building was about 150,000 pounds. Figure 2.16 depicts the composition of the waste from this building.

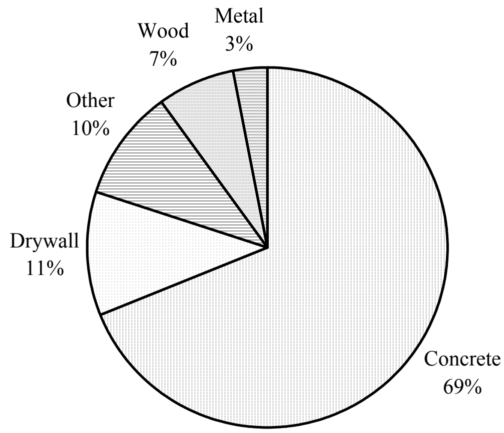


Figure 2.16. Debris Composition from a Nonresidential Building Construction in Alachua County, Florida (Townsend 1998 b).

2.3 RESIDENTIAL RENOVATION WASTE COMPOSITION STUDIES

2.3.1 Oregon Study

The purpose of this project was to demonstrate cost effective waste reduction when performing a residential remodeling project (O'Brien and Associates et al. 1993). Three remodeling jobs were selected: one kitchen renovation, one kitchen and family room renovation, and one bathroom renovation. The wastes were weighed individually by type. The characteristics of each renovation job are listed in Table 2.3.

Table 2.3. Characteristics of Three Remodeling Projects (O'Brien And Associates et al. 1993).

	Kitchen	Family room/kitchen	Bathroom
Value	$24,200	$80,500	$9,781
Area (ft^2)	275	550	90
Waste (lbs)	1,588	10,382	2,313
Waste generation (lbs/ft)	5.77	18.88	25.70

The first kitchen-remodeling job took place in a house built in the 1940s in Portland, Oregon. The contractor replaced the wood flooring, drywall, cabinet doors and drawers, sink, window, island, appliances, ceiling lights, shelves, and paint. The second renovation involved a one-room area that served as both a kitchen and family room area in a fairly new house (less than ten years). The area was remodeled and an addition was built. The contractor added floor area, walls, windows, a large island, and doors. The contractor replaced cabinets, countertops, the sink, appliances, shelves, and paint. The third job involved two bathrooms in a 1950s house. The contractor replaced a shower stall, vanity, sink, and toilet from one bathroom and only removed a window and installed a skylight in the second bathroom. The contractor also replaced the vinyl flooring, trim, light fixtures, and mirrors in both bathrooms and repainted the walls. Figures 2.17 through 2.19 depict the waste composition of each remodeling job.

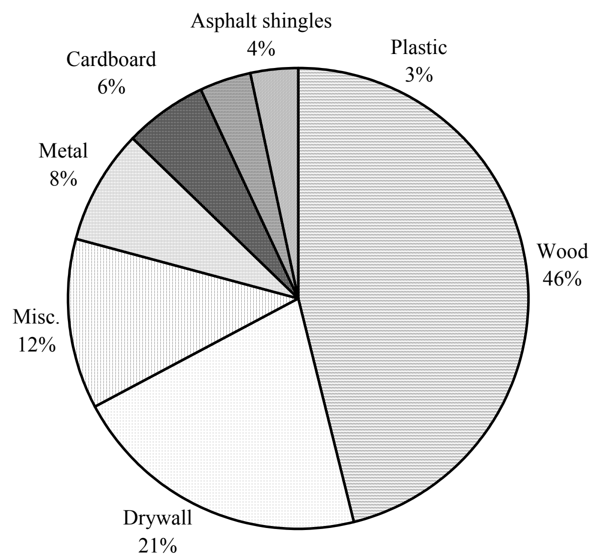


Figure 2.17. Debris Composition from a Kitchen-Remodeling Job (O'Brien and Associates et al. 1993).

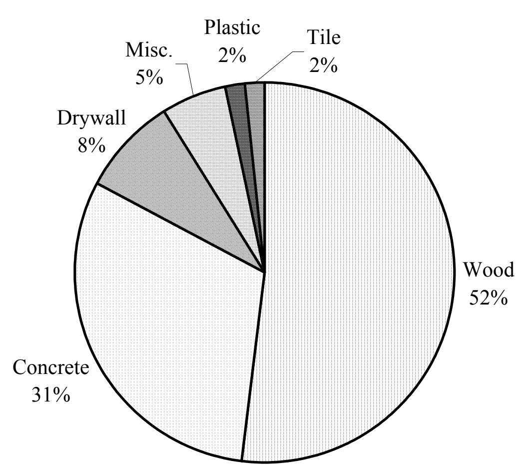


Figure 2.18. Debris Composition from a Kitchen/Family Room Remodeling Job (O'Brien and Associates et al. 1993).

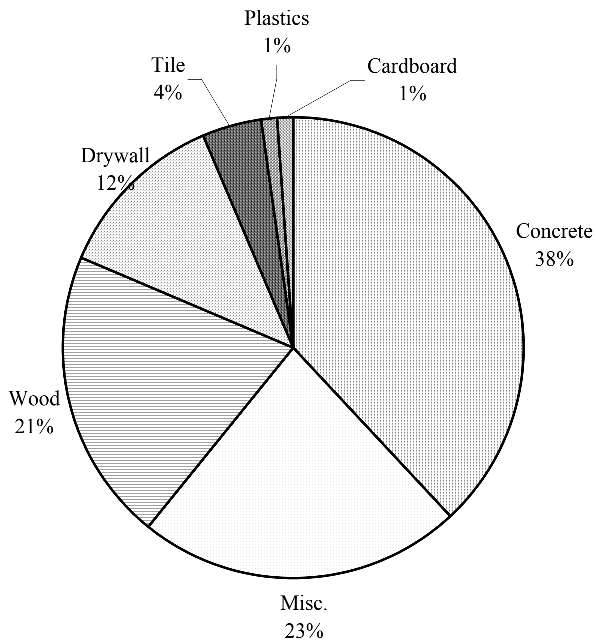


Figure 2.19. Debris Composition from a Bathroom-Remodeling Job (O'Brien and Associates et al. 1993).

2.4 NONRESIDENTIAL RENOVATION WASTE COMPOSITION STUDIES

2.4.1 Oregon Study

The description of this project is detailed in Section 2.2.1.3 (McGregor et al. 1993). This section will only discuss the nonresidential renovation waste audits that were performed as a part of this project. The project team performed audits on the waste from three office improvements. The first took place in Portland, Oregon. The other two took place in one large commercial building in Tigard, Oregon. The characteristics of the buildings are listed in Table 2.4. All weights are listed in pounds. The compositions of the waste from each of the three waste audits are provided in Figures 2.20 through 2.22.

Table 2.4. Characteristics of Three Nonresidential Renovation Jobs in Oregon. (McGregor et al. 1993).

Component	Richard White	Lincoln Center	Lincoln Center #2
Metal Studs	950	NA	NA
Wood Framing	3,270	NA	NA
Drywall	8,444	2,430	5,980
Wallpaper	50	NA	NA
Carpet & Padding	NA	1,890	920
Cabinets and Shelving	NA	540	920
Ceiling Tile	NA	540	NA
Miscellaneous	NA	NA	1,380
Total (lbs)	12,714	5,400	9,200
Area (ft^2)	1,500	2,825	4,895
Value ($)	NA	31,500	102,469
Waste generation (lbs/ft^2)	8.4	1.9	1.8

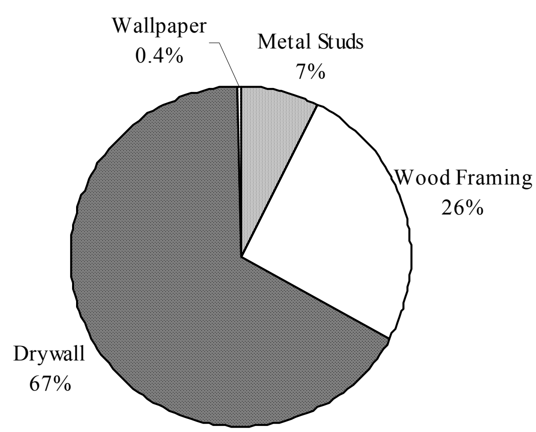


Figure 2.20. Debris Composition from a Nonresidential Renovation Project in Oregon (Richard White Project, McGregor et al.1993).

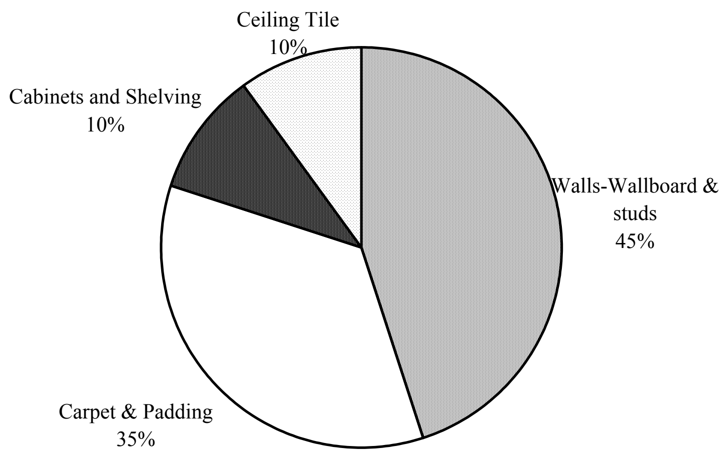


Figure 2.21. Debris Composition from Nonresidential Construction Project (Lincoln Center #1, McGregor et al. 1993).

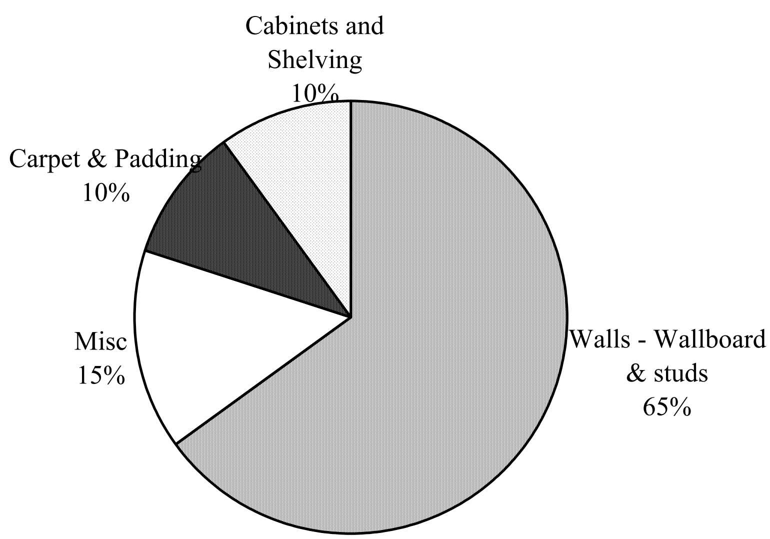


Figure 2.22. Debris Composition from Nonresidential Construction Project (Lincoln Center #2 McGregor et al. 1993).

2.5 RESIDENTIAL DEMOLITION DEBRIS COMPOSITION STUDIES

2.5.1 Riverdale Deconstruction

The NAHB (1994) performed a manual disassembly of a multi-family residential home in Baltimore County, Maryland. This was a 2,000 square foot, four-unit brick building with wood framing. The primary purpose of this was to determine the economic feasibility and practicality of disassembling structures, instead of demolishing them, with the intent of salvaging the building materials. These materials were then sold, recycled, or disposed. The amount of waste generated from the disassembly project totaled 127.2 tons. The composition of the waste that was generated, including all of the materials recycled and landfilled, is represented in Figure 2.23.

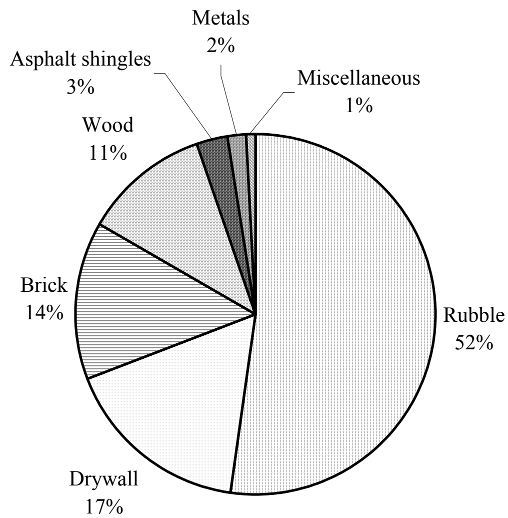


Figure 2.23. Building Disassembly Debris Composition from the Riverdale Case Study (NAHB 1997).

2.6 NONRESIDENTIAL DEMOLITION WASTE COMPOSITION STUDIES

2.6.1 University of Florida Study

The University of Florida conducted a job-site recycling project in Alachua County, Florida (Townsend 1998 b). The building had an area of 22,000 square feet and a concrete block frame. The project team sorted the waste. They then weighed each component and recorded the weight data. The total amount waste from the building was 1,904 tons. Figure 2.24 depicts the composition of this waste.

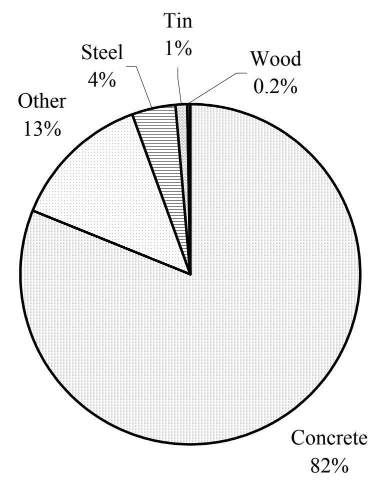


Figure 2.24. Debris Composition from a Nonresidential Building Demolition in Alachua County, Florida (Townsend 1998 b).

2.7 Summary of Areal Waste Generation Rates by Sector

The estimates of waste generation in the next chapter were calculated using waste generation per square foot for the respective job activity. These waste generation rates were taken from various studies on C&D waste described in this section. Table 2.5 lists these generation rates used.

Table 2.5. Summary of Waste Generation per Square Foot for All Building-Related C&D Activities.

<table>
<tr><th>Building-related C&D Activity</th><th colspan="2">Type</th><th>Waste Generation Rate</th></tr>
<tr><td rowspan="2">Residential Construction</td><td colspan="2">Wood frame</td><td>4.32 pounds per square foot</td></tr>
<tr><td colspan="2">Concrete block frame</td><td>8.95 pounds per square foot</td></tr>
<tr><td rowspan="2">Nonresidential Construction</td><td colspan="2">Wood frame</td><td>4.02 pounds per square foot</td></tr>
<tr><td colspan="2">Concrete block frame</td><td>9.40 pounds per square foot</td></tr>
<tr><td rowspan="4">Residential Demolition</td><td colspan="2">Single family (crawl space)</td><td>49.50 pounds per square foot</td></tr>
<tr><td colspan="2">Single family (basement)</td><td>158.20 pounds per square foot</td></tr>
<tr><td colspan="2">Single family (concrete slab)</td><td>97.90 pounds per square foot</td></tr>
<tr><td colspan="2">Multi-family</td><td>127.00 pounds per square foot</td></tr>
<tr><td>Nonresidential Demolition</td><td colspan="2"></td><td>173.00 pounds per square foot</td></tr>
<tr><td rowspan="8">Residential Renovation</td><td colspan="2">Kitchen alterations (major)</td><td>4.50 tons per job</td></tr>
<tr><td colspan="2">Kitchen alterations (minor)</td><td>0.75 tons per job</td></tr>
<tr><td colspan="2">Bathroom alterations (major)</td><td>1.00 tons per job</td></tr>
<tr><td colspan="2">Bathroom alterations (minor)</td><td>0.25 tons per job</td></tr>
<tr><td colspan="2">Additions</td><td>0.75 tons per job</td></tr>
<tr><td colspan="2">Driveway replacements</td><td>9.00 tons per job</td></tr>
<tr><td rowspan="2">Roof replacements</td><td>Asphalt</td><td>1.68 tons per job</td></tr>
<tr><td>Wood</td><td>1.40 tons per job</td></tr>
</table>

3.0 REVIEW OF LITERATURE: C&D DEBRIS GENERATION

3.1 HISTORICAL ESTIMATES OF C&D DEBRIS GENERATION IN THE U.S.

C&D debris has not historically been tracked as a national statistic in the same fashion as has municipal solid waste from commercial and institutional activities. Early efforts by Franklin Associates (U.S. EPA's contractor for the MSW waste generation estimate) did include an estimate of C&D debris, but this was dropped because of a lack of confidence in the data.

3.2 1996 U.S. C&D DEBRIS GENERATION ESTIMATE

A study was commissioned by the U.S. Environmental Protection Agency (EPA) to determine the amount and composition of C&D debris in the U.S for 1996 (Franklin & Associates, 1998 a). The study only characterized the building-related C&D debris, omitting the debris that originates from the construction and demolition of bridges, roads, and other non-building structures. Franklin & Associates used a series of equations using statistical data on the number and value of C&D related activities. These statistical data came from either the U.S. Census Bureau or word-of-mouth from trade organizations.

Their results included calculations of the amount of C&D produced and did not provide any composition estimates. Since C&D varies drastically from different regions of the country as well as among job types, to attempt to estimate the composition of C&D waste for the entire country would create large data ranges.

This section describes the method that was used to calculate the C&D waste generation for the entire United States. It describes the steps taken to determine waste tonnages.

3.2.1 Residential Construction

To determine the amount of waste generated as a result of residential construction in the United States, the EPA-sponsored study first started with the total amount spent on new residential construction in 1996. Using the value of residential construction and the residential floor space from construction contracts in 1995, a cost per square foot of new construction was determined. Due to the fact that data for 1996 were not released at the time the report was written, the data for 1995 were multiplied by a three-percent inflation factor to get an estimate for 1996. The cost per square foot that resulted was multiplied by the total spent on new residential construction to determine a total square footage of new residential construction. This number was then multiplied by an average waste generation rate to determine the total weight of waste generated from residential construction annually. The generation rate was determined from several weight-based composition studies performed on wood-frame houses. The total weight found from their calculation equals 6,564,000 tons per year. Equation 3.1 presents the calculation used to determine this amount.

Calculation of the annual residential construction waste generation in the U.S.

$$Q = \frac{A}{\left(B/C\right) \times (1+\alpha)} \times D \qquad \textbf{(3.1)}$$

where:

Q = Amount of waste generated

A = Total dollars of new residential construction, 1996

B = Total value of residential construction from construction contracts, 1995

C = Total square feet of new residential construction, 1995

α = Inflation rate

D = Waste generation rate from residential construction

$$\text{Amount of waste generated} = \frac{\$181{,}795{,}000{,}000}{\left(\$127{,}900{,}000{,}000 / 2{,}172{,}000{,}000\ \text{sq ft}\right) \times (1.03)} \times \frac{4.38\ \text{lbs/sq ft}}{2000\ \text{lbs/ton}}$$

$$= 6{,}564{,}000\ \text{tons}$$

3.2.2 Nonresidential Construction

The national method calculated the amount of waste generated from nonresidential construction similar to the one used to calculate the amount of waste generated from residential construction. First, the total expenditures for nonresidential construction were found. Then, using the total square footage of new nonresidential construction and the total value of nonresidential construction from construction contracts in 1995, the cost of new construction per square foot was determined. A three-percent inflation rate was factored in to get a cost per square foot for 1996. Once this number was found, the total expenditures were divided by the average cost per square foot for 1996 to get a total square footage built in 1996. An average of waste generation rates from several weight-based composition studies on nonresidential construction was taken. This generation rate (in pounds per square foot) was multiplied by the total square footage built in the nation in 1996 to get a total waste amount (in pounds). This number was multiplied by a conversion factor to get a total amount of 4,417,000 tons per year. Equation 3.2 presents the equation and the factors used to calculate this amount.

Calculation of the annual nonresidential construction waste generation in the U.S.

$$Q = \frac{A}{\left(B/C\right)\times\left(1+\alpha\right)} \times D \qquad \textbf{(3.2)}$$

where:

Q = Amount of waste generated

A = Total dollars of new nonresidential construction, 1996

B = Total value of nonresidential construction from construction contracts, 1995

C = Total square feet of new nonresidential construction, 1995

α = Inflation rate

D = Waste generation rate from nonresidential construction

$$\text{Amount of waste generated} = \frac{\$198{,}694{,}000{,}000}{\left(\$112{,}000{,}000{,}000 / 1{,}276{,}000{,}000 \text{ sq ft}\right)\times\left(1.03\right)} \times \frac{4.02 \text{ lb/sq ft}}{2000 \text{ lbs/ton}}$$

$$= 4{,}417{,}000 \text{ tons}$$

3.2.3 Residential Demolition

To calculate the total amount of waste that results from residential demolitions annually, an annual number of residential demolitions from the National Association of Home Builders (NAHB) was obtained. No one collects these data at a state or at a federal level and the NAHB could only give an estimate. Since single- and multi-family homes that are demolished are usually at least 20 years old, the average square foot values per house from 1975 were used. The waste generation rates were then estimated for multi-family buildings and single-family homes with three different foundation types: basements, concrete slab, and crawl space. Again, these generation rates were determined from weight-based composition studies. The fractions of the total amount of residences (single- and multi-family) demolished for each single-family home foundation type were multiplied by their respective waste generation rates. These were summed and then multiplied by the average square footage of a single-family home. This was added to the number produced when multiplying the fraction of multi-family homes, the waste generation rate for multi-family homes, and the average square footage for a multi-family home. This sum is then multiplied by the total amount of annual residential demolitions to arrive at 19,700,000 tons of waste produced from residential demolitions annually. Equation 3.3 presents the calculations used to compute this number.

Calculation of the annual residential demolition waste generation in the U.S.

$$Q = A\left[B\left(\chi C + \delta D + \varepsilon E\right) + F\left(\gamma G\right)\right] \qquad \textbf{(3.3)}$$

where:

Q = Amount of waste generated

A = Total number of residential demolitions per year

B = Average area of a single-family home (square feet)

χ = Percentage of all residential buildings that are single-family homes with a basement

C = Waste generation rate for a single-family home with a basement (pounds per square foot)

δ = Percentage of all residential buildings that are single-family homes with a concrete slab foundation (no basement)

D = Waste generation rate for a single-family home with a concrete slab foundation (no basement, pounds per square foot)

ε = Percentage of all residential buildings that are single-family homes with a crawl space foundation

E = Waste generation rate for a single-family home with a crawl space foundation (pounds per square foot)

F = Average area for multi-family homes (square feet)

γ = Percentage of all residential buildings that are multi-family homes

G = Waste generation rate for multi-family homes (pounds per square foot)

$$\begin{aligned}\text{Amount of waste generated} &= 245{,}000\{(1{,}600)[(.3\times158.2)+(.17\times97.9)+(.19\times49.5)]+[1{,}000(.34\times127)]\}\\ &= 19{,}700{,}000 \text{ tons}\end{aligned}$$

3.2.4 Nonresidential Demolition

The method for calculating the amount of waste generated from nonresidential demolitions in the United States annually is very simplistic in comparison to the residential demolition calculation. The EPA first found the number of buildings that were demolished in 1995 (the last year that the Census Bureau collected this data due to budget cuts). The average size of buildings built between 1920 and 1969 was determined by dividing the total square footage of nonresidential buildings built during that time period by the total number of buildings. An average generation rate was determined from weight-based composition studies and multiplied by the average size of buildings between 1920 and 1969 and by the total number of buildings demolished during 1995. This calculation resulted in a total generation of 50,400,000 tons of nonresidential demolition waste. Equation 3.4 presents the calculation performed to compute this number.

Calculation of the annual nonresidential demolition waste generation in the U.S.

$$Q = A \times \frac{B}{C} \times D \qquad \textbf{(3.4)}$$

where:

Q = Amount of waste generated

A = Total number of demolition permits in 1995

B = Total square footage of nonresidential construction built between 1920 and 1969

C = Number of buildings built between 1920 and 1969

D = Waste generation rate for a nonresidential demolition (pounds per square foot)

$$\text{Amount of waste generated} = 43{,}795 \text{ bldgs} \times \frac{31{,}745.000{,}000 \text{ sq ft}}{2{,}387{,}000 \text{ bldgs}} \times \frac{173 \text{ lb/sq ft}}{2000 \text{ lb/ton}} = 50{,}400{,}000 \text{ tons}$$

3.2.5 Residential Renovation

To calculate the total amount of waste produced annually in the United States from residential renovations, a series of steps were taken. Estimates of how many jobs of each type of renovation that are performed in one year were obtained from the National Association of Home Builders. How much waste each type of renovation produced was then estimated. These estimates were added together for a total amount of 31,920,000 tons of residential renovation waste generated. Equation 3.5 presents the calculation of this amount.

Calculation of the annual residential renovation waste generation in the U.S.

$$Q = A + B + C + D + E + F + G \qquad \textbf{(3.5)}$$

where:

Q = Amount of waste generated

A = Tons of waste produced from kitchen remodeling jobs

B = Tons of waste produced from bathroom remodeling jobs

C = Tons of waste produced from additions

D = Tons of waste produced from concrete driveway replacements

E = Tons of waste produced from asphalt roof replacements

F = Tons of waste produced from wood roof replacements

G = Tons of waste produced from heating and air conditioning replacements

$$\begin{aligned}\text{Amount of waste generated (in million tons)} &= 6.56 + 1.65 + 0.94 + 13.00 + 6.80 + 1.40 + 1.57 \\ &= 31.92 \text{ million tons}\end{aligned}$$

3.2.6 Nonresidential Renovation

To estimate the amount of waste generated from nonresidential renovations, a ratio of the estimated residential renovation waste generation to the expenditures of residential renovations was taken and then multiplied by the expenditures of nonresidential renovations. This resulted in a total of 28,042,000 tons. The calculation for this method is presented in Equation 3.6.

Calculation of the annual nonresidential renovation waste generation in the U.S.

$$Q = \left[\frac{A}{B}\right] \times C \qquad \textbf{(3.6)}$$

where:

Q = Amount of waste generated

A = Amount of annual residential renovation waste generated in the U.S.

B = Amount spent on residential improvements and repairs in the U.S., 1996

C = Amount spent on nonresidential improvements and repairs in the U.S., 1996

$$\text{Amount of waste generated} = \left[\frac{31{,}924{,}000}{\$114{,}300{,}000{,}000}\right] \times \$100{,}400{,}000{,}000 = 28{,}042{,}000 \text{ tons}$$

4.0 C&D DEBRIS IN FLORIDA

4.1 FLORIDA C&D DEBRIS REGULATIONS

C&D debris is defined and regulated in Florida under Florida Administrative Code 62-701. This regulation provides facility design and operation requirements. Facilities that dispose or process mixed C&D debris are required to obtain a permit from the FDEP (or delegated county regulatory agency). Some types of C&D debris are considered clean debris and are not regulated under 62-701.

4.2 TYPICAL FLORIDA C&D DEBRIS MANAGEMENT

C&D debris is most commonly managed via one of two mechanisms. The first is disposal in a landfill. As discussed above, several different types of landfills may be permitted to operate in Florida. C&D debris generators and waste haulers have the option of disposing of C&D debris in Class I lined landfills (those typically used for household and commercial MSW), but the higher tipping fees associated with these facilities usually result in most C&D debris being disposed in Class III or C&D debris landfills. Some fractions of the C&D debris stream might be managed as clean fill (Portland cement concrete and asphalt pavement) and disposed in non-permitted areas.

A second option for management of C&D debris is processing at a materials recovery facility. A number of facilities in Florida are permitted to accept C&D debris, process it to recover saleable commodities, and then haul the non- recoverable material for disposal in an appropriate landfill. The layout of these facilities varies depending on operator, location, and objectives of the facility. Typical operations include separation of large or easily recoverable items up front, screening to remove soil, and separation using a combination of manual labor and mechanical equipment. The major commodities recovered include wood, concrete, metal, cardboard, and soil.

4.3 GENERATION OF C&D DEBRIS IN FLORIDA

Under 62-701.730 (12) of the Florida Administrative Code (FAC), all C&D facilities in Florida are required to report annually the amounts of wastes received and disposed as well as the amounts and types of wastes that were recycled. They are also required to report the county in which the waste was generated. They are not, however, required, to have a scale at their facility and are, therefore, able to report volumes instead of weights. Currently, data have only been finalized for 1998. Based on current estimates in Florida, C&D waste contributes 25 percent of the total waste stream resulting from municipal activities (FDEP 2000).

The total amount of C&D waste collected in Florida in 1998, as reported by C&D facilities to the Florida Department of Environmental Protection (FDEP), was 9,401,388 tons. This suggests a generation rate of approximately 3.43 pounds per person per day. Of the amount collected, 3,288,465 tons were recycled. The rest was disposed in C&D landfills. Figure 4.1 depicts the percentage that is C&D waste when added to the MSW waste stream in Florida in 1998. Figure 4.2 depicts the percentage of C&D waste that is recycled and the percentage that is disposed.

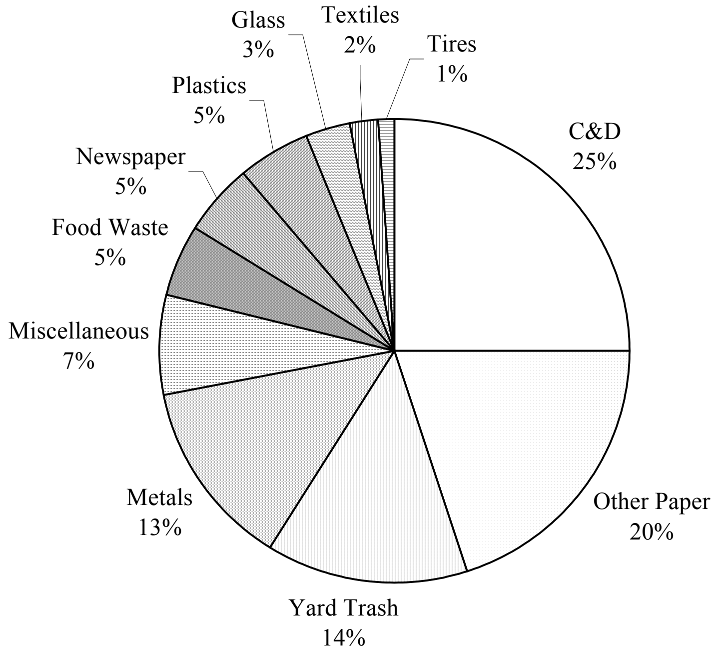


Figure 4.1. Composition of 1998 MSW in Florida with C&D waste added (FDEP 2000).

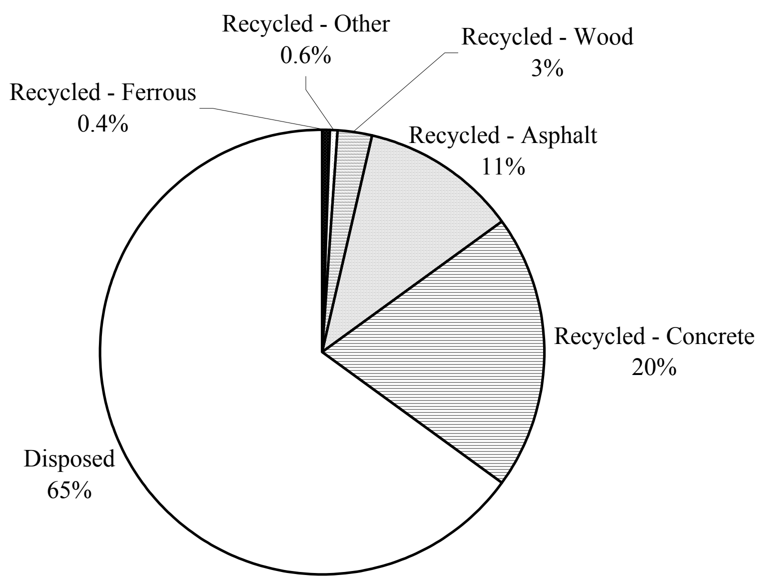


Figure 4.2. Amounts of 1998 C&D wastes that were recycled or disposed (FDEP 2000).

The above numbers represent all of the C&D waste generated in Florida, including waste from the construction and demolition of roads and bridges. The methods used in this report apply only to waste generated during the construction, renovation, and demolition of buildings. The exact amount of waste that was generated from only these activities is unknown. It can be assumed that all of the asphalt concrete that was recycled (approximately 1.07 million tons) originated from activity on roads and bridges, but the amount of portland cement concrete waste (of the approximately 1.88 million tons recycled) resulting from activity on roads and bridges is unknown. It is also unknown what percentage of the total amount of waste disposed is not building-related, including land-clearing debris.

SECTION II

C&D GENERATION IN FLORIDA

5.0 METHODOLOGY FOR ESTIMATING C&D DEBRIS GENERATION IN FLORIDA

Introduction

This chapter presents the application of the method of calculating the amount of C&D debris in the U.S. to Florida. It also goes a step further by discussing the composition of the C&D waste as well. This calculation is divided by job activity (see Table 5.1) because each activity produces debris with different characteristics. The composition analysis includes the following major component categories: wood, concrete, drywall, cardboard, metal, asphalt roofing materials, and a miscellaneous category.

Table 5.1. List of job activities used in waste calculations.

Job Activities	Description
Residential Construction	Single and multi-family new home construction
Nonresidential Construction	Commercial new construction (includes hotels, stores, restaurants, business complexes, skyscrapers etc.)
Residential Demolition	Single and multi-family home demolition
Nonresidential Demolition	Commercial demolition (includes hotels, stores, restaurants, business complexes, skyscrapers etc.)
Residential Renovation	Residential additions, alterations, re-roofs, and driveway replacements
Nonresidential Renovation	Commercial additions, alterations, and re-roofs

To calculate the amount of waste from each job activity, the total area (ft^2) of job activity was determined first. Then, a waste generation (by mass) per area (lb/ft^2) was used to determine a total waste amount (lb) for that job activity throughout the state. Once the generation amount had been determined, the composition was calculated. Average waste generation rates (by mass) per area (e.g. lb drywall/ft^2) were determined from composition studies for each component. These numbers were multiplied by the total area of job activity in the state to estimate a composition of the waste from that job activity.

In its most basic form, the calculation used to determine waste generation takes the total number of construction, demolition, or renovation activities that have occurred and multiplies them by the average weight of waste per activity (see Equation 5.1). A different method of calculating this number for each job activity is used. These methods are described in the following sections.

Simplified equation used to calculate the amount of waste from each construction, demolition, or renovation activity.

(5.1)

$$\text{Waste produced (tons)} = \begin{bmatrix}\text{Number of construction, demolition,} \\ \text{or renovation activities (\#)}\end{bmatrix} \times \begin{bmatrix}\text{Waste produced} \\ \text{per activity (tons/\#)}\end{bmatrix}$$

A preliminary estimate of the generation of construction and demolition debris was made in a paper for the Air and Waste Management Association (AWMA) (Cochran et al. 2001). It used a similar method to the national estimate, but included data on Florida. The estimate in this report goes a step further by tailoring the equations to the construction activity in Florida. This report also estimates the composition of the C&D debris stream, something not done in the national estimate.

5.1 RESIDENTIAL CONSTRUCTION

The method used to calculate the annual residential construction waste generation in Florida is somewhat similar to the U.S. method. The primary difference came about when calculating the weight generated per square foot. The number that was used in the U.S. method (4.32 pounds per square foot) came from weight-based composition studies on wood-frame houses. Although some wood-frame houses are built in Florida, most are concrete-block frame houses. As shown in composition studies completed in Citrus County, Florida, the average waste generation is 8.95 pounds per square foot for concrete-block frame houses (Cochran and Townsend 2001). This value, however, includes a very large amount of drywall. Since the composition study was performed on only two homes, it was decided that this large amount was an anomaly and the amount of drywall was reduced to the industry standard of one pound per square foot to 8.06 lbs/sq. ft. As expected, this value increased the total estimated tonnage wasted from this sector.

The percentage of wood-frame houses versus concrete-block frame houses had to be determined to be able to utilize these generation rates correctly. The Florida Concrete and Products Association (FPCA) keeps this information for its members to use. The FPCA estimated that 79.6% of the homes built in Florida in 2000 were built with a concrete block frame (Sitter 2001). The remaining 20.4% of the homes built in 2000 were assumed to have a wood frame. The NAHB also collects data on materials used in the U.S. The NAHB has determined that 56 percent of the framing materials are concrete, while wood represents 44 percent (NAHB Research Center 2001). Most of the concrete block homes are built in Central and South Florida, while most of the wood frame activity occurs in north Florida.

The other part of the methodology used for the U.S. changed to conform to Florida's characteristics was the average cost per square foot. This number was instead taken from the U.S. Census report (A, 2000) for the Southern U.S[1]. As reported, the average price per square foot in the South in 1997 was $56.65. This number is not very different from the national estimate of $58.89 per square foot. The cost per square foot for the South ($56.65) was inflated using the Engineering News Record's Construction Cost Index History (ENR 2001). All pre-2000 numbers were inflated to accurately

[1] Southern U.S. includes DE, MD, District of Columbia, VA, WV, NC, SC, GA, FL, KY, TN, AL, MS, AR, LA, OK, and TX.

represent those numbers in 2000 dollars. The total amount of residential construction waste generated was estimated to be 1,000,000 tons. A calculation of how the residential construction waste amount was determined is presented in Equation 5.2.

Calculation of the annual residential construction waste generation in Florida.

$$Q = \frac{A}{B}\left[\left(C \times (1-\beta)\right) + \left(D \times \beta\right)\right] \quad \textbf{(5.2)}$$

where:

Q = Amount of waste generated

A = Total annual value of residential construction work, 2000 (inflated from the 1997 data, U.S. Census Bureau, 2000)

B = Average price per square foot for residential construction in the South (1999 data inflated to 2000, U.S. Census Bureau A, 2000)

C = Waste generation (lb/sq ft) from construction of wood frame houses (average)

$1-\beta$ = Annual percentage of all houses built in Florida that are wood frame houses, 20% (NAHB Research Center, 2001)

D = Waste generation (lb/sq ft) from construction of concrete block frame houses (Cochran and Townsend 2001)

β = Annual percentage of all houses built in Florida that are concrete block frame houses, 80% (NAHB Research Center, 2001)

$$\text{Amount of waste generated} = \frac{\$17{,}462{,}411{,}000}{\$63.20 \text{ per sq ft}}\left[\left(0.20 \times 4.32 \text{ lb/sq ft}\right) + \left(0.80 \times 8.06 \text{ lb/sq ft}\right)\right]$$
$$= 1{,}000{,}000 \text{ tons}$$

5.2 NONRESIDENTIAL CONSTRUCTION

To estimate the amount of waste generated in Florida from nonresidential construction, a method almost identical to the one used to estimate the waste generated in Florida from residential construction was used. Again, a value was obtained for the total value of new nonresidential construction, which was used with the average amount spent per square foot of new nonresidential construction to determine a value for the total area of new construction. This number was given for 1997 and, therefore, inflated just as the value for residential construction was. The average mass of waste per square foot of construction was determined from the composition studies.

Again, two separate waste generation rates were used, one for concrete-block frame buildings and one for wood-frame buildings. The concrete-block frame generation rate that was used (9.4 pounds per square foot) came from the report, "Demonstration of Job-Site Separation of Construction and Demolition Waste and C&D Debris Recycling

Economics and Job Creation Opportunities in Florida" (Townsend, 1998). The waste generation rate for wood frame buildings was determined from a METRO Solid Waste Department study, "Characterization of Construction Site Waste" (McGregor et al.1993). The same percentage of buildings that have concrete-block frames versus wood frames that was used here as that used in the estimation of residential construction waste in Florida. The application of Equation 5.3 resulted in a total of 530,000 tons.

Calculation of the annual nonresidential waste generation in Florida.

$$Q = \frac{A}{B}\{[(1-b)\times C] + (b\times D)\} \qquad \textbf{\textit{(5.3)}}$$

where:

Q = Amount of waste generated

A = Annual amount that was spent on nonresidential construction, 1997 (U.S. Census B, 2000)

B = Average cost per square foot of new nonresidential construction (Franklin Associates 1998, inflated)

$1-\beta$ = Percentage of new construction that is wood frame, 20% (Sitter 2000)

C = Waste generated per square foot for wood frame buildings (McGregor et al. 1993)

β = Percentage of new construction that is concrete block frame, 80% (Sitter 2000)

D = Waste generated per square foot for concrete block frame buildings (Townsend, 1998)

$$\text{Amount of waste generated} = \frac{\$12{,}843{,}389{,}379}{\$99.82/\text{ft}^2}\left[\left(0.20\times 2.47\ \text{lbs/ft}^2\right)+\left(0.80\times 9.67\ \text{lbs/ft}^2\right)\right]$$
$$= 530{,}000\ \text{tons}$$

5.3 RESIDENTIAL DEMOLITION

To estimate the amount of waste generated from residential demolitions annually in Florida, a similar method to that performed for the national estimate was employed. Since no agency collects a total number of residential demolitions on a state level, a different method of determining the total area (in square feet) of residential demolitions was selected. A value of the total amount spent on demolitions in the state was found in the 2000 U.S. Bureau of the Census report, "Construction – Geographic Area Series: Florida." This value was multiplied by the percentage of demolitions that are residential demolitions (by cost) to get a cost of residential demolitions in Florida. The percentage of residential demolition (28%) of the total demolitions in Florida was derived from a survey of demolition contractors in Florida (Cochran, 2001). The value of demolition work was divided by the price per square foot to get an estimate of total area of demolitions. A survey of demolition contractors in the state was made to find a weighted average price per square foot of \$2.73 for demolitions. The average was weighted by residential construction in the areas that responded (Cochran, 2001). This number was multiplied by the sum of the generation rates and the percentages of each type of demolition. The average percentage of foundation types was also extracted from the demolition contractor survey for use in this equation. The same percentage of concrete-block-frame houses versus wood-frame houses was used in the concrete slab foundation percentages. A total of 260,000 tons of annual residential demolition waste in Florida was calculated. This calculation is presented in Equation 5.4. Figure 5.1 provides an estimate of the composition of residential demolition waste.

Calculation of the annual residential demolition waste generation in Florida.

$$Q = \frac{(A \times \alpha)}{B}\left[(C \times \chi) + (D \times \delta) + (E \times \varepsilon) + (F + \phi) + (G \times \gamma)\right] \qquad \textbf{(5.4)}$$

where:

Q = Amount of waste generated

A = Total value of all demolition work in Florida, 1997 (U.S. Census Bureau, 1999)

α = Percentage of all demolitions that are residential in Florida (from the demolition contractor survey)

B = Average cost per square foot for residential demolition (from the demolition contractor survey)

C = Waste generation rate (pounds per square foot) for a wood-frame single-family house with a concrete slab foundation (Franklin Associates 1998 and Tansel et al. 1994)

D = Waste generation rate for a concrete-block frame single-family house with a concrete slab foundation. (Franklin Associates 1998 and Tansel et al. 1994)

E = Waste generation rate (pounds per square foot) for a house with a crawl space foundation (Franklin Associates 1998 and Tansel et al. 1994)

F = Waste generation rate (pounds per square foot) for a house with a basement (Franklin Associates 1998 and Tansel et al. 1994)

G = Waste generation rate (pounds per square foot) of waste for multi-family building (Townsend, 1998)

χ = Percentage of units demolished that are wood-frame single-family homes with a concrete slab foundation (Sitter 2001 and from the demolition contractor survey)

δ = Percentage of units demolished that have are wood-frame single-family homes with a concrete slab foundation (Sitter 2001 and from the demolition contractor survey)

ε = Percentage of units demolished that have a crawl space foundation (from the demolition contractor survey)

ϕ = Percentage of units demolished that have a crawl space foundation (from the demolition contractor survey)

γ = Percentage of units demolished that are multi-family buildings (from the demolition contractor survey)

$$\text{Waste generated} = \frac{(\$34{,}580{,}434 \times 0.28)}{\$2.73/\text{ft}^2} \times \left[\begin{array}{l} (92.9\ \text{lbs/ft}^2 \times 0.14) + (193.6\ \text{lbs/ft}^2 \times 0.57) + \\ (44.5\ \text{lbs/ft}^2 \times 0.17) + (153.2\ \text{lbs/ft}^2 \times 0.01) + \\ (127\ \text{lbs/ft}^2 \times 0.12) \end{array}\right]$$

$$= 260{,}000\ \text{tons}$$

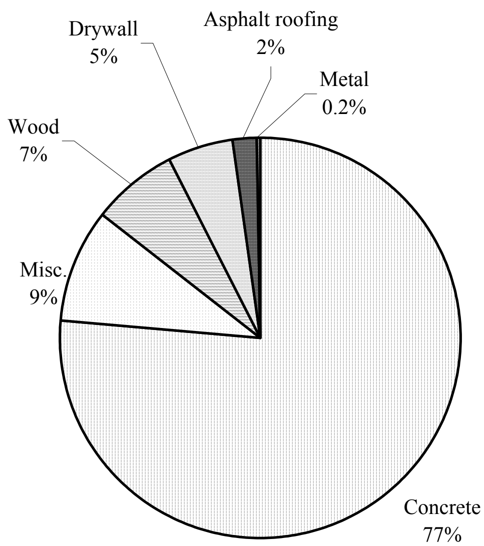


Figure 5.1. Estimated Composition by Weight of the Debris From Residential Demolition Activity.

5.4 NONRESIDENTIAL DEMOLITION

The method for calculating the waste generated from nonresidential demolitions in Florida annually is very similar to that used to calculate the annual waste generation from residential demolitions in Florida. The difference is that this calculation does not involve multiple foundation types as in the residential demolition calculation, due to a lack of data. Again, there are no data that describe the amount spent on nonresidential demolition work. A figure of 72% of the total value of demolitions in Florida was again inferred from the demolition contractor surveys for the value of nonresidential demolitions in Florida. Equation 5.5 presents the calculation used to find the total waste generation for nonresidential demolitions. A total of 900,000 tons was tabulated.

Calculation of the annual nonresidential demolition waste generation in Florida.

$$Q = \left[\frac{(A \times \alpha)}{B}\right] \times C \qquad \textbf{(5.5)}$$

where:

Q = Amount of waste generated

A = Total value of all demolition work in Florida, 1997 (U.S. Census Bureau, 2000)

α = Percentage of all demolitions that are nonresidential in Florida (from the demolition contractor survey)

B = Average cost per square foot for nonresidential demolition (from the demolition contractor survey)

C = Amount of waste generated per square foot (Townsend, 1998)

$$\text{Amount of waste generated} = \left[\left(\frac{\$34{,}580{,}434}{\$2.39 \text{ per sq ft}}\right) \times 0.72\right] \times 173 \text{ lb/sq ft} = 900{,}000 \text{ tons}$$

5.5 RESIDENTIAL RENOVATION

5.5.1 Residential Renovation Components

The State of Florida does not keep track of how many jobs of each type of renovation work are performed in a year. Even if it did, it would be impossible to lump all types of renovations together as they are vastly different and produce different amounts and types of wastes. A sum of the amounts of wastes from each type of renovation activity can best determine the amount of total waste. These activities include alterations, additions, roof replacements, and driveway replacements. Table 5.2 describes each of these renovation activities. Equation 5.6 presents an equation used to calculate the amount of waste produced from residential renovations. This section is broken into four sub-sections, each describing an equation used to calculate the waste from each renovation activity.

Table 5.2. Description of renovation activities.

Renovation Activity	Description
Additions	Any construction that adds a previously non-existing room or building onto a currently existing building.
Alterations	Any activity that changes the interior or exterior structure of a building or house.
Driveway Replacements	The complete removal and replacement of a driveway.
Roof Replacements (Re-roofs)	The removal and replacement of roofing material without removing the interior roofing structure of a building or house.

Calculation of the annual residential renovation waste generation in Florida.

$$Q = A + B + C + D \qquad \textbf{(5.6)}$$

where:

Q = Amount of waste generated (tons)

A = Amount of waste generated from additions (tons)

B = Amount of waste generated from alterations (tons)

C = Amount of waste generated from driveway replacements (tons)

D = Amount of waste generated from roof replacements (tons)

5.5.2 Method of Extrapolation Used for Residential Renovation Estimate

Data on each of the four residential renovation sections could not be gathered from the entire state. Thus, data were collected from 11 building permit offices (see Table 5.3). These values were extrapolated for the entire state. Two choices were available for extrapolation: population and new residential construction value. Equation 5.7 is a basic description of the calculation used for the extrapolations. The resulting extrapolated values are presented for each sector in Table 5.4 for both methods. Residential construction value is a good indicator as it shows the activity of the construction industry. It is assumed that the population of an area underestimates the amount of activity that actually occurs. Thus, the value of residential construction in these areas was chosen to extrapolate numbers in this section and in following sections. The residential construction values were taken from the U.S. Census Bureau's website.

Basic equation used for the extrapolation calculations:

(5.7)

$$\begin{bmatrix}\text{Level of renovation}\\ \text{activity in Florida}\end{bmatrix} = \begin{bmatrix}\text{Value of residential}\\ \text{construction in Florida}\end{bmatrix} \times \left[\frac{\sum \begin{matrix}\text{Level of renovation activity}\\ \text{in a selected region}\end{matrix}}{\sum \begin{matrix}\text{Value of residential construction}\\ \text{in a selected region}\end{matrix}}\right]$$

Table 5.3. Counties and municipalities where building-permit data were gathered for extrapolation calculations.

County	City
Escambia	Pensacola
Dade	Tallahassee
Hillsborough	Orlando
Leon	Tampa
Lee	Jacksonville
Orange	

Table 5.4. Extrapolated values used in the residential renovation waste estimates.

Activity	Variable	Extrapolated Value Using Residential Construction Value Data	Extrapolated Value Using Population Data
Additions	Number of additions in Florida in 2000	51,704	35,824
Alterations	Area of alterations in Florida in 2000	79,086,189	59,232,439
Driveway replacements	Number of driveway replacements in Florida in 2000	8,051	8,256
Roof replacements	Number of roof replacements in Florida in 2000	152,442	87,066

5.5.3 Residential Additions

In order to calculate the amount of waste from additions, a similar calculation to the one used in the residential construction calculation was employed here. Instead of using the value of residential additions, a value for the estimated number of additions in Florida in 2000 was used. Again, this is because the data for the area of residential additions are not readily available. The number of additions was extrapolated using data gathered from building permit offices for unincorporated Dade, Escambia, Lee, Leon, and Orange counties and for the cities of Orlando and Tampa. The total number of additions was multiplied by a ratio of the total value of residential construction in Florida in 2000 ($17,462,411,000) to the value of residential construction for these areas. Table 5.5 lists the data collected from building permit offices as well as the value of residential construction for the same regions.

Table 5.5. Number of additions in selected counties and their respective value of residential construction.

County	Number of Additions (2000)	Value of Residential Construction (2000)
Dade	1,282	$697,706,026
Escambia	322	$124,548,970
Lee	671	$1,013,677,907
Leon	233	$76,253,442
Orange	1,697	$613,110,817
Tampa	750	$246,613,984
Orlando	34	$81,964,569
Total	*4,989*	*$2,853,875,715*

Next, the average area for additions is multiplied by the extrapolated number of additions. The average area of additions was also found from the building permit data collected. The mass of waste per area for both concrete block and wood frame additions here is the same as that used for the residential construction equation (see Section 5.1). The percentage of wood frame additions versus the percentage of concrete block frame additions is also assumed to be the same as that of residential construction. Equation 5.7 details the calculation of the amount of waste from residential additions.

Calculation of the annual waste generated from residential additions

$$A = E \times F \times [(G \times \gamma) + (H \times \eta)] \tag{5.7}$$

where:

A = Annual amount of waste generated from residential additions (tons)

E = Estimated number of additions in Florida in 2000 (extrapolated from building permit data)

F = Average area per addition (ft^2)

G = Waste amount per area for wood frame additions (lb/ft^2)

γ = Percentage of the additions in Florida that are wood frame (Sitter 2001)

H = Waste amount per area for concrete block frame additions (lb/ft^2)

η = Percentage of the additions in Florida that are concrete block frame (Sitter 2001)

$$\text{Amount of waste} = 51{,}704 \times 634 \times [(4.32 \times 0.44) + (8.95 \times 0.56)] = 130{,}000 \text{ tons}$$

5.5.3 Residential Alterations

The alterations category includes improvements and repairs of buildings. The method performed for the nation estimated the number of alterations in the country, dividing this category into kitchens (major and minor improvements) and bathrooms (major and minor improvements). Since there is no way to estimate the number of kitchen and bathroom renovations in Florida, a different method must be developed.

A composition study, "Residential Remodeling Waste Reduction Demonstration Project," performed for the METRO Solid Waste Department in Portland, Oregon gave some insight into the composition waste mass per area of alteration waste. The variable *K* represents this waste generation below in Equation 5.8. The area of alterations was supplied by building permit offices for unincorporated Dade, Escambia, Lee, Leon, Orange, and Hillsborough counties and for the cities of Pensacola and Tampa. Table 5.6 lists these data. The total area of alterations from these regions was then extrapolated to the entire state to determine a value of area for alterations for the entire state. To extrapolate these data, the area was multiplied by a ratio of the total value of residential construction in Florida ($17,462,411,000) in 2000 to the residential construction value for these select areas. The residential construction values were taken from the U.S. Census Bureau's website. Residential construction value is a good indicator as it shows the activity of the construction industry. Table 5.5 also lists the residential construction value for these areas. Equation 5.8 was used to calculate the amount of waste generated from alterations. The variable *J* represents the estimated area of alterations in Florida.

Table 5.6. Summary of county data used to extrapolate the total area of alterations in Florida.

County	Area of Alterations (ft^2)	Value of Residential Construction
Dade	278,665	$697,706,026
Escambia	34,689	$124,548,970
Lee	189,674	$1,013,677,907
Leon	29,753	$76,253,442
Orange	262,472	$613,110,817
Pensacola	41,911	$12,157,849
Hillsborough	2,686,681	$722,241,752
Tampa	719,918	$246,613,984
Total	*4,243,763*	*$3,506,310,747*

Calculation of the annual waste generated from residential alterations.

$$B = J \times K \qquad \textbf{(5.8)}$$

where:

B = Annual amount of waste generated from residential alterations (tons)

J = Estimated area of alterations in Florida (ft^2)

K = Average waste generation per area for alterations (lb/ft^2), (O'Brien & Associates and Palermini & Associates 1993)

$$\text{Amount of waste} = 79{,}086{,}189 \times 14.18 = 560{,}800 \text{ tons}$$

5.5.4 Driveway Replacements

The number of driveway replacements in the nation was extrapolated in the national estimate by estimating the total number of driveways in the U.S. and multiplying that by the percentage that might be replaced. Instead, for the estimate for Florida, an extrapolation of the number of driveways replaced from building permit data was multiplied by the average amount of concrete removed from a driveway. The calculation of the amount of concrete removed is performed in the national estimate. The number of driveways replaced in Florida was calculated by multiplying the number of driveways replaced in unincorporated Hillsborough County by a ratio of the value of residential construction in Florida ($17,462,411,000) to the value of residential construction in Hillsborough County ($722,241,752). Equation 5.9 was used to calculate the amount of waste from driveway replacements.

Calculation of the annual waste generated from residential driveway replacements.

$$C = L \times M \qquad \textbf{(5.9)}$$

where:

C = Annual amount of waste generated from residential driveway replacements (tons)

L = Estimated number of driveways replaced in Florida

M = Estimated amount of concrete disposed from a driveway replacement (tons/job), (Franklin and Associates 1998)

$$\text{Waste Amount} = 8{,}051 \times 8.99 = 72{,}400 \text{ tons}$$

5.5.5 Roof Replacements

In order to determine the amount of waste from roof replacements, it was important to determine the percentage of the total amount of building materials used in roof replacements that are represented by each type of roofing material. Roofing materials have different weights and determining the percentage represented by each material will have an affect on the end result. The National Association of Roofing Contractors (NARC) publishes an annual report on the percentage of roofing materials used in the U.S. In this report, Florida is represented as a part of the South Atlantic[2]. Table 5.7 lists a summary of their findings.

[2] South Atlantic includes Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, Washington D.C., and West Virginia.

Table 5.7. Summary of roofing materials usage in the South Atlantic (NARC 2001).

Roofing Material	Percentage of Market
Metal	24.0%
Clay tile	1.3%
Concrete tile	8.4%
Fiberglass asphalt shingle	40.0%
Organic asphalt shingle	0.0%
Wood shingle/shake	4.4%
Slate	6.1%

The National Association of Home Builders (NAHB) Research Center also collects data on building materials, but narrows their findings down to each state. The NAHB Research Center conducts an annual survey of builders across the country. This report describes the types of roofing materials used for roof replacements in the South Atlantic region. The NAHB Research Center estimates are used in Equation 5.10. Table 5.8 describes amounts used for each type of material. It is important to note that concrete tile and clay tile are not listed due to fact that these materials do not have to be replaced often, if at all. It is also a relatively new building material, so replacements are not usually warranted at this point in time.

Table 5.8. Materials used for roof replacements in Florida in 2000 (NAHB Research Center, Inc, 2001).

Material	Percentage of the total
Asphalt shingles	71%
Metal	10%
Other	19%
Total	*100%*

Calculation of the annual waste generated from residential roof replacements.

$$D = N \times O \times [(P \times \pi) + (R \times \rho)] \quad \textbf{(5.10)}$$

where:

D = Annual amount of waste generated from residential roof replacements (tons)

O = Average area of a roof (ft^2)

P = Weight of asphalt shingles per area (lb/ft^2)

π = Percentage of roof replacements that have asphalt shingles (NAHB Research Center, Inc. 2001)

R = Weight of metal shingles per area (lb/ft^2)

ρ = Percentage of roof replacements that have metal shingles (NAHB Research Center, Inc. 2001)

$$\text{Amount of waste generated} = 152{,}442 \times 1{,}500 \times \left[(2.4 \times 0.71) + (0.64 \times 0.10)\right] = 200{,}000 \text{ tons}$$

5.6 NONRESIDENTIAL RENOVATION

5.6.1 Nonresidential Renovation Components

The same method used to estimate the amount of residential renovation waste is used here. Nonresidential renovation activity was broken down into three sub-activities: additions, alterations, and roof replacements. Table 5.9 describes each of these activities. Equation 5.11 was used to calculate this value.

Calculation of the annual nonresidential renovation waste generation in Florida

$$Q = A + B + C \qquad \textbf{(5.11)}$$

where:

Q = Amount of waste generated

A = Amount of annual waste from nonresidential additions

B = Amount of annual waste from nonresidential alterations

C = Amount of annual waste from nonresidential roof replacements

5.6.2 Method of Extrapolation Used for Nonresidential Renovation Estimate

Again, data on each of the three nonresidential renovation sections could not be gathered from the entire state. Thus, data were collected from building permit offices (see Table 5.10). These values were extrapolated for the entire state. Two choices were available for extrapolation; population and new residential construction value. The resulting extrapolated values are presented for each sector in Table 5.9 for both methods. The new construction value was selected for all extrapolated numbers. Residential construction value is a good indicator as it shows the activity of the construction industry. Population data were also thought to be an indicator of construction activity. It is assumed that the population of an area underestimates the amount of activity that actually occurs. Thus, the value of residential construction in these areas was chosen to extrapolate numbers in this section and in following sections. The residential construction values were obtained from the U.S. Census Bureau's website. The calculations were used to determine the extrapolated values found in Cochran 2001.

Table 5.9. Extrapolated values used in the nonresidential renovation waste estimates.

Activity	Variable	Extrapolated Value
Additions	Area of additions in Florida in 2000	20,174,147
Alterations	Area of alterations in Florida in 2000	132,233,549
Roof replacements	Area of roof replacements in Florida in 2000	91,538,834

5.6.3 Nonresidential Additions

A similar method to the residential addition waste generation calculations was used for nonresidential addition waste. First the total area of nonresidential additions in Florida for the year 2000 was estimated by gathering building permit data from selected regions in the state and extrapolating the data to the entire state. The area of nonresidential additions was multiplied by a ratio of the residential construction value for the state to the residential construction value for the regions. Table 5.10 lists all of the building permit data and residential construction value for the selected regions. The bolded values were extrapolated.

This estimated area of nonresidential additions was then multiplied by the percentage of homes that have a wood frame and the waste generation rate for wood frame nonresidential construction. The same process is then repeated for concrete block frame nonresidential additions. This waste amount for wood frame nonresidential additions is then added to the waste amount from concrete block frame nonresidential additions to produce the total waste amount for nonresidential additions. Equation 5.12 was used to determine the amount of waste from nonresidential additions in Florida in 2000.

Table 5.10. Nonresidential additions building permit data gathered from various county or municipal building permit offices in the state.

Region	Total Area of Nonresidential Additions (ft^2)	Residential Construction Value
Dade County*	570,744	$697,706,026
Escambia County*	111,461	$124,548,970
Lee County*	1,217,908	$1,013,677,907
Leon County*	28,661	$76,253,442
Orange County*	904,432	$613,110,817
City of Tampa	369,155	$246,613,984
Total	*3,202,361*	*$2,771,911,146*
State of Florida	**20,174,147**	$17,462,411,000

*unincorporated

Calculation of the annual waste from nonresidential additions in Florida.

$$A = D \times [(E \times \varepsilon) + (F \times \phi)] \qquad \textbf{(5.12)}$$

where:

A = Annual amount of waste generated from nonresidential additions (tons)

D = Estimated total area of nonresidential additions in Florida in 2000 (lb/ft^2)

E = Waste generation per area of a wood frame addition (lb/ft^2)

ε = Percentage of additions that have a wood frame (Sitter 2001)

F = Waste generation per area of a concrete block frame addition (lb/ft^2)

ϕ = Percentage of additions that have a concrete block frame (Sitter 2001)

$$\text{Amount of waste} = 20{,}174{,}147 \times [(2.47 \times 0.20) + (9.67 \times 0.80)] = 83{,}000 \text{ tons}$$

5.6.4 Alterations

A similar method to the nonresidential additions method was applied to nonresidential alterations. Again, the building permit data were collected from selected regions in the state and residential construction values for the regions and for the state were used to extrapolate the total area of alterations for the state. Table 5.11 lists these sets of data. Again, the values in bold were extrapolated. Once the total area of alterations was determined, it was then multiplied by the weight of waste per area of alteration. This value was determined by averaging the weight of waste per area of alteration of three separate nonresidential alterations (see Section 2.5.4). Table 5.12 lists the data from the three composition studies. Equation 5.13 was used to calculate the amount of waste generated from nonresidential alterations.

Table 5.11. Nonresidential alterations building permit data from selected regions of the state.

Region	Area of Alterations (ft^2)	Residential Construction Value
Dade County*	7,351,668	$697,706,026
Escambia County*	322,091	$124,548,970
Lee County*	917,207	$1,013,677,907
Leon County*	99,512	$76,253,442
Orange County*	8,728,824	$613,110,817
City of Pensacola	139,312	$12,157,849
City of Tampa	3,523,659	$246,613,984
Total	*21,082,273*	*$2,784,068,995*
Florida	**132,233,549**	$17,462,411,000

*unincorporated

Table 5.12. Summary of nonresidential addition composition studies (McGregor et al. 1993).

Alteration Project	Total waste (lbs)	Area (ft^2)	Weight of waste per area (lbs/ft^2)
Richard White	12,714	1,500	8.48
Lincoln Center #1	5,400	2,825	1.91
Lincoln Center #2	9,200	4,895	1.88
Average	9,105	3,073	4.09

Calculation of the annual waste generation from nonresidential alterations.

$$B = G \times H \quad \textbf{(5.13)}$$

where:

B = Annual amount of waste generated from nonresidential alterations (tons)

G = Estimated area of nonresidential alterations in Florida in 2000 (ft^2) (extrapolated from building permit data)

H = Waste generation per area of alteration (lb/ft^2)

$$\text{Amount of waste} = 132{,}233{,}549 \times 4.09 = 270{,}000 \text{ tons}$$

5.6.5 Roof replacements

Low-slope roof replacements are work intensive and expensive. This activity generates great amounts of waste. The entire roof system must be replaced down to the structural system of the roof. To calculate the amount of waste generated from low-slope roof systems, it is first important to determine the materials used in these roofing systems. The percentage of these materials used in Florida was determined from the NARC, which only summarized data for the South Atlantic, not specifically for Florida (NARC study 2001). To calculate the amount of waste generated, the total square footage of nonresidential roofing replacements was multiplied by the weight of roofing material per square foot. These weights were also determined from the NARC study (NARC 1993). The individual weights were multiplied by the percentage used in the South Atlantic. Equation 5.14 presents this calculation.

Calculation of the annual waste generation from nonresidential roof replacements.

(5.14)

$$C = J \times \left[(K \times \kappa) + (L \times \lambda) + (M \times \mu) + (N \times \nu) + (O \times o) + (P \times \pi) + (Q \times \theta) + (R \times \rho) \right]$$

where:

C = Annual amount of waste generated from nonresidential roof replacements (tons)

J = Estimated total area of nonresidential re-roofing jobs in Florida (ft^2)

K = Waste generation per area of built-up asphalt roofing (lb/ft^2) (NARC 1993)

κ = Percentage of nonresidential re-roof jobs that are built-up asphalt roofing (NARC 2001)

L = Waste generation per area of asphalt shingles (lb/ft^2) (NARC 1993)

λ = Percentage of nonresidential re-roof jobs that use asphalt shingles (NARC 2001)

M = Waste generation per area of EPDM roofing (lb/ft^2) (NARC 1993)

μ = Percentage of nonresidential re-roof jobs that use EPDM roofing (NARC 2001)

N = Waste generation per area of SBS-modified bitumen roofing (lb/ft^2) (NARC 1993)

ν = Percentage of nonresidential re-roof jobs that use SBS-modified bitumen roofing (NARC 2001)

O = Waste generation per area of APP-modified bitumen roofing (lb/ft^2) (NARC 1993)

o = Percentage of nonresidential re-roof jobs that use APP-modified bitumen roofing (NARC 2001)

P = Waste generation per area of CSPE roofing (lb/ft^2) (NARC 1993)

π = Percentage of nonresidential re-roof jobs that use CSPE roofing (NARC 2001)

Q = Waste generation per area of PVC roofing (lb/ft^2) (NARC 1993)

θ = Percentage of nonresidential re-roof jobs that use PVC roofing (NARC 2001)

R = Waste generation per area of other single pile roofing (lb/ft^2) (NARC 1993)

ρ = Percentage of nonresidential re-roof jobs that use other single pile roofing (NARC 2001)

$$\text{Waste Amount} = 91{,}538{,}834\ \text{ft}^2 \times \begin{bmatrix} (6.0\ \text{lb/ft}^2 \times 0.37) + (2.4\ \text{lb/ft}^2 \times 0.15) + (4.7\ \text{lb/ft}^2 \times 0.17) + \\ (4.8\ \text{lb/ft}^2 \times 0.20) + (5.2\ \text{lb/ft}^2 \times 0.06) + (4.7\ \text{lb/ft}^2 \times 0.01) + \\ (4.7\ \text{lb/ft2} \times 0.02) + (5.0\ \text{lb/ft}^2 \times 0.02) \end{bmatrix}$$

$$= 220{,}000\ \text{tons}$$

6.0 RESULTS OF FLORIDA C&D DEBRIS GENERATION ESTIMATE

DISCUSSION OF THE GENERATION AND COMPOSITION OF ALL JOB ACTIVITIES

Totaling the results from all of the equations in this chapter, C&D waste generated in 2000 was approximately 4.22 million tons. Table 6.1 lists the totals for each of the job activities and for each waste component. Figure 6.1 depicts the composition of the entire building-related C&D debris waste stream as estimated in this chapter. Figure 6.2 depicts the sources of the C&D debris as estimated in this chapter.

Table 6.1. Summary of the estimated waste generation from all job activities.

Component	Res.Const.	Nonres. Const.	Res. Demo.	Nonres. Demo.	Res. Reno.	Nonres. Reno.	Total
Concrete	520,000	340,000	200,000	730,000	315,600	224,000	*2,329,600*
Wood	210,000	54,000	18,000	1,700	210800	64,900	*559,400*
Drywall	140,000	56,000	13,000		82,990	178,800	*470,790*
Misc.	44,330	58,000	23,900	120,000	120,711	49,100	*416,041*
Cardboard	33,000	3,600			10,461	570	*47,631*
Asphalt roofing materials	37,000		5,400		196,193	44,000	*282,593*
Metal	22,000	15,000	470	47,000	14,012	16,300	*114,782*
Total	*1,006,430*	*526,600*	*261,670*	*898,700*	*950,767*	*577,670*	***4,221,837***

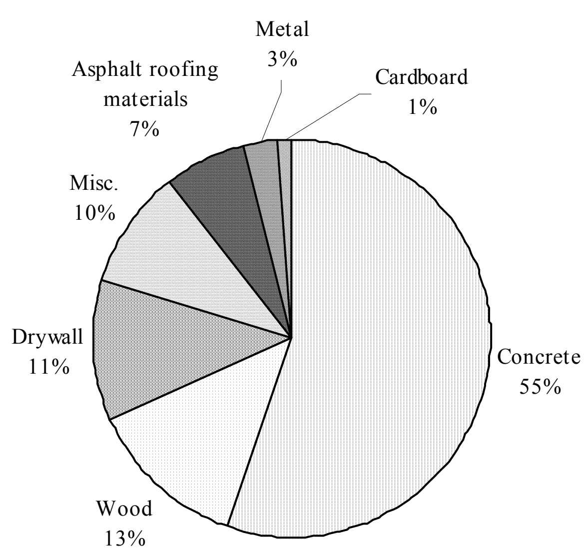


Figure 6.1. Estimated composition by weight of C&D debris in Florida in 2000 by component.

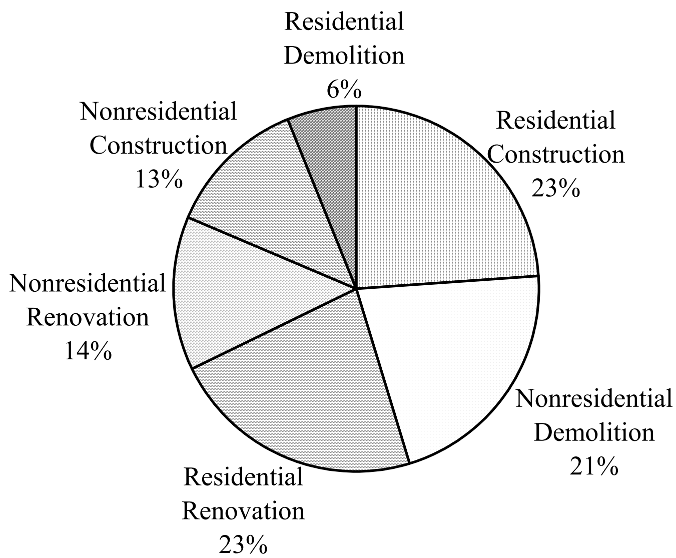


Figure 6.2. Estimated composition by weight of C&D debris in Florida by job activity.

Generation Comparison

Figures 6.3 and 6.4 depict the per capita per day waste generation for the U.S. and Florida. In Figure 6.3 there are two generation columns for Florida, one representing the data collected by the FDEP and one representing the data estimated in this report. The waste generation for the U.S. is the highest, followed by the generation reported by FDEP. The reason the FDEP's waste generation rate is much higher than that in this report is that the FDEP accounts for land clearing and other wastes that are collected by Class III facilities. Class III facilities collect approximately 500,000 tons of waste per year. This entire amount is included as C&D debris, although not much of the waste stream is building-related C&D debris.

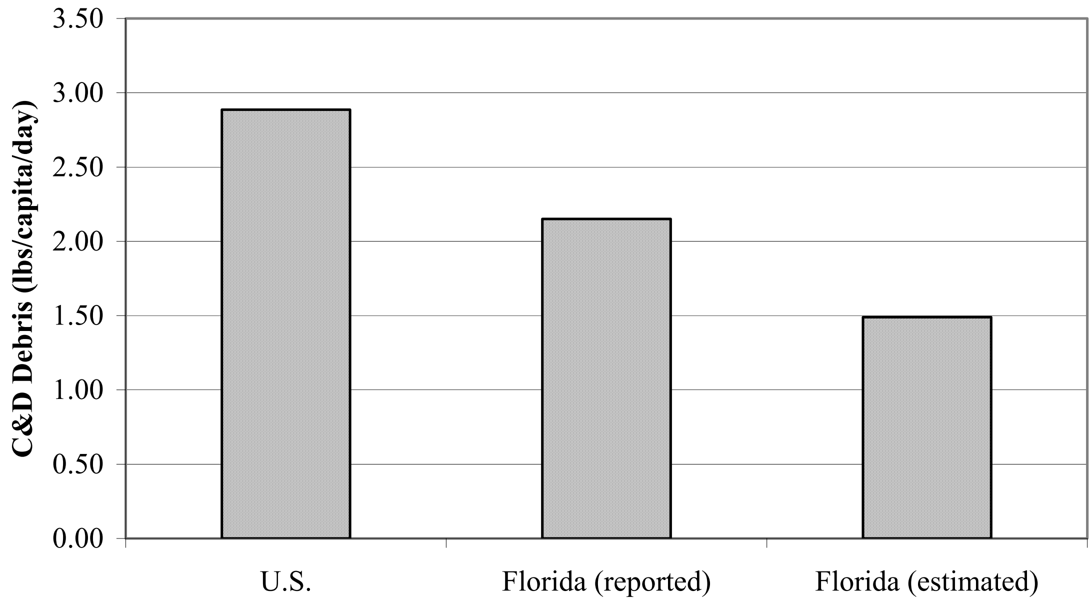
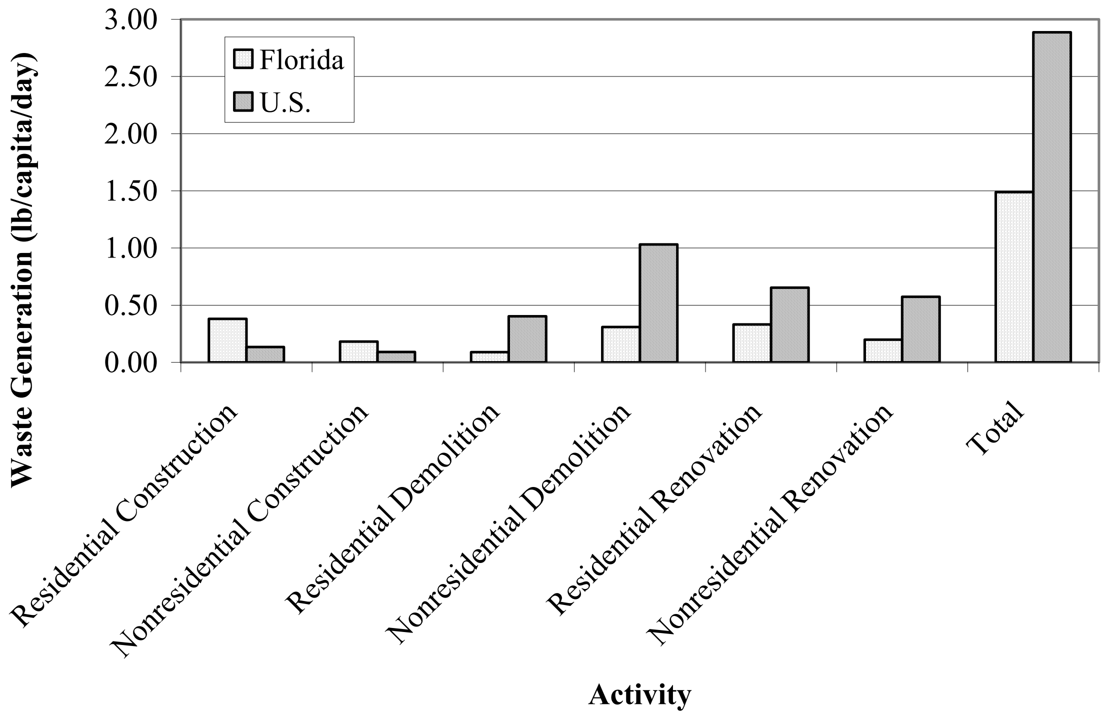


Figure 6.3. Comparison of C&D debris generation in the nation and in Florida (Franklin and Associates 1998 and FDEP 2000).

Figure 6.3 depicts the waste generation (pounds per capita per day) for the nation as well as for the estimate for Florida. The waste generation for the nation is larger except in residential construction and nonresidential categories. Florida has a large growth rate and, therefore, the waste from construction is considerable. Florida does not have an extensive amount of old structures that need to be renovated or demolished due to new growth. There is still plenty of room for expansion and the old buildings are not replaced frequently. This is not the case in many parts of the U.S. The amount of waste per capita will be larger for renovation and demolition activities than in Florida.



Fgure 6.4. Comparison of the waste generation (lb/capita/day) for the national estimate and the Florida estimate (Franklin andAssociates 1998).

SECTION III

C&D DEBRIS COMPOSITION IN FLORIDA

7.0 METHODS FOR ESTIMATING C&D DEBRIS COMPOSITION

Many different studies have been carried out in an attempt to better understand the C&D waste stream and its management. This section discusses different methodology used for studying C&D waste composition.

7.1 MATERIAL BALANCE

The main objective of the study was to develop a methodology to characterize and estimate generation rate of C&D waste using the USEPA material flow methodology used for MSW characterization. The main benefit of such a methodology was to use readily available national data and periodic updates. The materials flow methodology uses the national production data by material and product, adjusts for imports, exports, average lifetimes, and consumption, and then calculates national generation by summing up all the materials and products that make up MSW. Because of variable lifetime of buildings and natural calamities that cause sudden increase in the waste stream it was not practical to use the materials flow methodology for C&D debris.

Another methodology that was investigated during this study was waste sampling and weighing waste at landfills. This method, if used, would give fairly accurate results. However, there were a few shortcomings of the method. Sampling from a mixed waste stream with statistical confidence is very difficult, time consuming and costly. Another challenge with applying this method on a national basis was to locate all the facilities that accept C&D waste, and conduct such a study, which was again beyond of the scope of the project. Obtaining permission to sample at a private landfill is also problematic. Therefore the methodology used for this study combines national census data with point source waste assessment data (i.e. waste sampling and weighing at a variety of construction and demolition sites) to estimate the amount of C&D debris produced nationally (Franklin and Associates, 1998 a).

There is a significant difference in the definition of C&D debris from state to state; therefore the first objective of the study was to define C&D waste in a broad way. Table 7.1 provides the definition of C&D waste used in this study. Based on this definition of C&D waste periodical update of the amount of C&D waste generated in each state can be reported and used for calculation of generation rate of C&D waste in the United States.

Table 7.1. Representative Generation Sources of C&D Sector Material.

Site clearance materials *	Brush, tree, and stumpage material
Excavated material *	Earth, fill, and other excavated rock and granular materials
Roadwork materials *	Concrete slabs and chunks, asphalt chunks and millings from bridge/ overpass construction and renovation materials
New construction material	Residential, commercial and industrial project sources
Renovation, remodeling and repair materials	Residential, commercial, and industrial project sources
Demolition materials	Residential, commercial, and industrial project source
Disaster debris *	All of the above

* Estimates from site clearance, excavated materials, disaster debris and roadwork materials are not included in this report.

Adapted From: Greshman, Brickner & Bratton, Inc. Fairfax, Virginia

7.2 MASS SORTING OR PHYSICAL SORTING

Mass sort is the process of estimating the composition of C&D waste by actually measuring the weight of the waste stream. In this method, loads are chosen randomly at a landfill and are characterized into different components and weighed to get a mass characterization of C&D waste. Usually five or sixpeople are required to conduct such study.

In a study conducted by Casacadia Consulting Group ("Waste Stream Composition Study," Cascadia Consulting Group 1997) C&D waste was divided into 124 different components and mass sorting was used to characterize C&D waste. Although this method is best to characterize C&D waste and estimate composition, because of the amount of time and labor required in most cases it is not feasible to use it.

7.3 VISUAL CHARACTERIZATION

Visual characterization (VC) is the process of estimating the volume composition of a C&D waste load by observing the load at the landfill and estimating the percent volume distribution by visual observation. Usually two or three researchers are needed to estimate the percent distribution of a waste load using visual characterization and the average is used as the volume distribution.

In a study performed by Townsend (2000), characterizations for 171 loads were analyzed. Both volume and weight of C&D waste were measured. Visual characterization was also performed during the study. Waste loads were distributed among 14 different components comprised of waste produced from construction, demolition and renovation of residential and commercial buildings. A similar approach was used in the study reported here. If enough data are available this can be a very reliable and economic solution to characterize and estimate C&D waste.

7.4 PHOTOGRAMMETRY STUDY

Photogrammetry is defined as "the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images (Slama et al. 1980)". Photogrammetry is divided into two categories, metrical photogrammetry and photo interpretation, based on the type of analysis or interpretation required. Metrical photogrammetry deals with quantitative measurements obtained from a photograph. For example, this type of photogrammetry is used for determining the distance between two landmarks on an aerial photograph. Photo interpretation deals with the qualitative analysis of photographs. Here, the focus is on interpretation and identification of images. For example, this type of photogrammetry is used for identifying potential military targets from an aerial photograph of enemy territory (Slama et al. 1980). The photogrammetric analysis technique used in this study is a combination of both metrical photogrammetry and photo interpretation.

7.5 METHODOLOGY SELECTION

In this report, three techniques were used to evaluate waste composition. The first was based on literature values and the generation study described in Chapter 5. The second approach used visual characterization validated with a mass sort. Finally, photogrammetry was used to determine C&D waste composition. These three estimates are described in following chapters.

8.0 C&D COMPOSITION FROM GENERATION STUDY

8.1 RESIDENTIAL CONSTRUCTION

The waste composition was determined by first calculating the mass per area for each component and each job. These amounts for each job were then averaged together by waste component (wood, drywall, concrete, etc.). Table 8.1 lists the amount per square foot of each component that was generated for each wood-frame house. Table 8.2 lists the amount per square foot of each component that was generated for each concrete-frame house. As seen in both of these tables, the average generation for each component is listed on the right-hand-side, while the total weight per square foot per job is listed at the bottom of the table. In both tables, the jobs are labeled by the state the composition study was performed in. In Table 8.1, the labels "OR_1"through "OR_3" refer to the study "Construction Industry Recycling Project" (Palermini & Associates 1993). The labels "OR_4" through "OR_7" refer to the study "Characterization of Construction Site Waste" (McGregor et al 1993). MD_{1-2} and MI refer to "Residential Construction Waste Management Demonstration and Evaluation" (NAHB Research Center 1995). The FL_1 label refers to "Demonstration of Job-Site Separation of Construction and Demolition Waste and C&D Debris Recycling Economics and Job Creation Opportunities in Florida" (Townsend 1998). Finally, in Table 8.2, the FL_2 and FL_3 labels refer to the composition study performed in Citrus County, Florida (Cochran and Townsend 2001). Again the waste generation for drywall in the concrete-bloc-frame housing was reduced to the industry standard of one pound per square foot.

Once the average weight of an individual component per square foot was calculated, these numbers could then used in Equation 5.2 to determine the amount generated for that component. A complete list of the calculations used is in Cochran (2001). A summation of all of the component amounts should equal the number generated in Equation 5.2. The percentage of the total waste for one component can then be determined from these two numbers and a total composition can be estimated. Table 8.2 lists the amount of waste generated from residential construction waste in Florida by component. The categories plastic, brick, and paper were added to the miscellaneous category. Figure 8.1 depicts the estimated composition of residential construction waste.

Table 8.1. Waste generation per building area for each waste component generated from each wood-frame job (pounds per square foot).

Component	OR_1	OR_2	OR_3	MD_1	MD_2	MI	OR_4	OR_5	OR_6	OR_7	FL_1	Avg.
Wood	2.15	3.13	2.27	1.96	1.35	2.04	2.66	3.49	2.65	2.65	2.94	2.48
Drywall	0.92	0.50	1.27	1.22	1.20	1.12	1.48	0.76	0.83	0.95	1.52	1.07
Cardboard	0.07	0.15	0.09	0.19	0.20	0.48	-	-	-	0.11	0.25	0.14
Metal	0.04	0.05	0.05	0.10	0.13	0.11	0.14	-	-	0.02	0.03	0.06
Plastic	0.03	0.01	0.02	0.06	0.03	0.16	-	-	-	-	0.03	0.03
Misc.	0.26	0.06	0.28	0.54	0.22	0.46	0.47	0.25	0.26	0.36	-	0.29
Asphalt roofing materials	-	0.01	-	0.05	0.22	0.30	-	-	-	-	0.30	0.08
Brick	0.11	-	-	0.52	0.51	-	-	-	-	-	-	0.10
Paper	0.09	0.03	0.02	-	-	0.02	-	-	-	-	-	0.02
Concrete	0.01	0.00	0.57	-	-	-	-	-	-	-	-	0.05
Total	*3.68*	*3.94*	*4.56*	*4.64*	*3.85*	*4.69*	*4.75*	*4.50*	*3.74*	*4.09*	*5.06*	*4.32*

Table 8.2. Waste generation per building area for each waste component generated from each concrete-frame job.

Component	FL_2	FL_3	Average
Concrete	3.66	5.72	4.69
Wood	1.04	1.58	1.31
Cardboard	0.27	0.26	0.26
Plastic	0.11	0.09	0.10
Asphalt roofing materials	0.58	0.05	0.32
Metal	0.14	0.23	0.18
Misc.	0.13	0.25	0.19
Drywall	0.98	2.81	1.89[a]
Total	*6.91*	*10.99*	*8.95*

(Yost 1993).

Table 8.3. Summary of the estimated composition of residential construction waste in Florida.

Component	Amount (tons)
Concrete	520,000
Wood	210,000
Drywall	140,000
Miscellaneous	44,330
Asphalt roofing materials	37,000
Cardboard	33,000
Metal	22,000
Total	*1,006,330*

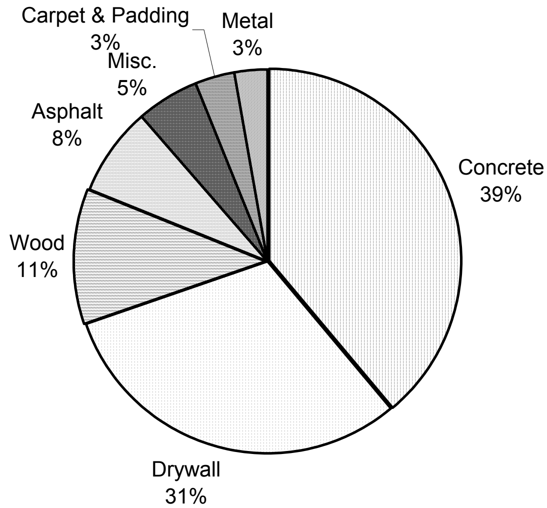


Figure 8.1. Estimated composition by weight of residential construction waste in Florida.

8.2 NONRESIDENTIAL CONSTRUCTION

To calculate the composition of C&D waste generated from nonresidential construction, individual composition studies were again used. These studies included those performed by McGregor et al. (1993) and Townsend (1998). Table 8.4 provides a summary of the waste generation from both of these studies in pounds per square foot. The same equation used for the total waste generation was again used for individual component generation. The waste generation for each component replaces the total waste generation. These calculations are provided in Cochran (2001). Table 8.5 lists the estimated generated amount by component of nonresidential construction waste in Florida in 2000. Figure 8.2 depicts the total composition of nonresidential construction waste in Florida in 2000.

Table 8.4. Summary of waste generation for nonresidential construction (McGregor et al. 1993 and Townsend 1998).

Component	Wood Frame (lbs/ft^2)	Concrete-Block Frame (lbs/ft^2)
Wood	1.49	0.68
Drywall	0.10	1.06
Cardboard	0.28	0.00
Miscellaneous	0.60	0.97
Concrete	0.00	6.68
Metal	0.00	0.29
Total	*2.47*	*9.67*

Table 8.5. Summary of the estimated composition of nonresidential construction waste.

Component	Amount (tons)
Wood	54,000
Drywall	56,000
Miscellaneous	58,000
Cardboard	3,600
Metal	15,000
Concrete	340,000
Total	*526,600*

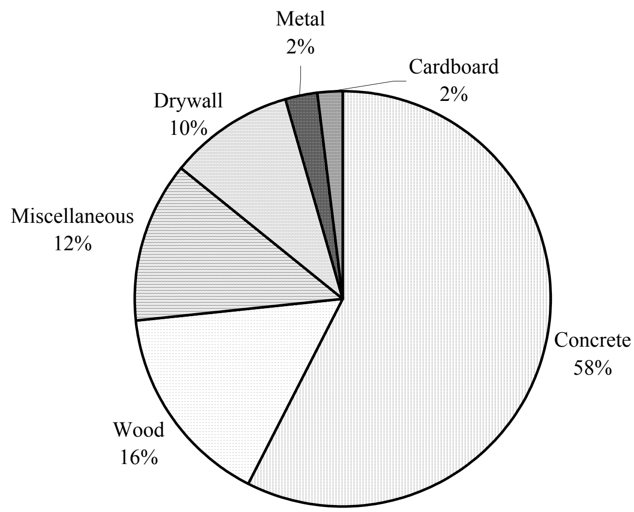


Figure 8.2. Estimated composition by weight of nonresidential construction waste in Florida in 2000.

8.3 RESIDENTIAL DEMOLITION

The composition of residential demolition waste was estimated in a similar manner to both of the construction estimates. As in the generation calculation, the estimates for composition were divided into five building types; wood-frame single family with a concrete slab foundation, concrete-block-frame single family with a concrete slab foundation, wood frame single family with a crawl space, wood-frame single family with a basement, and wood-frame multi-family. The waste mass generation per area for each component of the waste stream was calculated by averaging the waste mass generation per area for each component from each study. Table 8.6 lists these waste generations from each study and their average. These numbers were used in Equation 5.4 in place of the total waste generation numbers (variables C through F). The concrete generation is different for each of the three different foundation types for the single-family homes. These generations were taken from the national estimate and are listed in Table 8.7. See Cochran (2001) for a complete listing of the calculations. Table 8.8 is a summary of the amount of each component generated from residential demolition activity in Florida in 2000. The brick and glass categories were added to the miscellaneous category in Table 8.8.

Table 8.6. Waste Generation (Lb/Ft^2) Data Used.

	Multi-Family (NAHB 1997)	Single Family (Tansel 1994)	
Framing	Wood	Wood	Concrete
Area	2,000 ft^2	-	-
Concrete	66.5	0.0	122.2
Drywall	21.6	5.5	6.0
Brick	17.9	0.0	0.0
Wood	14.4	21.0	3.0
Asphalt shingles	3.5	3.0	3.0
Metals	2.3	0.0	0.0
Miscellaneous	1.0	7.0	3.0
Glass	0.0	8.0	8.0
Total	*127.2*	*44.5*	*145.2*

Table 8.7. Waste generation rate used for the concrete generation calculations from single-family residential demolitions (Franklin and Associates 1998).

Foundation Type	Concrete Generation (lb/ft^2)
Crawl space	0.0
Concrete Slab	48.4
Basement	108.7

Table 8.8. Summary of residential demolition waste generation by component in Florida in 2000.

Component	Amount (tons)
Concrete	200,000
Wood	18,000
Drywall	14,000
Miscellaneous	23,900
Asphalt roofing	5,400
Metal	470
Total	261,670

8.4 NONRESIDENTIAL DEMOLITION

The report "Demonstration of Job-Site Separation of Construction and Demolition Waste and C&D Debris Recycling Economics and Job Creation Opportunities in Florida" also contains a study on a nonresidential demolition (Townsend 1998). The composition of the waste in this study was used here to determine the composition of nonresidential demolition in Florida. Table 8.9 summarizes the waste generation (in pounds per square foot) that was used in this estimate. Table 8.10 presents a summary of the estimated waste amounts for each component. Figure 8.3 is a pie chart depicting the summary composition of nonresidential demolition waste.

Table 8.9. Summary of the Estimated Composition of Nonresidential Demolition Debris.

Component	Waste Amount (lbs/ft^2)
Concrete	140
Miscellaneous	23
Metal	9
Wood	0.32
Total	*173*

Table 8.10. Summary of the Estimated Generation of Nonresidential Demolition Debris.

Component	Amount (tons)
Concrete	730,000
Miscellaneous	120,000
Metal	47,000
Wood	1,700
Total	*898,700*

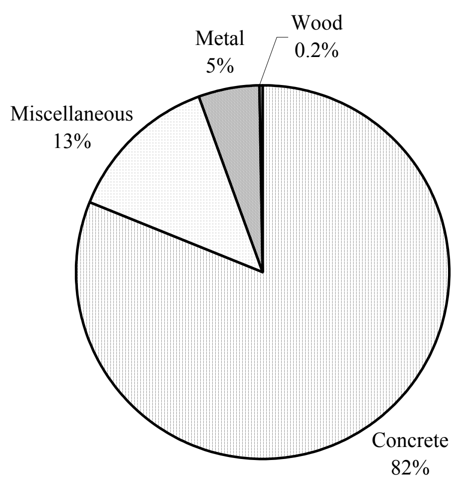


Figure 8.3. Estimated Composition by Weight of Nonresidential Demolition Debris.

8.5 RESIDENTIAL RENOVATION

The same equations used in calculating the amount of waste were also used here in calculating the composition of the waste. The only difference is that the mass of waste per area for the total waste is replaced by the average mass of waste per area for each component. Again, this section is divided into four subsections: additions, alterations, driveway replacements, and roof replacements.

8.5.1 Residential Additions.

The same composition used for both wood frame and concrete block frame additions here in residential construction is used. Section 5.1 describes how the compositions of these structures were determined. The composition of residential addition waste was determined by substituting the total waste generation (in pounds per square foot) with the waste generation for each component. Cochran (2001) presents a complete list of these calculations. Table 8.17 lists the generation amounts of each component of waste from residential additions in Florida in 2000. Figure 8.4 depicts the estimated composition of residential addition waste in Florida in 2000.

Table 8.11. Summary of the Estimated Composition of Residential Additions.

Component	Waste Amount (tons)
Wood	25,000
Drywall	28,000
Miscellaneous	5,291
Cardboard	3,900
Asphalt roofing materials	4,400
Metal	2,600
Concrete	62,000
Total	*120,191*

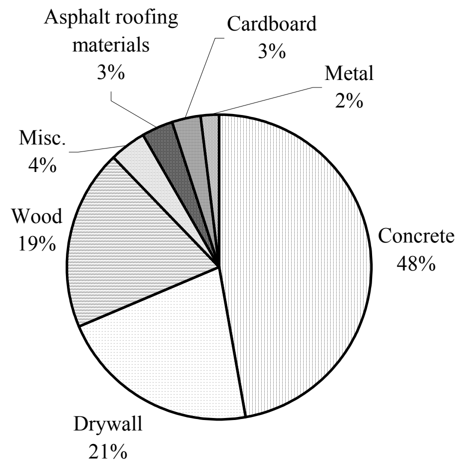


Figure 8.4. Composition by Weight of Residential Addition Waste.

8.5.2 Residential Additions.

The composition of residential alteration waste was extracted from the report "Residential Remodeling Waste Reduction Demonstration Project" (O'Brien & Associates and Palermini & Associates, 1993). Table 8.12 summarizes the mass of waste per area of each component. The averages of these numbers are listed on the left. The composition was determined by substituting the total waste generation rate (pounds per square foot in the generation equation (Equation 5.8) with these averages in Table 8.12. Cochran (2001) presents a complete list of these calculations. Table 8.13 lists the computed generation amounts of waste from residential alterations in Florida in 2000. Figure 8.5 depicts the composition of waste from residential alterations in Florida in 2000.

Table 8.12. Mass of Waste per Area (lb/ft^2) for Each Alteration Job.

Component	Kitchen	Kitchen/Family room	Bathroom	Ave
Wood	1.75	7.25	5.09	4.70
Drywall	0.80	1.18	3.02	1.67
Miscellaneous	0.44	0.76	5.62	2.27
Metal	0.31	0.00	0.00	0.10
Cardboard	0.22	0.00	0.28	0.17
Asphalt shingles	0.14	0.00	0.00	0.05
Plastic	0.13	0.25	0.29	0.22
Concrete	0.00	4.34	9.41	4.58
Tile	0.00	0.22	1.04	0.42
Total	3.80	14.00	24.76	14.18

Table 8.13. Summary of the Estimated Composition of Residential Alteration Debris.

Component	Waste Amount (tons)
Wood	185,800
Drywall	65,990
Misc.	115,420
Metal	4,112
Cardboard	6,561
Asphalt shingles	1,793
Plastic	8,850
Concrete	181,200
Tile	16,640
Total	*560,876*

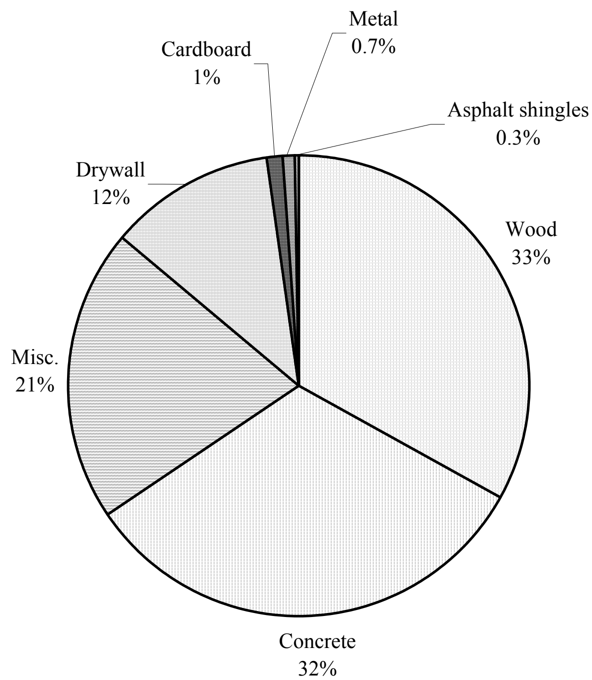


Figure 8.5. Estimated Composition by Weight of Residential Alteration Debris.

8.5.3 Driveway replacements.

The entire composition of waste from driveway replacements can be assumed to consist entirely of concrete with negligible amounts of miscellaneous waste. Therefore, 72,400 tons of concrete were generated from driveway waste. This value was calculated using the same equation used for the generation amount (Equation 5.9) and the entire calculation is presented in Cochran (2001).

8.5.4 Roof replacements.

The composition of waste from roof replacements consists of asphalt shingles, metal shingles, and a negligible amount of miscellaneous waste. The same equation used to calculate the amount of waste (Equation 5.10) is used to calculate the amount of each waste component. The calculation for the amount of asphalt shingles does not include an amount for metal shingles and vice versa. These calculations for the composition are presented in Cochran (2001). Figure 8.6 depicts the estimated composition of residential re-roofing waste.

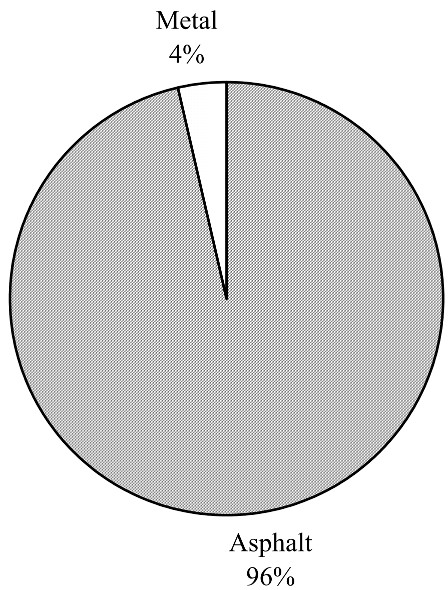


Figure 8.6. Estimated Composition of Residential Re-roofing Waste by Weight.

8.5.5 Summary of All Residential Renovation Activities.

Residential renovation activities produce a range of different waste components and amounts. The waste produced from additions is very similar to that of residential construction due to the similar activity that is conducted. Alterations also produce similar waste components due to the fact that this activity requires the alteration of the structure. Roofing replacements and driveway replacements produce fairly uniform waste streams that can easily be diverted when they arrive at a disposal site. Although roofing renovations, as a whole, produce two different materials, each house only uses one of these materials. Therefore, when a load of roofing replacement waste comes into a disposal site it will be almost entirely one of these materials. Table 8.14 lists the estimated amount of residential renovation waste generated by component and by activity. Figure 8.7 depicts the estimated composition of residential renovation waste by weight.

Table 8.14. Summary of the Estimated Waste Components Generated from Residential Renovation Activities in Florida in 2000.

Component	Additions	Alterations	Roof Replacements	Driveways	Total
Concrete	62,000	181,200	-	72,400	315,600
Wood	25,000	185,800	-	-	210,800
Drywall	17,000	65,990	-	-	82,990
Misc.	5,291	115,420	-	-	120,711
Asphalt roofing materials	4,400	1,793	190,000	-	196,193
Cardboard	3,900	6,561	-	-	10,461
Metal	2,600	4,112	7,300	-	14,012
Total	120,191	560,876	197,300	72,400	950,767

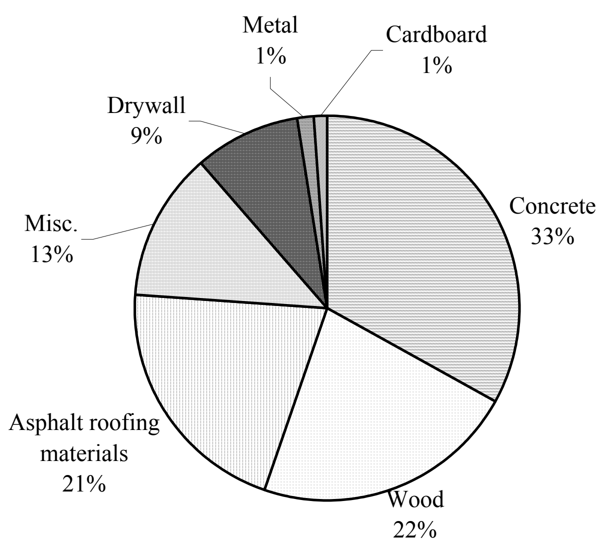


Figure 8.7. Estimated Composition by Weight of Residential Renovation Debris.

5.6 NONRESIDENTIAL RENOVATION

8.6.1 Residential Additions.

The composition of the waste from nonresidential additions was determined using the same composition studies and waste generation rates as that of nonresidential construction waste (see Section 5.3). The individual weight per area of each component substituted the total weight per area of the total waste from additions. This resulted in a generation amount for each component. Table 8.15 is a summary of these generation amounts and Figure 8.8 is an estimated composition of the waste from nonresidential additions.

Table 8.15. Summary of the Composition of Nonresidential Addition Waste.

Component	Amount (tons)
Concrete	54,000
Wood	8,500
Miscellaneous	9,000
Drywall	8,800
Metal	2,300
Cardboard	570
Total	*83,170*

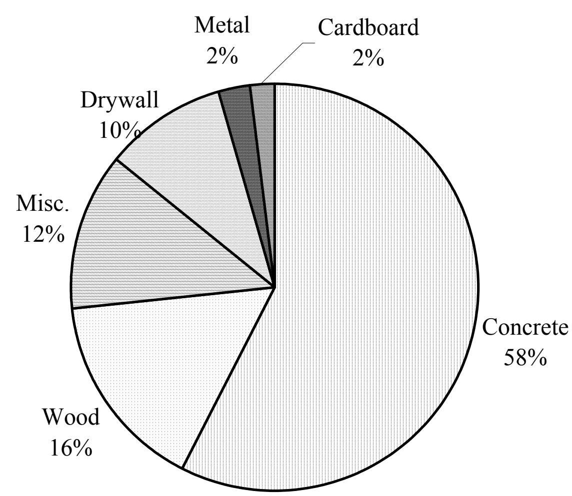


Figure 8.8. Estimated Composition by Weight of the Waste from Nonresidential Additions.

8.6.2 Alterations.

The composition of waste from nonresidential alterations was determined using the same composition studies in the generation calculation for this category. Table 8.16 is a summary of the weight per area for each component. The average amount is listed along the right side. The total area of nonresidential renovations in Florida multiplied this value for each component. A value for the total amount of waste from nonresidential waste resulted. Cochran (2001) presents lists the calculations used to calculate the composition. Table 8.17 summarizes the generation amounts for each component and Figure 8.9 depicts the estimated composition of nonresidential alteration waste.

Table 8.16. Summary of the Waste Weight per Area (lb/ft^2) for Three Nonresidential Alteration Projects.

Component	Richard White	Lincoln Center #1	Lincoln Center #2	Average
Metal	0.63	0.00	0.00	0.21
Wood	2.18	0.19	0.19	0.85
Drywall	5.63	0.86	1.22	2.57
Miscellaneous	0.03	0.19	0.28	0.17
Carpet & Padding	0.00	0.67	0.19	0.29
Total	*8.48*	*1.91*	*1.88*	*4.09*

Table 8.17. Summary of the Estimated Composition of Nonresidential Alteration Debris in Florida.

Component	Waste Amount (tons)
Drywall	170,000
Wood	56,400
Miscellaneous	30,100
Metal	14,000
Total	*270,500*

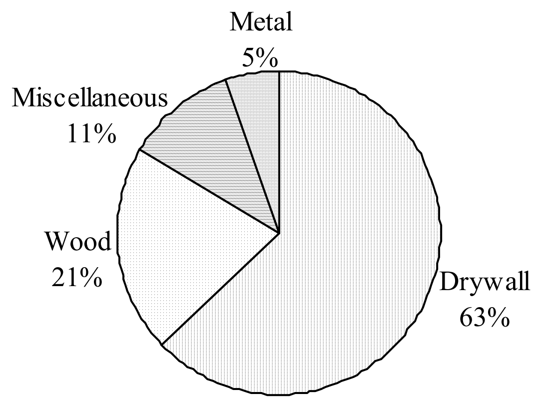


Figure 8.9. Estimated Composition by Weight of the Waste from Nonresidential Alterations.

8.6.3 Roof replacements.

The roofing components fall into three categories: asphalt, aggregate, and other. Here, the aggregate amounts are in the concrete category. All of the roofing systems require an aggregate surfacing. It is assumed that it is removed with the bottom layer if the roof is replaced. Table 8.18 lists the composition of roofing replacements from this estimate. Consult Cochran (2001) for all of the calculations for this section.

Table 8.18. Estimated Composition of Nonresidential Re-roofing Debris in Florida.

Component	Amount (tons)
Miscellaneous	10,000
Asphalt	44,000
Concrete	170,000
Total	224,000

8.6.4 Summary of All Residential Renovation Activities.

The composition of the nonresidential renovation waste varies in composition by activity. The composition of nonresidential addition waste is similar to the composition of nonresidential construction waste. The composition of nonresidential alteration waste is also similar to the nonresidential construction waste, with a heavier emphasis on drywall, as this is the most heavily used material for this activity. Roofing replacement waste is not as heavily diverse. A load of nonresidential roofing replacement waste is expected to contain two of three materials; concrete, asphalt, and some sort of plastic protective sheeting. Table 8.19 summarizes the generation amounts by component and Figure 8.10 depicts the composition of nonresidential alterations.

Table 8.19. Summary of the Composition of All Nonresidential Renovation Waste in Florida (tons).

Component	Additions	Alterations	Roof Replacements	Total
Concrete	54,000	-	170,000	224,000
Wood	8,500	56,400	-	64,900
Miscellaneous	9,000	30,100	10,000	49,100
Drywall	8,800	170,000	-	178,800
Metal	2,300	14,000	-	16,300
Cardboard	570	-	-	570
Asphalt	-	-	44,000	44,000
Total	83,170	270,500	224,000	577,670

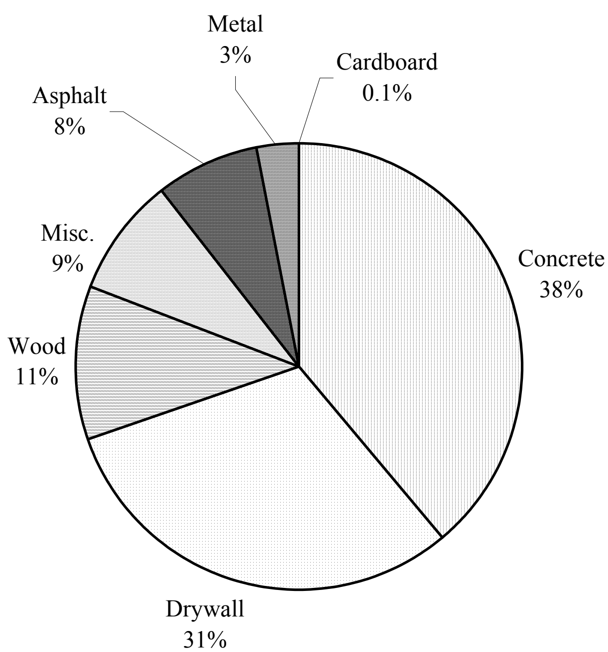


Figure 8.10. Estimated Composition by Weight of Nonresidential Renovation Debris.

9.0 WEIGHT-BASED AND VOLUME-BASED CHARACTERIZATION OF C&D DEBRIS LOADS

For this study, visual characterization (VC) was chosen as a method to characterize C&D waste because of the reduced time and manpower required to complete the characterization. VC was used to obtain a volume distribution for C&D waste loads. In order to obtain a volume distribution, the components of the load were first clearly identified. Once a volume distribution was determined, the individual volumes for each component were calculated based on the total volume of the truck (a value obtained at the landfill). Bulk unit weight of each component was determined from mass sorts conducted simultaneously with VCs. Using the bulk unit weight values, the component volumes were converted into component weights. The estimated component weights for each load were divided by the total weight of the load to obtain a percentage weight distribution.

9.1 C&D COMPONENTS AND SOURCES EXAMINED

C&D waste was divided into fourteen major components (including others) based on previous studies. Table 9.1 summarizes terminology used to identify different components of C&D waste. A brief explanation of what is included in each component is also provided. Table 9.2 summarizes the six categorizes of C&D waste used.

Table 9.1. C&D Debris Components.

Wood	material that is a direct product or derived from wood, including dimensional lumber, plywood, oriented strand board and particleboard, wooden pallets and other objects constructed out of wood.
Concrete	concrete products including block (whole or broken), rubble including walls, foundations, slabs, concrete pavements, mortar, plaster and other products of similar origin.
Drywall	products such as greenboard, wonderboard, blueboard, gypsum wallboard, sheets of cured, plaster-like compounds with heavy-duty paper or material laminated to both sides.
Metal	all ferrous and non-ferrous metal products including re-bar, pipe, sheet metal, wire/cable, fasteners, metal buckets, mesh, strapping, trim, flashing and gutters.
Paper/cardboard	any paper or cardboard product used in construction and demolition projects including but not limited to cardboard boxes, packages, and packing material.
Roofing materials	any product originated from the construction of the outer layer of a roof including asphalt shingles, tarpaper, roofing compound and clay tile shingles.
Plastic	plastic wrap, mesh strapping and PVC, HDPE or ABS pipe. Buckets or any kind of plastic barrel are not included.
MSW	any waste objects that are not generated during construction, demolition or renovation of a building including category includes food waste, food wrappers and containers, beverage containers, bottles and paper bags
Carpet/padding	any material which is used to cover the floor, usually made of woven wool or synthetic fiber.
Insulation	any material used to insulate an object or structure including boards, fiberglass insulation, and other flexible wraps used for insulation. In addition, included are heating, venting or air conditioning ducts comprised of a soft fiberglass insulation tube reinforced by a metal or plastic coil.
Buckets	plastic containers of any size and shape used by the construction industry. This category also includes barrels of different size and shape.
Vegetative debris	different products originating from earthwork, including stumps, branches, brush etc.
Dirt/soil/rocks	products formed by earthwork which is not included in vegetative debris such as rocks, soil and dirt.
other	materials that are produced or are byproduct of a construction, demolition or renovation project but cannot be classified into any of the above thirteen categories including rubber hoses, pipes, and television set, etc. which cannot be directly included into any other category.

Table 9.2. Sources of C&D Waste.

Residential Construction	wastes from new construction of single-family houses, multiple-family houses and apartment complexes
Non-residential Construction	wastes from new construction of commercial buildings like hotels, motels, schools, marketplace and shopping complexes.
Residential Demolition	waste from demolition of single-family houses, multiple-family houses and apartment complexes.
Non-residential Demolition	waste from demolition of commercial buildings such as hotels, motels, schools, market places, shopping complexes, etc.
Residential Renovation	waste from renovation of single-family houses, multiple-family houses and apartment complexes.
Non-residential Renovation	waste from renovation of commercial buildings such as renovation of hotels, motels, schools, shopping complexes, and market places.

9.2 VISUAL CHARACTERIZATION METHODOLOGY

VC is the process of estimating the volume composition of a C&D waste load by observing the load at the landfill and estimating the percent volume distribution. Usually two or three researchers are needed to estimate the percent distribution of a waste load using visual characterization and the average is used as the volume distribution. The whole waste load is distributed into different components comprising of waste produced from construction, demolition, and renovation of residential and commercial buildings. It is important to watch the load when it is dumped because assists estimating what is inside the waste pile.

9.2.1 Visual Characterization Technique

Two or three researchers characterized each waste load into percent volume represented by fourteen components leaving blank the ones that were not present in that particular waste load. The total volume of the load was considered as the volume of the truck in which the load is brought to the landfill. Photos were taken of each waste load for which a VC was conducted. Initially VC was conducted on the waste load as placed. Because it is difficult to see what is inside a waste pile, a different technique was employed midway through the project. The whole waste load was spread using front-end loaders or other available machines at the site. Photos of typical loads are included in Chakrabarti (2002).

9.2.2 Questions to Driver

Once a C&D waste load was chosen for VC one of the researchers interviewed the driver of the truck delivering the load. The common set of information collected from the driver (apart from any load-specific question) is provided below.

- Volume of the load/truck
- Vehicle type; i.e. roll-off container, dump truck, etc.
- Generator type or source type
- Weight of the load (from ticket issued by the landfill)
- Name of the hauling company

9.2.3 Tipping Floor

The driver was then directed to an area apart from general drop-off area where the load was deposited. If possible a concrete surface was selected for load placement. In the case of unavailability of a concrete surface, plastic sheeting or tarp was laid over a relatively flat area to define the boundaries of the tipping surface. However, because of the high number of VC loads in a single day, a relatively flat surface of ground was often used as the tipping floor. Selection of these areas was done in consensus with the landfill operators. During the average workday at the landfill, there were heavy machines moving around the landfill and there were very few defined roads. For the safety of the researchers it was important to choose a place which was away from general traffic.

9.2.4 Data Collection

An example of a typical data collection form can be found in Chakrabarti 2002. Using this data collection form, researchers would break down the whole load into fourteen different components assigning percentage of each component category in the load by volume. Once each researcher assigned a number to each component present in the load, the average distribution was calculated.

9.3 MASS SORTS

The mass sorts were performed at landfills in Citrus, Palm Beach, and Brevard Counties. Researchers at University of Florida conducted the mass sorts and provided the results in Citrus County. Researchers from Florida Institute of Technology conducted the Palm Beach and Brevard County sorts.

9.3.1 Equipment

The required equipment included the following:

- Working gloves
- Eye protection
- Weighing scale
- Field notebook
- Hauling truck

- Barrels of known volume
- Buckets of known volume
- Sledge hammer to break large pieces of concrete

9.3.2 Research Team

The research team consisted typically of four or five laborers, one or two technicians and a supervisor. The responsibility of each team member is defined as follows.

- The supervisor arranged landfill access, coordinated with landfill operators, managed the personal needs of the team and oversaw the research activities
- The technicians operated the weight scale, recorded data, interviewed drivers and guided laborers for separation of waste load into components.
- The laborers were responsible for manually sorting the load into components and placing material into containers and the pickup truck.

9.3.3 Tipping Floor

Either concrete floor or tarp/plastic sheeting was used as the tipping floor. Placing the waste load directly onto the ground may cause substantial loss of dirt and soil, which is difficult to recover.

9.3.4 Methodology

Components were placed in different areas of the tipping floor. The research team, with the help of laborers, placed the components into containers. Each container that was used in the sorting process was of known volume. The volume and weight of the truck used for the mass sort was also calculated and the weight of the truck was recorded before using it to haul the waste. Weights of the containers were also recorded before use. Once the containers were full or the quantity of the component was exhausted, the research team estimated the utilization factor of the container. The utilization factor is the percent usage of the container. It is important to note how much of the container is full. Usually the utilization factor varied from 0.4 to 1.3, which was then used to calculate the volume of each component. Each researcher determined the utilization factor of the container and reported it to the technician for the records. The utilization values were averaged and multiplied by the known volume of the container to obtain the volume of the component. After the component was placed into the container, it was weighed. The barrels and buckets were weighed on the 200-pound capacity scale. The process continued until the complete C&D waste load was weighed. For sorts performed at Citrus County Landfill, the volumes were not recorded. Using the measured weight and volume, bulk unit weights were calculated (to be defined in Section 9.4 and presented in Table 9.3). The individual volumes and the volume distribution were calculated based on Equation 9.1 and Equation 9.2.

$$\text{Individual Component Volume (yd}^3) = \frac{\text{Mass Sort Weight}}{\text{Bulk Unit Weight}} \qquad \textbf{(9.1)}$$

$$\text{Percent of Total Volume} = \frac{\text{Individual Component Volume}}{\sum \text{Individual Component Volumes}} \ \textbf{X}\ 100 \qquad \textbf{(9.2)}$$

The weights and volumes measured in the mass sorts were tabulated to give the total weight of the load and volume of each component present in the load.

9.4 DETERMINATION OF BULK UNIT WEIGHT

9.4.1 Visual Characterization Correction

The first step in determining the bulk unit weight values using visual correction (BUWVC) was the completion of a visual sort for each waste load for which a mass sort was conducted. The result of the visual sort is a percent volume distribution of the C&D waste load. The percent volume of the load occupied by each component is multiplied by the total volume of the load, yielding an individual volume for each component present in the load. Next, the weights of the components determined by the mass sort in each load were summed. The volume of the component by visual characterization was also summed. The total weight of the component (determined by the mass sort) was then divided by the total component volume (determined by the VC) as shown in Equation 9.3.

$$BUWVC\left(\frac{lbs}{yd^3}\right) = \frac{\sum \text{Component Weight}_j}{\sum \text{Estimated Component Volume}_j} \qquad \textbf{(9.3)}$$

where:

j = different components present in the waste load

9.4.2 Field Measurement

The first step in determining the bulk unit weight values using the field measurement (BUWFM) was to sum the weights of each component determined during all the mass sorts conducted. Only Brevard county mass sorts were used to calculate the BUWFM because no volumes were recorded for Citrus County Landfill sorts. The total weight of each component was divided by the total volume of the component measured during the period of mass sorts. Then the BUWFM was calculated using Equation 9.4

$$BUWFM\left(\frac{lbs}{yd^3}\right) = \frac{\sum \text{Measured Component Weight}_j}{\sum \text{Measured Component Volume}_j} \qquad \textbf{(9.4)}$$

where:

j = different component present in the waste load.

9.5 VISUAL CHARACTERIZATION STUDIES

In this study VC was conducted at seven different landfills. In this section a brief description of each landfill is presented along with the measured component distribution by volume for each waste. The bulk unit weight calculation was performed for each component based on the data collected at America Recyclers of Melbourne, Florida. This bulk unit weight was then used for verification of the VC technique against the mass and visual sort conducted at Delta Recycling Facility in Broward County, Florida.

9.5.1 Landfill Description

This section briefly describes the seven landfills visited during the course of the project and provides results of the visual characterization performed at each landfill. The landfills were selected based on their geographical location and demographic characteristics.

9.5.2 Citrus County Landfill

The Citrus County Landfill was the first site visited during the course of this study. This landfill opened in 1975 and the current cell is projected to continue accepting waste until 2003. The site currently has a design capacity of 2 million cubic yards. A design project is currently underway which will increase the life of the landfill by approximately five years. The landfill has an annual acceptance rate of 80,000 tons. In 1998, the landfill had about 1,300,000 tons of waste in place as reported to the EPA (1998). The Citrus County Solid Waste Management Division operates the landfill.

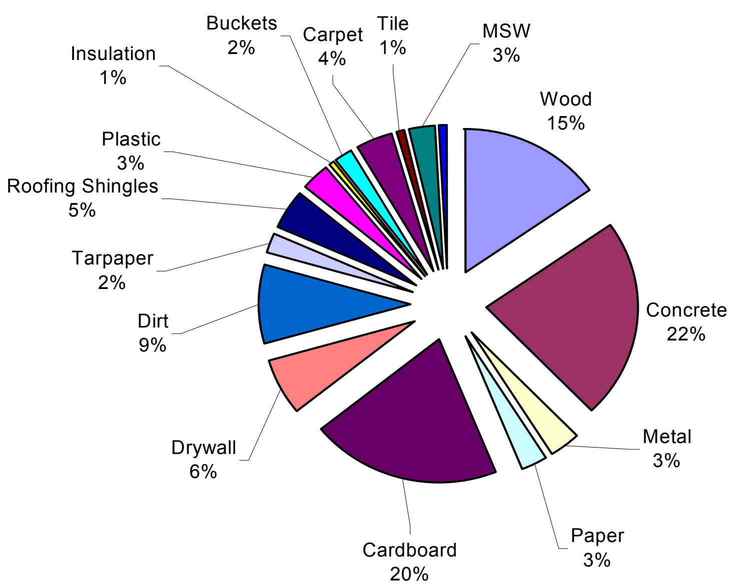


Figure. 9.1. Volume Distribution of C&D Waste at Citrus County Landfill.

The Citrus County Landfill receives about 50 to 60 trucks in a single day. A VC was conducted on seven occasions at the landfill. Mass sorts were conducted at the same time. Mass sort results from this landfill were not used in the calculation of bulk unit weight, because the volume of each component was not measured along with its mass. Figure 9.1 shows the average volume distribution of C&D waste at the landfill calculated through VC of C&D waste and Figure 9.2 shows mass distribution of C&D waste.

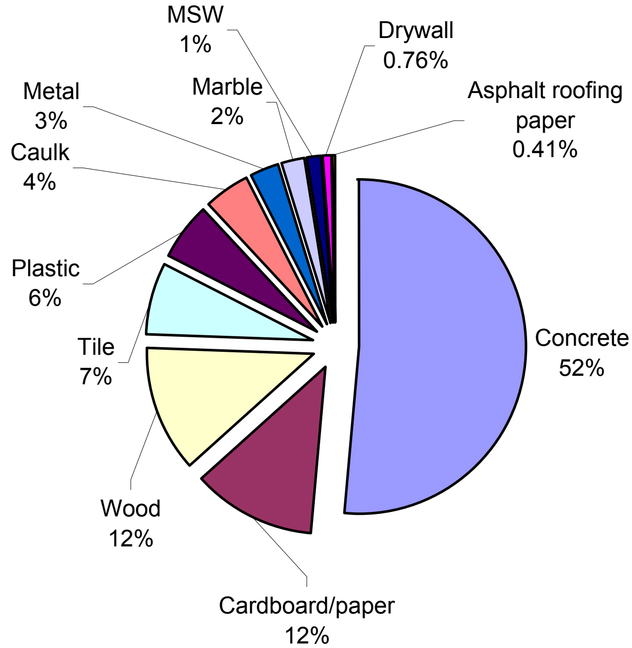


Figure 9.2. Average Mass Distribution of C&D Waste at Citrus County Landfill, Florida.

9.5.3 Pine Ridge Landfill

The Pine Ridge Landfill (PRL) was the second site visited during the course of this study. The Pine Ridge Landfill owned by Waste Management, is located in Winter Garden, Florida. This landfill was opened in the early 1980's and is projected to remain open until 2010. The landfill was initially opened as a Florida Class III landfill but presently only accepts C&D waste. The Class III area stopped accepting Class III waste in April 1999 and was closed in early 2000. The total property is 224 acres of which waste is placed in an area of 102 acres (50 acres Class III and 52 acres C&D). The 50 acres of Class III Landfill was filled to design capacity while only 22 acres of the C&D portion is presently filled. The landfill had an average annual acceptance rate of 120,000 tons of C&D waste. According to the 2000 FDEP report, the landfill received 166,332 tons of C&D waste of which 87,171 tons was recycled and the rest disposed of in the landfill.

This landfill receives about 70 to 80 trucks per day. Monday and Tuesdays are slow in the morning and picks up late in the afternoon. Usually Wednesday and Thursday are the busiest days at the landfill and Fridays are relatively slow. The Pine Ridge landfill also has its own recycling program, primarily processing wood and concrete. They do not opt for manual sorting - rather they choose loads of mainly wood or concrete and process them. The landfill mainly receives new construction waste with lesser amounts of renovation waste.

Visual characterization was conducted on four different occasions. Two people were used to conduct VC at the landfill. Figure 9.3 shows the average waste distribution at PRL average of all four days. Figure 9.4 shows source-based distribution of C&D waste at the PRL.

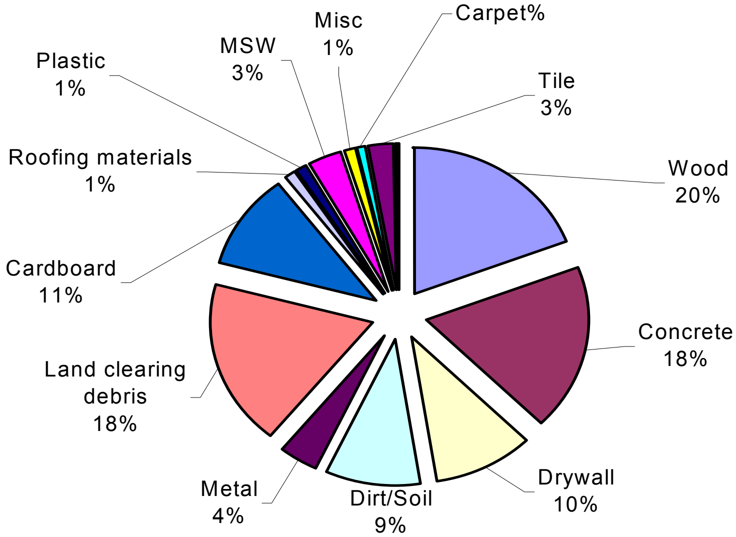


Figure 9.3. Average Volume Distribution of C&D Waste at the PRL.

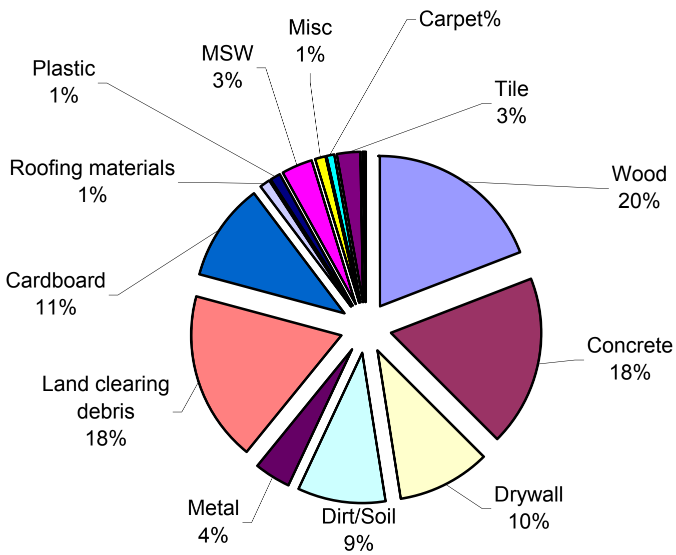


Figure 9.4. Average Source Distribution of C&D Waste at the PRL.

9.5.4 State Road 545 C&D Landfill

The SR 545 C&D Landfill is located in Winter Garden, Florida. Republic Inc. operates this landfill. The landfill began operation in 1991 and is projected to be operational until 2003. The total property is 80 acres with landfilling presently on 60 acres. The site currently has a design capacity of 4,000,000 cubic yards. A design project is currently underway which will increase the life of the landfill by approximately four years. The landfill has an annual waste acceptance rate of 240,000 tons. The landfill has about 2,670,000 tons of waste in place. The SR 545 landfill is also a recycling facility, primarily recovering wood and concrete. According to a 2000 report submitted to Florida Department of Environmental Protection (FDEP), the landfill has received 447021 tons of C&D waste of which 43,322 tons were recycled and 403,699 were disposed of in the landfill (FDEP, 2000). The SR 545 C&D Landfill on average receives 240 to 250 trucks per day, varying slightly during the week.

VC was performed on four different dates. A slightly different technique was used to conduct the VCs at this landfill. Earlier VCs were performed on piled waste, where it was difficult to estimate percentage of each component inside the pile. The characterization was based on personal judgment of components inside the waste. In the revised technique the whole waste load was evenly spread and a VC was performed for the waste load. To evaluate this revised technique, both methods were used at the SR 545 C&D Landfill and results were compared.

The SR 545 C&D Landfill receives mainly new residential and nonresidential construction waste. New construction comprises more than 50% of the total waste stream coming to the SR 545 C&D Landfill. Renovation is the second major source. Figure 9.5 shows average volume distribution at the SR 545 C&D landfill. Figure 9.6 compares the two techniques used for VC. There are some differences between the two techniques, particularly for denser components like concrete, wood and land-clearing debris.

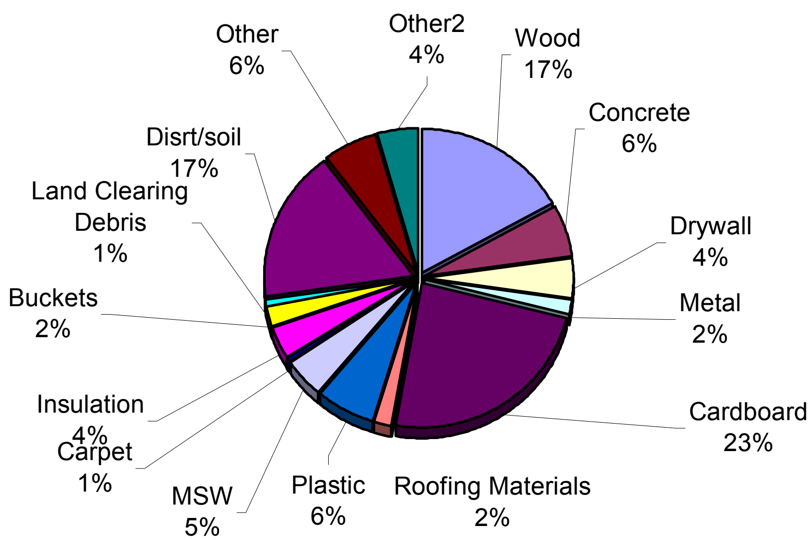


Figure 9.5. Average Volume Distributions at the SR 545 C&D Landfill Spread Waste.

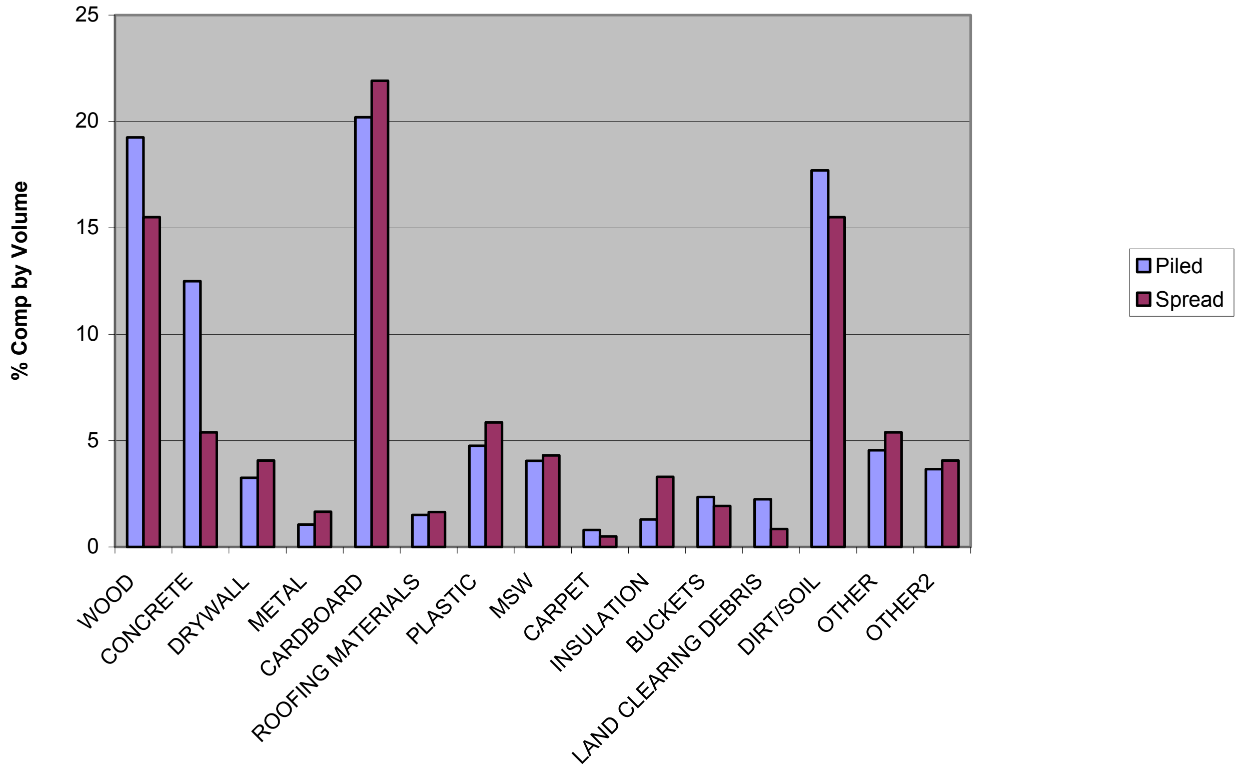


Figure 9.6. Comparison of the Spread and Piled Waste VC at the SR 545 C&D Landfill.

9.5.5 Florida Recyclers Landfill

The Florida Recyclers Landfill is located in Melbourne, Florida. Florida Recyclers of Brevard Inc. is the owner of the landfill. The landfill began operating in 1991 and is projected to be at capacity in 2003. The total property is 40 acres. The site currently has a design capacity of 4,000,000 cubic yards. The landfill receives and processes 10,000 cubic yards of land-clearing debris, 2,000 tons of C&D debris, and 9 tons of yard trimmings every month from a county contract. This is a private landfill that charges $25/yd^3 for C&D debris, $20/yd^3 for yard trimmings and $5/yd^3 for land-clearing debris. Florida Recyclers is mainly a recycling facility as suggested by the name. Construction and demolition waste arrives primarily in roll-off containers, and then is spread out with a front-end loader. Several spotters then separate MSW, metal, and wood by hand. The loadScontain an estimated 60% wood by weight. Recovered metal can be sold as scrap metal. Wood comprises about 80% of the land-clearing debris, which consists mainly of oak, heavy pine and palmetto. According to a report submitted to FDEP, the landfill received 25301 tons of waste during 2000, of which 247 tons was recycled and the rest disposed of at the landfill (FDEP, 2000).

The landfill receives an average of 30 to 40 trucks per day. VC was conducted on the ten different dates at the landfill. For the first few days VC waste was conducted for only piled waste and then both methods (piled and spread) were used. Mass sorts were also conducted at Florida Recyclers Landfill. These data were used for calculation of bulk unit weight. Once the calculation of bulk unit weight was completed these numbers were used to predict mass of individual component at the Delta Recycling Facility. Once these calculated bulk unit weights were verified against mass sorts from another site they were used to convert all VC volume data to mass numbers.

Students from the Florida Institute of Technology spearheaded the fieldwork at this landfill under the supervision of Dr. H. Heck. More extensive data collection was done on the first day at the landfill. In all sixty-four truckloads were inspected and VC was conducted for each waste load. A detailed source or generator distribution was recorded. Figures 9.7 and 9.8 show average waste distribution and source distribution of C&D waste at the landfill, respectively. America Recyclers Landfill mainly receives renovation and new construction waste.

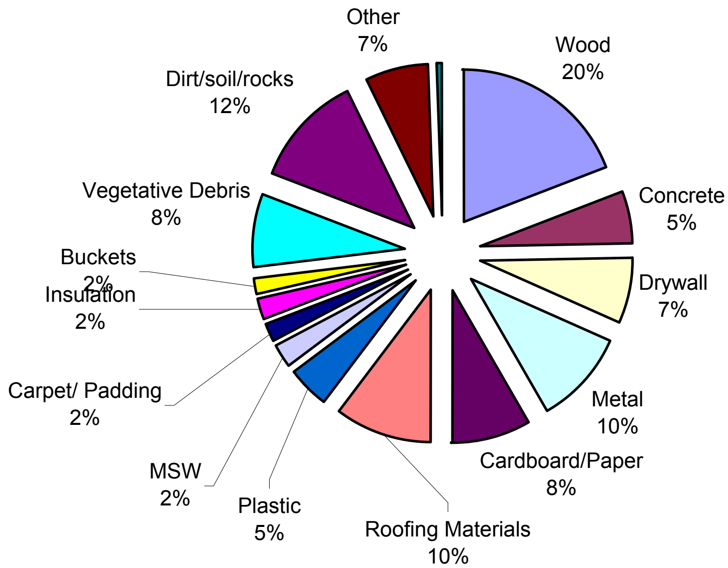


Figure 9.7. Typical Volume Distribution of C&D Waste at Florida Recyclers Landfill, Florida.

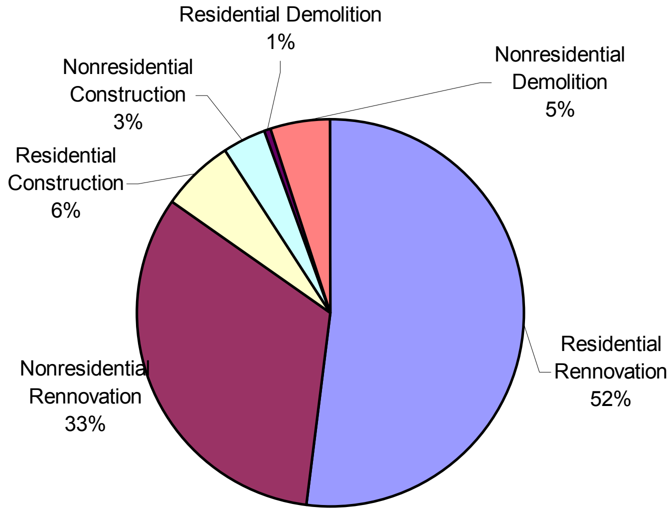


Figure 9.8. Source Distribution of C&D waste at America Recyclers Landfill, Florida.

9.5.6 Bass Road Landfill (BRL)

The Bass Road Landfill (BRL) is located in Kissimmee, Florida. The landfill started its operation in the mid 70's and is expected to close in the year 2003. The present capacity of the landfill is 850,000 cubic yards. The active area for C&D landfilling is about 22 acres. However, the landfill management is trying to expand the landfill and increase its design capacity to 2,000,000 cubic yards using a total area of 30 acres. The planned modification will increase the landfill life by approximately 7 to 8 years. The landfill has an annual acceptance rate of 80,000 tons of C&D debris. According to a 2000 FDEP report, the landfill accepted 102,462 tons of C&D waste of which 5819 tons was recycled and the rest disposed to the landfill (FDEP, 2000).

The BRL receives approximately 60 to 70 trucks per day. In addition to receiving C&D waste from large sites, it also receives C&D waste from small home renovations. The landfill also has a recycling facility, where paper, plastic, cans and wood are recovered. They use both manual sorting and automated machines to pick up recyclable material out of waste piles before landfilling the remaining waste.

The landfill primarily receives new construction and renovation waste. Wood, concrete, drywall, and dirt and soil are the main components of both new construction and demolition.

VC was performed on three different days. VC was conducted for 10 to 12 waste loads each day. The VC was conducted in two different ways. For each waste load VC was performed for piled waste first and then waste was uniformly spread and another VC was completed for the waste load. A comparison of the spread loads VC and piled loads VC is shown in Figure 9.9. Differences range from 0 to 50 percent, average difference was around 15 percent. Highest differences were for wood (33 %) and concrete (50%) lowest was 0 percent for roofing materials and MSW. The higher difference can be attributed to higher densities of the components, causing them to sink inside the waste load.

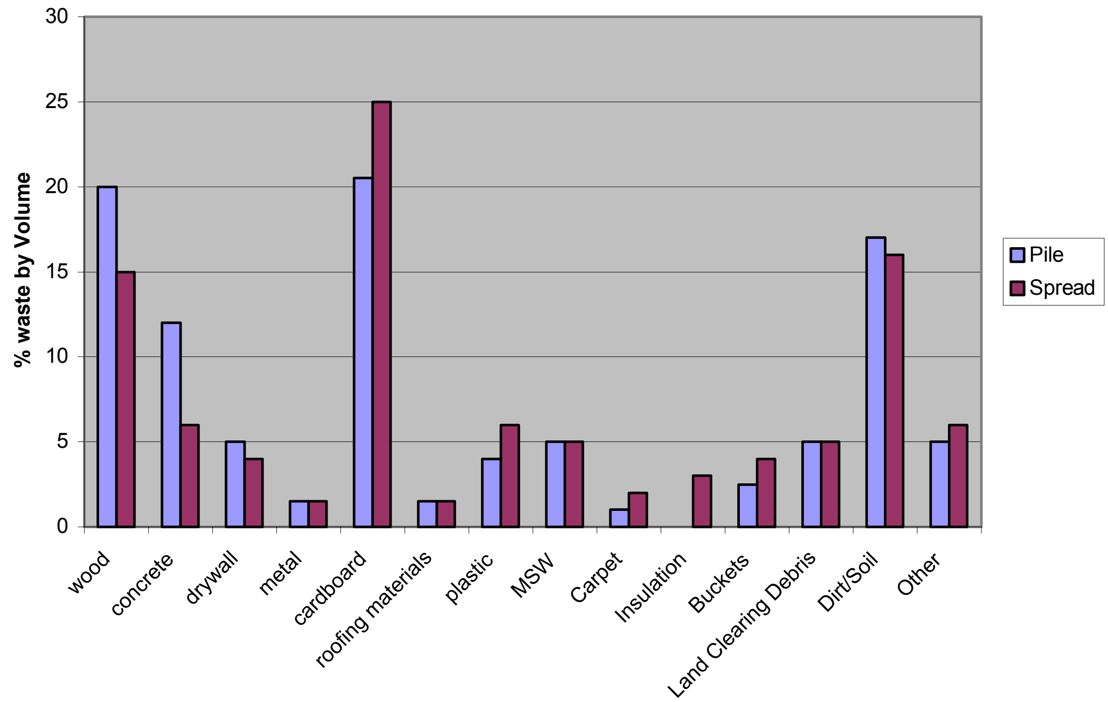


Figure 9.9. Comparison of Average Volume Distribution of C&D Waste by Two Methods at BRL.

9.5.7 Delta Recycling Facility

The Delta Recycling Facility is located in West Palm Beach, Florida. The Delta Recycling Facility receives 40 to 50 trucks per day, varying slightly during the week. Delta Recycling Facility is primarily a recycling facility, recovering almost everything that comes to the landfill. They use both manual and mechanical sorting to sort individual components of C&D waste.

Both VC and mass sorts were conducted at the landfill. VCs were conducted for both piled and spread loads. VC was conducted on three days at this landfill. Mass sorts were conducted for three waste loads. Mass sort results from this landfill were used for verification of the VC technique. Figure 9.10 shows average volume distribution of C&D waste at the Delta Recycling Facility.

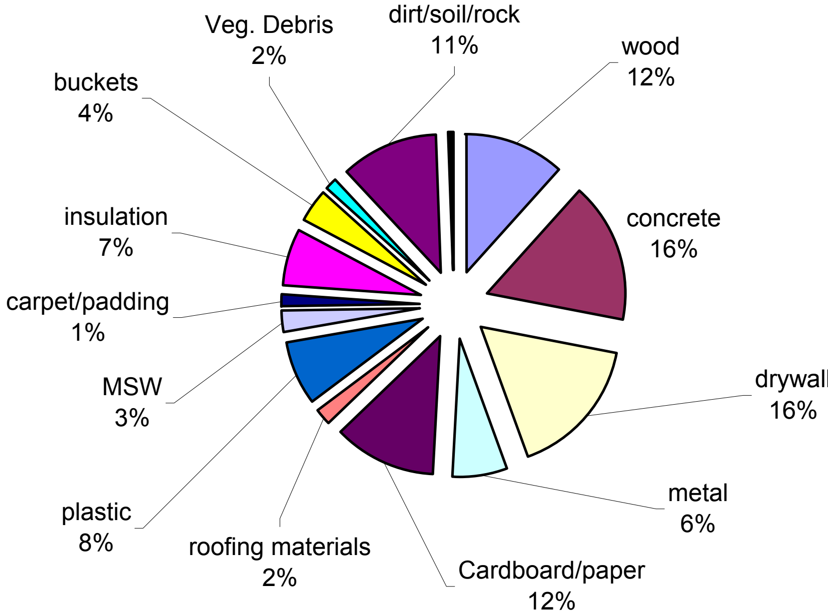


Figure 9.10. Average Volume Distribution of C&D Waste at the Delta Recycling Facility, Florida.

9.5.8 Aenon Church Landfill

The Aenon Church Landfill is located in Leon County, Florida. The landfill receives about 30 to 40 trucks per day. The landfill mainly receives renovation waste followed in volume by construction waste. A total of 18 truckloads were characterized using the VC technique. Students from University of Florida conducted fieldwork at this landfill. Figure 9.11 shows typical volume distribution of a C&D waste load at the Aenon church Landfill. Figure 9.12 shows source distribution of a C&D waste arriving at the landfill. The landfill was visited only one time during the course of this project.

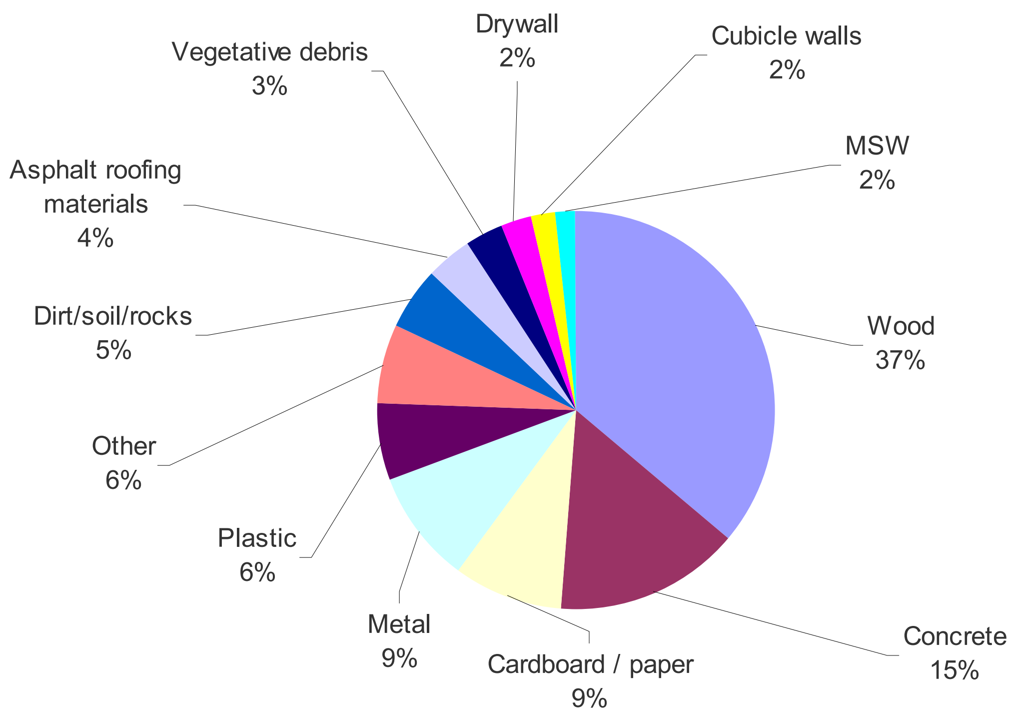


Figure 9.11. Average Volume Distribution of C&D Waste Aenon Church Landfill, Florida.

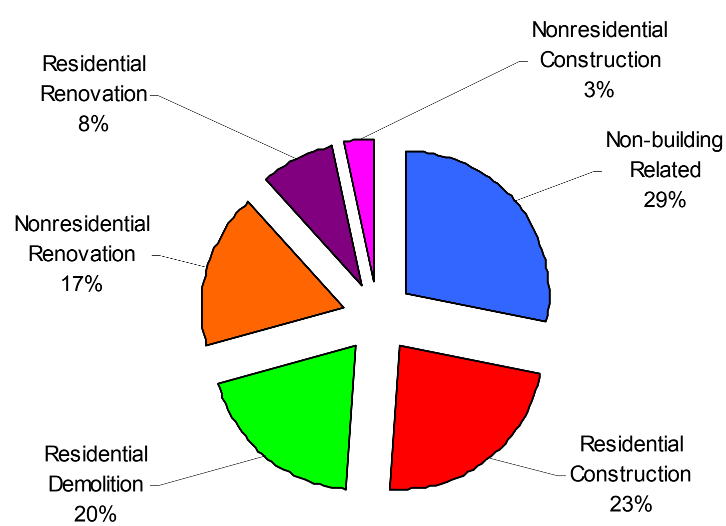


Figure 9.12. Source Based Distribution of C&D Waste at the Aenon Church Landfill, Florida.

9.5.9 Composition of C&D waste in Florida (Visual Characterization)

Table 9.3 shows the composition of C&D waste as observed at all seven landfills. Wood, concrete and cardboard are major components of C&D waste, accounting together for more than 50 percent of the total waste stream. There are also differences in composition of C&D waste generated from different types of source. Figure 9.13 compares source based average composition of C&D waste for the three primary sources. There is more wood and drywall in renovation waste as compared to construction waste. Demolition waste is similar to renovation waste in composition.

Table 9.3. Composition of C&D waste in Florida (All Seven Landfills).

	PRL	CCL	ACL	CWI	ARL	BRL	DRF
Components	**% Volume**	**% Volume**	**% Volume**	**% Volume**	**% Volume**	**% Volume**	**% Volume**
Wood	20	15	35	17	19	19	12
Concrete	18	22	15	6	5	12	16
Drywall	10	6	2	4	7	5	16
Dirt and soil	9	3	5	17	11	17	6
Metal	4	3	9	2	9	2	12
LCD	18	1	3	1	8	5	13
Cardboard	11	3	9	23	8	20	10
Roofing Material	1	7	4	2	10	3	2
Plastic	1	3	6	6	4	4	12
MSW	1	3	2	5	2	5	3
Misc.	1	1	2	1	3	3	8
Carpet	1	1	1	4	2	1	1
Tile	1	1	0	1	1	0	0
Other	5	5	6	6	7	5	2

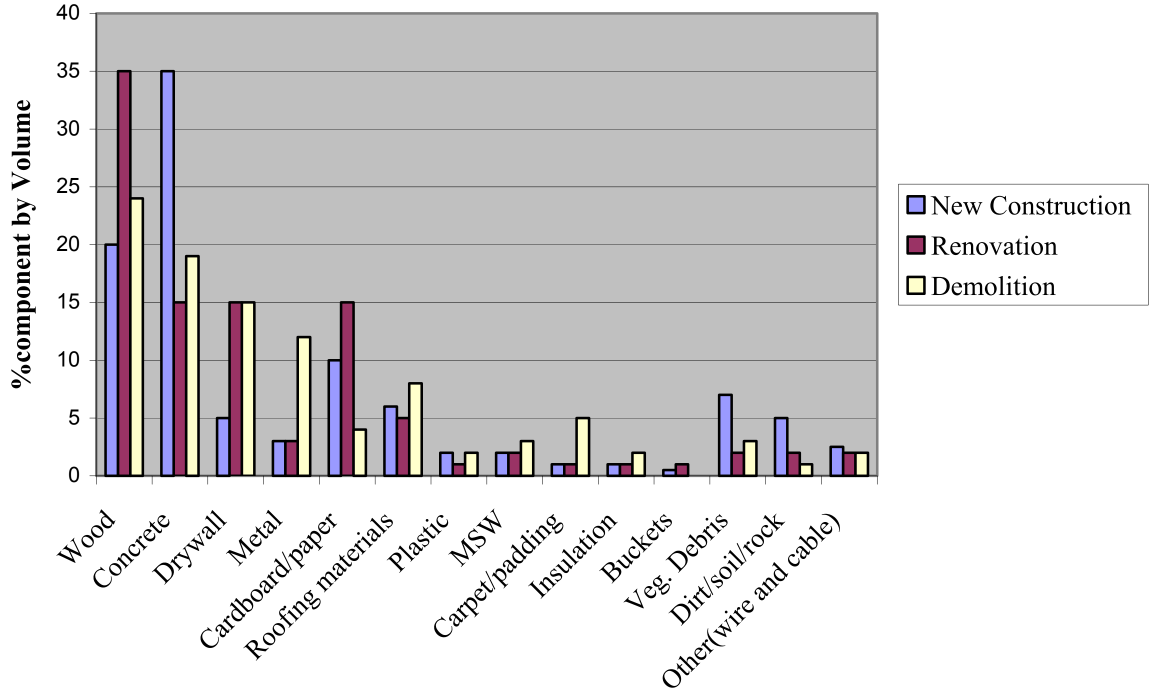


Figure 9.13. Source Based Comparison of Composition of C&D Waste in Florida.

9.6 BULK UNIT WEIGHT

Mass sorts at Florida Recyclers Landfill were used to calculate bulk unit weight of C&D waste. Component mass and volumes were determined from nine loads. Calculation of bulk unit weights for components, which were either absent or present at low levels, was not possible. In such cases bulk unit weight from the literature were used (Townsend 2001). Tables 9.4 and 9.5 show bulk unit weight calculated from both direct field measurements and visual characterization.

As shown in Tables 9.4 and 9.5 some Bulk Unit Weight Field Measurement (BUWFM) values are quite different from the corresponding Bulk Unit Weight Visual Characterization (BUWVC) values. If the BUWVC for a component is larger than its BUWFM, it indicates that the component is not always entirely visible while doing VC and the volume tends to be underestimated. Concrete, land clearing and other categories are all dense materials that are usually granular in shape and have a high volume to surface area ratio. These materials can be expected to migrate to the bottom of the load during container loading and transport. Wood, flooring materials and metal are not typically granular in nature however they were also underestimated. If the BUWFM is larger than the BUWVC for a component, it suggests that the component's estimated volume is larger than its actual volume. The components that fall into this category are paper/cardboard, drywall/greenboard, and roofing materials. All of these components are essentially flat, which means that their surface area to volume ratio is large. These calculated and estimated bulk unit weights were validated using a mass sorts. For that reason visual and mass sorts at the Delta Recycling Facility were conducted.

9.6.1 Comparison of Weight Predictions

Mass sorts at Delta Recycling were conducted to verify the calculated and estimated unit weight values. Independent sorts were carried out at the facility and both mass and volume measurements were recorded. VC was also conducted at the landfill. Estimated mass was calculated using Delta Recycling VC and mass data using both BUWVC and BUWFM previously determined (see Tables 9.4 and 9.5). Calculated mass values were compared to actual mass values to verify the bulk unit weights calculated and accuracy of the visual characterization technique. Table 9.4 compares the two method used for mass estimation and Table 9.5 compares the two methods mass estimation and actual field recorded mass of each component.

Table 9.5 shows comparison between the estimated mass distribution, based on the BUWVC, estimated mass distribution based on the BUWFM, and actual mass distribution. The largest percent differences occur in the categories with smaller surface area to mass ratio. Also the volume distributions were based on the truck volume. The truck volumes are not necessarily correct representations of actual volumes of the waste loads. The truck may be half full or a quarter full, and depending on that the mass estimation will vary.

Table 9.4. Estimated Weights of Components of C&D Waste (Delta Recycling Facility).

	Avg. Volume Dist	BUWVC Lb/yd^3	BUWFM Lb/yd^3	Estimated weight (calculated) lbs*	Estimated weight (field) lbs**
Wood	3.2	225	198	722	636
Concrete	4.6	907	1501	4135	6844
Drywall	4.6	365	403	1669	1841
Metal	1.8	427	259	758	461
Cardboard/paper	3.3	93	67	308	224
Roofing materials	0.5	253	387	136	208
Plastic	3.2	64	70	204	225
MSW	0.7	88	156	65	116
Carpet/padding	0.3	93	67	29	21
Insulation	1.9	34	52	66	98
Dirt/soil/rock	3.5	977	1480	3441	5215
Other (floor Ceramic)	0.2	1845	784	369	157
Total	**100**			**11,902**	**16,046**

*using the BUWVC

** using the BUWFM

Table 9.6 compares the correlation coefficients for calculation of mass using the two bulk unit weights with actual mass recorded in the field. All of the estimated weights correlate well to the actual field measured values. The correlation values were better in the case of estimated weights using BUWVC.

Table 9.5. Comparison of Estimated Weight Distribution, Measured Weight Distribution and Actual Mass Distribution (Delta Recycling Facility, 2002).

	Estimated Weight Distribution (calculated)	Estimated Weight Distribution (field)	Actual Weight* Distribution (field)
Wood	6.1	4.0	7.8
Concrete	34.7	42.7	19.6
Drywall	14	11.5	27.3
Metal	6.4	2.9	3.0
Cardboard/paper	2.6	1.4	3.7
Roofing materials	1.1	1.3	2.8
Plastic	1.7	1.4	3.2
MSW	0.6	0.7	0.6
Carpet/padding	0.2	0.1	0.4
Insulation	0.5	0.6	0.6
Dirt/soil/rock	28.9	32.5	27
Other (floor Ceramic)	3.1	1.0	3.8
Total	100	100	100

*Average of three mass sorts

Table 9.6. Comparison of Correlation Coefficient Values for Estimated and Measured weights of C&D waste.

	Correlation Coefficient	
	Estimated vs. Actual	**Measured vs. Actual**
Sort 1	0.8	0.69
Sort 2	0.77	0.76
Sort 3	0.95	0.96

9.6.2 Source Based Mass Distribution of C&D Waste

Mass distribution for all sources can be calculated using the VC values for each source type and calculated density and converting it to mass percent. These mass distribution numbers are mass percent and not actual mass numbers. Figures 9.14 to 9.20 show source-based mass distribution of C&D waste in Florida.

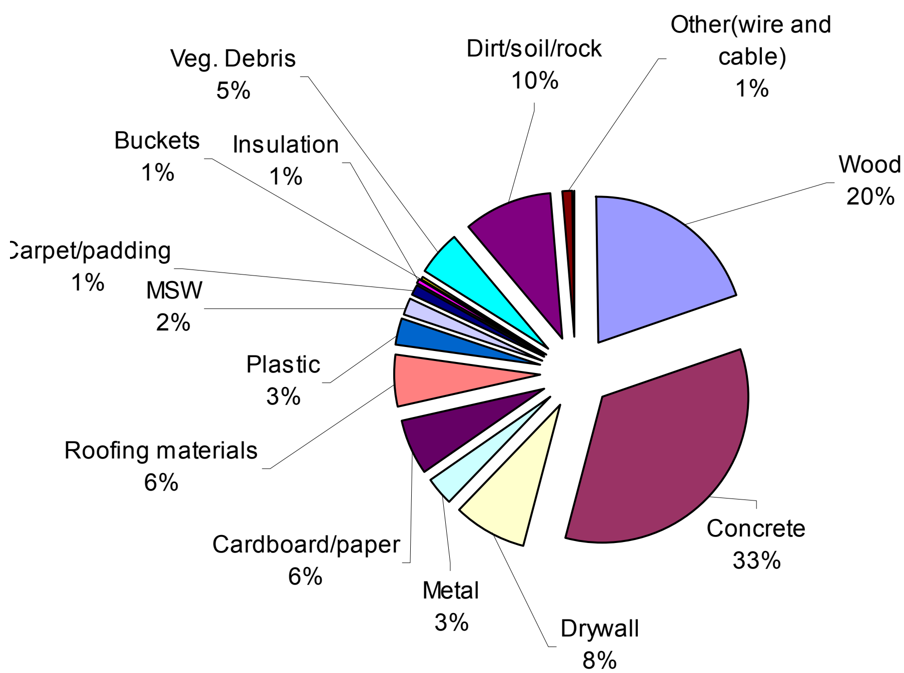


Figure 9.14. Composition of Residential C&D Waste for Florida, Percent by Mass.

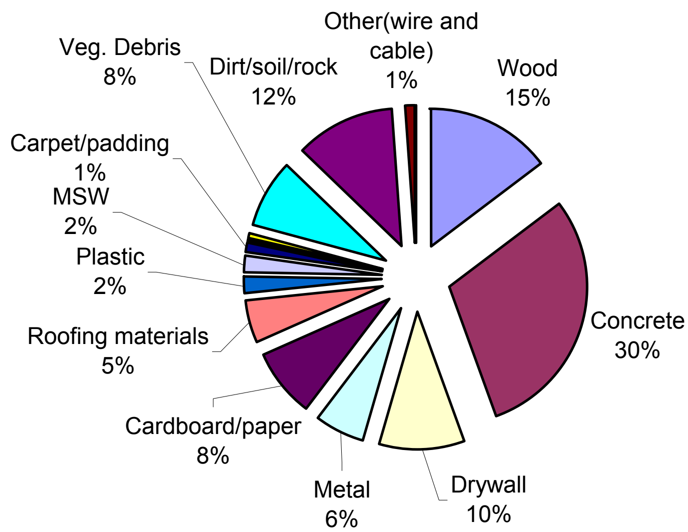


Figure 9.15. Composition of Non-Residential C&D Waste for Florida, Percent by Mass.

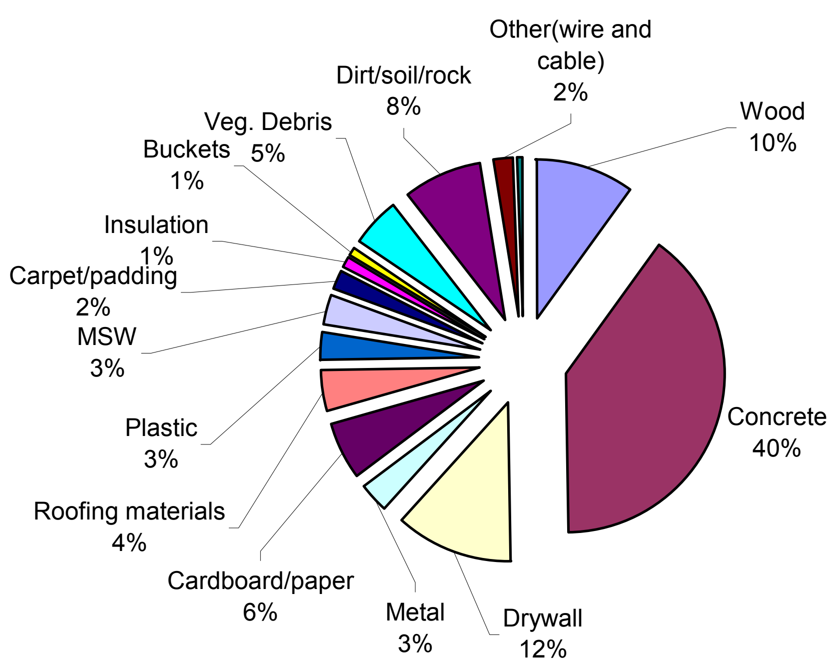


Figure 9.16. Composition of Residential Renovation Waste in Florida, Percent by Mass.

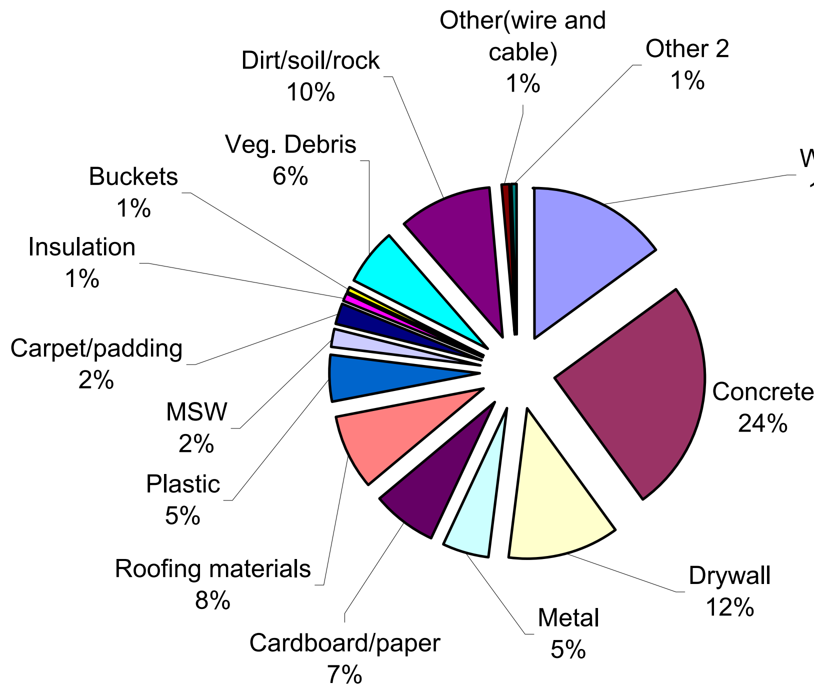


Figure 9.17. Composition of Non-Residential Renovation Waste in Florida, Percent by Mass.

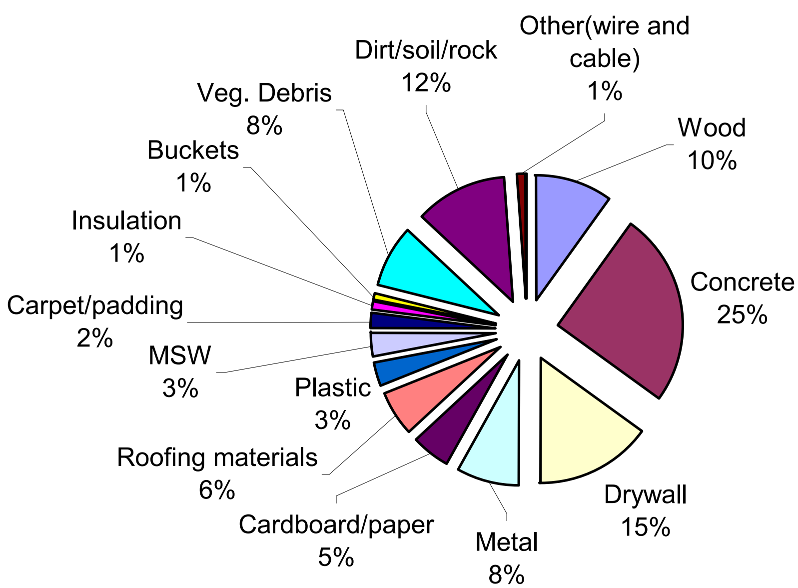


Figure 9.18. Composition of Residential Demolition Waste in Florida, Percent by Mass.

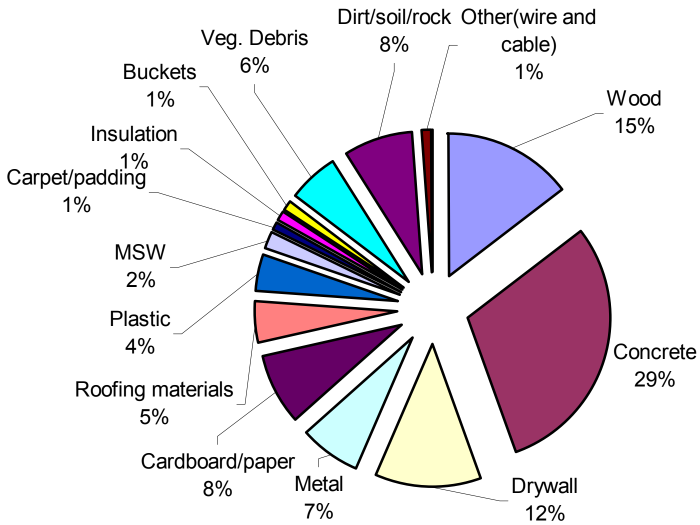


Figure 9.19. Composition of Non-residential Demolition Waste in Florida, Percent by Mass.

10.0 EVALUATION OF VISUAL CHARACTERIZATION AND PHOTOGRAMETRY AS METHODS OF ESTIMATING C&D DEBRIS COMPOSITION

10.1 METHODOLOGY

10.1.1 Photogrammetric Requirements and Procedure

There are three key elements in the photogrammetry procedure developed for this study: 1) Sampling site requirements, 2) picture acquisition, and 3) picture analysis. Sampling site requirements include having a tipping floor that is large enough and free of other waste so that when the solid waste container is emptied, there will be a clear space around the pile that clearly defines the boundary of the waste pile. In this study the waste material was placed on top of a clean plastic liner that was large enough to create a clear space around the pile. The acquisition requirements are that the picture should be taken from a point facing the pile center and perpendicular to the pile length. Furthermore, the photographer needs to get the entire waste pile in the picture and be as close to the waste pile as possible. Also, both sides of the pile should be photographed so that an average surface area distribution of the components can be obtained. A digital camera was used in this study to take the pictures, which were transferred to a computer in a digital format. Pictures can be taken with a 35mm camera and scanned to create the picture files. Adobe Photoshop 6.0, which has the capability to resize the picture and to superimpose a grid pattern on the picture, was used to display the pictures on the computer. The grid pattern included ten columns and eight rows, creating eighty cells. The contents of each cell were identified and a component distribution within the cell was determined. Each of the cells were subdivided to help estimate the component area coverage. The subdivisions used were based on the researchers' preference. The term background was used to identify non-waste areas of cells. After the whole picture was analyzed, the data were entered into a spreadsheet. The non-waste components (background) were subtracted from the total grid area leaving only the picture area containing waste. The component distribution for the picture was calculated and averaged with the component distribution of the picture from the other side of the waste pile. Two different people performed the picture analysis and the results were averaged. The actual volume of the waste load was measured based on the container size and utilization factor and weight of the waste load was measured at the scale house. The component volumes and weights were then estimated using Equations 10.1, 10.2, and 10.3.

10.1.2 Visual Characterization Requirements and Procedure

The visual characterization technique has fewer requirements than the photogrammetric technique. Sampling site requirements include having a large area to place the waste that is out of the traffic flow but it is not as important to create a clear space around the waste pile since the observers present will be able to easily distinguish what waste was in the pile from any material adjacent to the waste pile. The observers then spend a few minutes walking around the waste pile and observing its contents. In this study, the number of observers ranged from three to eight and the average number was five. They then estimate the volume distribution of the components in the pile. The actual volume of the waste load is measured based on the container size and utilization factor and weight of the waste load is measured at the scale house. The component volumes and weights are then estimated using Equations 10.1, 10.2, 10.3.

10.1.3 Calibration

Calibration of the visual characterization and the photgrametry technique was conducted based on data collected at two waste management facilities in Florida; Delta Recycling, Inc. Tall Pines transfer facility in West Palm Beach and the Florida Recycling, Inc. landfill in Melbourne, Florida. A total of thirteen truckloads of waste was used for calibration. Three truckloads were sorted at the Delta Recycling, Inc. transfer facility and ten truckloads were sorted at the Florida Recycling, Inc. landfill. The initial weights and volumes were measured and the sorted component weights and volumes were measured. The loads of waste were either the complete contents of a dump truck or a roll-off container. A total of 91,567 pounds of C&D waste were sorted.

One set of correction factors for each characterization method was developed to convert the characterization method estimated volume distribution into calibrated volume and weight distributions. The correction factor converts the characterization method estimated volume distribution into a weight, using Equation 10.1, that is used to calculate a weight distribution. When the correction factor is used to convert a volume to a weight it is referred to as a unit weight correction factor. When the total load weight is known, the component weights are the product of the total weight and the component weight distribution. If the total weights are not known, this equation can be used to estimate the components' weight. The component volume distribution is not adjusted, it is assumed that each characterization method is suitable for estimating component volume distributions and the adjustment should be applied when converting volumes to weights. Individual component volumes are the product of the total load volume and the method estimated component distribution.

The mass sort weights and the characterization method estimated volumes were summed to get a total weight and volume of each component. The total weights and volumes of each component were used to calculate a characterization method specific component density. The unit weight correction factor was determined by dividing the characterization method specific component density by the mass sort measured component bulk density. The bulk densities were measured by sorting the waste loads into components. The weight and volume of each component was measured and a bulk density was calculated. The term "bulk density" means that the air space is included in the weight and volume measurements. Nine loads of C&D waste were used to calibrate the unit weight correction factors. Equation 10.1 is used to predict the component weight.

$$W_c = V_{cm}*F_w*D_B \qquad \textbf{(10.1)}$$

where:

W_c = predicted component weight (lbs)

V_{cm} = predicted component volume based on the characterization method (yd^3)

F_w = correction factor for volume to weight conversions, unitless

D_B = bulk density of the component (lb/yd^3)

The correction factor F_w is used to correct the predicted weight of the components. This is necessary because most component weight distributions are consistently greater or less than expected after accounting for the bulk density.

The second method applies the correction factor to the characterization method predicted volume distributions. In this case the conversion from volume to weight is based solely on the field measured bulk density. The volume correction factor for each component was calculated by dividing the field measured volumes obtained from the mass sort by the characterization method predicted volumes. The same nine loads of C&D waste were used for this calibration. The component volumes are predicted using Equation 10.2:

$$V_c = V_{cm} * F_v \qquad \textbf{(10.2)}$$

where:

V_c = the corrected component volume (yd^3)

F_v = volume correction factor, unitless

The component weights are calculated using equation 10.3.

$$W_c = V_c * D_B \qquad \textbf{(10.3)}$$

If the waste load weight is known, then the predicted component weights are linearly adjusted to equal the waste load weight.

10.1.4 Verification of Method

Four truckloads of waste were sorted to compare the two characterization methods. One load was sorted at the Florida Recycling, Inc. landfill in Brevard County and three loads were sorted at the Delta Recycling, Inc. Tall Pines facility. The sorted components weights and volumes were measured for all four loads and the volume distributions were estimated using both the photogrammetric and visual characterization methods. The correction factors, unit weight correction and unit volume correction, were applied to each truckload. For each method, estimated volumes, estimated volume distributions, estimated weights, and estimated weight distributions were calculated for all four loads. The estimated weights were not calculated using the actual total load weight since this would provide the same results as comparing the weight distributions. All estimated values were then compared to the actual volumes, volume distributions, weights, and weight distributions determined from sorting the truckloads and measuring the individual components.

10.2 RESULTS AND DISCUSSION

Table 10.1 presents bulk unit weights found in the literature and field measured bulk unit weights and correction factors for each component based on analyzing nine waste loads. The literature and field measured densities were fairly close, the differences are most likely the result of compaction and sample variation. The unit weight and volume correction factors have the same value and are reported based on the characterization method. A correction factor greater than one suggests that the component weight or volume tended to be under predicted by the characterization method. Similarly, the correction factors with a value less than one suggest that component weight and volume tended to be over predicted.

Components can be over or under predicted for three reasons. First, if a component is not uniformly distributed throughout the pile, its apparent distribution will not be directly related to its weight or volume distribution. Non-uniform component distribution can result from the way the container was loaded, since the waste stream tends to be non-uniform and related to the specific activity occurring at the point of generation. Density and particle size sorting can occur within the container, which will result in components like soil, sawdust, or crushed concrete migrating to the bottom where they are not visible. Some objects tend to be more noticeable because of their shape, such as plastic film, plywood, or pallets. Second, if the waste cannot be identified, or is misidentified, then its weight or volume cannot be estimated or measured. Misidentification is more of a problem with the photogrammetric method since in pictures it is difficult to tell the difference between items such as white wood trim and white PVC pipe, or black plastic strapping and metal strapping. Items that are similarly colored, due to dust or cement particles (particularly with demolition waste), and the lack of adequate light shinning into the waste pile as one looks between components and tries to identify something in the shadows can also contribute to misidentification. Third, some waste components have different volumes depending on the size of container or how they are loaded into the container. Welded wire fabric (concrete reinforcement wire), electrical wire, and rebar when placed in a large container may fit in a compact manner, but when loaded into a smaller container like those used for a sorting study, the material may take up more space because it has to be folded or bent or because the space between the pieces of metal is empty and the space was filled with other waste material in the larger container. To minimize volume changes, the waste material was placed in the sorting containers as if a construction worker was adding them to any onsite storage container. The abnormally high value of the "other" correction factor was because there were only a few items present in that category in the waste samples and they were either misidentified or not visible.

Table 10.1. Literature Unit Weights, Field Measured Bulk Unit Weights, Unit Weight Correction Factors, and the Volume Correction Factors for Each Component.

Component	Literature* Unit Weight lb/yd^3	Field Measured Unit Weight lb/yd^3	Visual Analysis Correction Factor	Photogrammetric Analysis Correction Factor
Wood	400	220	1.05	1.66
Concrete	1900	1567	0.60	1.85
Paper	85	41	1.09	0.87
Drywall	400	339	0.84	1.14
Metal	540	236	1.02	3.85
Insulation	84	36	1.21	1.34
Roofing	360	514	1.13	0.94
Plastic	17	49	1.24	0.82
Flooring	108	294	0.27	1.00
MSW	220	138	0.49	0.28
Land Clearing	810	1771	0.55	2.15
Other	220	587	18.27	2.63

* Medeiros 2001.

Four waste loads, not used in the calibration study, were analyzed to verify the methodology. One waste load, Brevard 11, was sorted and analyzed using both characterization methods by a group of seven students who had never preformed this type of analysis before. The results are presented in Tables 10.2 and 10.3.

Table 10.2. Volume Distribution Estimates by Seven Researchers for the Same Waste Pile Using the Visual Characterization Method.

Component	Volume Distribution Using Visual Analysis							Average Volume Distribution	Standard Deviation	Measured Volume Distribution
	Analysis 1	Analysis 2	Analysis 3	Analysis 4	Analysis 5	Analysis 6	Analysis 7			
Wood	30.5	25.8	24.7	27.2	30.6	38.9	29.7	29.6	4.7	23.7
Concrete	10.2	10.3	6.2	3.3	3.1	3.3	8.2	6.4	3.2	2.0
Paper	35.5	30.9	49.4	32.6	35.7	33.3	35.9	36.2	6.1	52.1
Drywall	5.1	4.1	0.0	1.1	1.0	2.2	2.1	2.2	1.8	0.7
Metal	1.0	2.1	1.2	1.1	6.1	1.1	2.1	2.1	1.8	0.5
Insulation	2.0	8.2	1.2	5.4	4.1	5.6	1.0	3.9	2.7	1.8
Roofing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
Plastic	8.1	8.2	9.9	16.3	13.3	8.9	13.3	11.1	3.2	13.5
Flooring	3.0	1.0	1.2	5.4	1.0	1.1	4.1	2.4	1.8	2.2
MSW	0.5	7.2	3.7	5.4	2.0	2.2	2.1	3.3	2.3	0.8
Land Clearing	4.1	2.1	2.5	2.2	3.1	3.3	1.5	2.7	0.9	0.4
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
							Correlation Coefficient =			0.95

Table 10.3. Volume Distribution Estimates by Six Researchers for the Same Waste Pile Using the Photogrammetric Method.

Component	Volume Distribution Using Photogrammetric Analysis						Average Volume Distribution	Standard Deviation	Measured Volume Distribution
	Analysis 1	Analysis 2	Analysis 3	Analysis 4	Analysis 5	Analysis 6			
Wood	19.8	24.9	26.3	23.7	13.5	16.7	20.8	5.0	23.7
Concrete	4.1	4.9	5.3	2.0	2.7	5.3	4.0	1.4	2.0
Paper	37.1	38.4	38.3	52.1	53.9	20.9	40.1	12.0	52.1
Drywall	1.6	0.1	2.9	0.7	0.3	22.7	4.7	8.9	0.7
Metal	0.4	1.0	0.8	0.5	5.0	0.6	1.4	1.8	0.5
Insulation	5.9	2.6	1.4	1.8	8.0	4.9	4.1	2.6	1.8
Roofing	3.0	3.7	0.1	1.7	3.1	12.1	4.0	4.2	1.7
Plastic	16.0	15.4	23.8	13.5	9.5	10.7	14.8	5.1	13.5
Flooring	4.2	3.3	0.0	2.2	1.5	2.2	2.2	1.4	2.2
MSW	1.5	3.5	1.0	0.8	0.8	1.5	1.5	1.0	0.8
Land Clearing	0.9	1.9	0.0	0.4	0.2	1.9	0.9	0.8	0.4
Other	5.6	0.6	0.0	0.6	1.5	0.3	1.4	2.1	0.6
						Correlation Coefficient =			0.99

One purpose of this analysis exercise was to determine how variable the results would be between observers. Only the initial volume distribution estimates are presented since all others quantities are based on these values. For both methods, the standard deviations of the larger volume components are small compared to the means and the standard deviations of the components that compose less than five percent of the volume are about equal to the mean. This is typical for waste volume measurements. The correlation coefficients between the predicted and measured volumes were high, which mean that the estimation methods do reflect what is found when mass sorts are conducted.

The unit weight and unit volume correction factors were applied to all four waste loads. Correlation coefficients were calculated between the estimated volumes and actual volumes, between the estimated volume distributions and the actual volume distributions, between the estimated weights and the actual weights, and between the estimated weight distributions and the actual weight distributions for each load. Table 10.4 shows the measured and estimated amounts and resulting correlation coefficients for one of the waste loads, Tall Pines 3.

Table 10.4. Volume and Weight Data and the Associated Correlation Coefficients for theTall Pines 3 Waste Load.

Component	Photogrammetric Unit Weight Correction Predicted Volumes yd^3	Photogrammetric Unit Volume Correction Predicted Volumes yd^3	Visual Characterization Unit Weight Correction Predicted Volumes yd^3	Visual Characterization Unit Volume Correction Predicted Volumes yd^3	Mass Sort Volume yd^3	Photogrammetric Unit Weight Correction Predicted Weights lbs	Photogrammetric Unit Volume Correction Predicted Weights lbs	Visual Characterization Unit Weight Correction Predicted Weights lbs	Visual Characterization Unit Volume Correction Predicted Weights lbs	Mass Sort Weight lbs
Wood	2.3	3.8	4.3	4.5	4.1	844	844	998	998	680
Concrete	1.3	2.4	2.1	1.3	1.5	3721	3721	1996	1996	1974
Paper	6.7	5.8	4.1	4.5	3.1	238	238	185	185	280
Drywall	11.1	12.6	10.0	8.4	10.5	4255	4255	2852	2852	4260
Metal	2.0	7.6	3.8	3.9	4.3	1803	1803	921	921	340
Insulation	0.9	1.3	0.6	0.8	0.2	45	45	27	27	12
Roofing	0.7	0.7	0.3	0.3	0.9	354	354	152	152	380
Plastic	4.5	3.7	2.8	3.4	3.6	181	181	170	170	259
Flooring	0.0	0.0	0.4	0.1	0.0	0	0	29	29	0
MSW	0.7	0.2	0.5	0.3	0.2	29	29	37	37	34
Land Clearing	0.3	0.5	1.5	0.8	2.0	961	961	1427	1427	1640
Other	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0
Correlation	0.90	0.95	0.98	0.96		0.89	0.89	0.96	0.96	

Volumes are only adjusted when the volume correction method is applied. The volume correction method improves the correlation coefficient for the photogrammetric characterization procedure. The final weights are unaffected by where the correction is applied, either to the volume or when converting from volume to weight, therefore there is no difference in the correlation coefficients for weight for a given characterization method.

The four waste loads were combined and the correlation coefficients were calculated using the two correction factor methods. Table 10.5 shows the resulting correlation coefficients for the four combined loads. For both characterization methods, the component volume distributions were more accurately predicted than the component volumes but the component weights were more accurately predicted than the weight distributions. In all cases the component volumes were scaled to the total load volume but for analysis purposes the components weights were not scaled to the total weight. The component weights were predicted using Equations 10.1, 10.2, and 10.3. If the total load weight is known the accuracy of the estimated weights will be improved by scaling to the total load weight. Based on the correlation coefficients calculated for all four loads combined (Table 10.5), both characterization methods produce useable results. The visual characterization method gave slightly better results overall, but an average of five observers was used to classify the waste loads. The photogrammetric method used only two observers to analyze the photographs. Thirteen waste loads were analyzed. Nine waste loads were used to calibrate the characterization methods and four waste loads were used to compare their estimations. Since the characterization methods have been shown to be sufficient for estimating waste load contents, the correction factors developed can be improved by including all thirteen waste loads. Table 10.6 shows the initial correction factors based on nine waste loads and the final correction factors based on thirteen waste loads.

Table 10.5. Correlation Coefficients for All Four Loads Combined.

Method	Load*	Correlation Coefficients							
		Photogrammetric Characterization				Visual Characterization			
		Volumes		Weights		Volumes		Weights	
		Volumes yd3	Distributions yd3	Weights lbs	Distributions lbs	Volumes yd3	Distributions yd3	Weights lbs	Distributions lbs
Unit Weight Correction Factor	Br 11 TP 1 TP 2 TP 3	0.76	0.82	0.81	0.74	0.80	0.85	0.89	0.76
Unit Volume Correction Factor	Br 11 TP 1 TP 2 TP 3	0.71	0.78	0.81	0.74	0.86	0.89	0.89	0.75

Br is the Brevard County site.
TP is the Tall Pines Facility.

Table 10.6. Adjusted Correction Factors that Include all Mass and Volume Sort Data.

Component	Literature* Unit Weight lb/yd^3	Field Measured Unit Weight lb/yd^3	Visual Analysis		Photogrammetric	
			Initial Correction Factor	Final Correction Factor	Initial Correction Factor	Final Correction Factor
Wood	400	212	1.05	1.00	1.66	1.67
Concrete	1900	1570	0.60	0.56	1.85	1.19
Paper	85	49	1.09	1.10	0.87	0.81
Drywall	400	364	0.84	0.88	1.14	1.06
Metal	540	195	1.02	1.01	3.85	3.15
Insulation	84	34	1.21	1.34	1.34	1.38
Roofing	360	477	1.13	1.20	0.94	0.88
Plastic	17	57	1.24	1.26	0.82	0.82
Flooring	108	1349	0.27	1.51	1.00	3.49
MSW	220	147	0.49	0.44	0.28	0.28
Land Clearing	810	1354	0.55	0.53	2.15	1.09
Other	220	344	18.27	51.10	2.63	6.12

* Medeiros, 2001.

10.3 RECOMMENDATIONS AND CONCLUSIONS

In this study, the land clearing component included soil, trees, branches, brush, and stumps. Soil should be considered on its own because of the difference in the unit weight between soil and vegetative material. Also, soil tends to be hidden on the bottom of the pile and vegetative waste tends to be visible. Grouping soil into the land clearing component caused the weight distribution percent for land clearing to be significantly over estimated when vegetative waste was present. The methodology developed can be used to predict the percent distribution of specific waste components within the C&D waste stream on a weight or volume basis. Using the photogrammetric method requires about five man-hours of picture analysis time per waste load and the visual characterization method requires about 0.5 man hours per waste load. Both methods require much less time than the 25 man-hours to manually sort the waste load, which makes either of the characterization methods more cost effective than manual sorting and exposes the sorting personal to less risk since they do not have to touch the waste and will spend much less time working on the tipping floor. The photogrammetric method does allow the creation of permanent samples, the pictures that can be referred to or reanalyzed and has the least worker exposure to the waste material. The visual characterization method can be used to analyze approximately ten and fifty times as many truck loads compared to photogrammetric and mass sort techniques respectively for the same analysis costs.

11.0 SUMMARY OF COMPOSITION RESULTS FOR FLORIDA C&D DEBRIS

Table 11.1 presents the estimated C&D debris composition determined in Chapters 8 and 9.

Table 11.1
Comparison of Composition Results.

Component	Composition Predicted Using Generation Statistics and Literature Composition Values, by weight	Composition Estimate Using Composition Results from Field Studies, by weight
Concrete	54.2%	32.4%
Wood	13.6%	14.8%
Drywall	11.4%	11.7%
Asphalt Roofing	6.9%	6.1%
Metal	2.8%	5.4%
Other	11.2%	29.7%

As can be seen in Table 11.1 major component weight distribution is quite similar with the exception of concrete. The VC technique apparently is unable to "see" concrete that has settled to the bottom of the pile and overestimates the "other" category.

SECTION IV

REMAINING ISSUES AND CONCLUSIONS

12.0 ESTIMATING RECYCLING POTENTIAL OF C&D DEBRIS IN FLORIDA

12.1 OVERVIEW

Many components of C&D debris can be successfully recycled. The existence of viable markets for recovered materials is critical to successful recycling activity. Table 12-1 presents the primary markets for the major components of C&D debris. C&D debris facility operators in Florida currently recycle many of the components in Table 12-1. The efficiency with which these materials are recycled, however, is unknown. The production rates determined in Chapter 8 of this report may be used to estimate this rate. The Florida Department of Environmental Protection (FDEP) collects data on the amount of C&D debris currently recycled per year (see Chapter 2). One objective of this chapter is to provide an estimate of the current recycling efficiency (%) for the major components of C&D debris.

Table 12.1. Markets for C&D Debris Components (R. W. Beck 2001 and Townsend 1998).

C&D Debris Component	Market
Concrete	Road construction projects, erosion control, reuse in concrete production, drainage medium, and development of artificial reefs
Asphalt shingles	Asphalt (bituminous) concrete
Wood	Boiler fuel and mulch
Corrugated cardboard	New cardboard products, composting, roofing felt
Metal	New metal products
Drywall	Cement manufacture, drywall manufacture, agricultural amendment, and road stabilizer
Mixed C&D debris	Alternative daily cover in landfills

A second objective of this chapter is to determine whether the market capacity exists to accommodate the major C&D debris components produced in Florida. This analysis is presented in this chapter as well. First, estimates of market capacities are made. Then, these numbers are compared to the production numbers generated in Chapter 8 to form an understanding of the current recycling efficiency and the potential recycling efficiency helps solid waste planners and policy makers develop strategies for market development and implement new recycling programs.

This chapter focuses on the major components of C&D debris; concrete, wood, drywall, and asphalt shingles. These components are the most voluminous and dense components (see Table 12.2), and represent 88% of the C&D debris stream according to Chapter 8. Cardboard and metal, while also major C&D debris components, are not mentioned here because the infrastructure for recycling these materials is already well established. Other components (e.g. plastics) are impractical to separate or recycle due to the lack of a market or sufficient amount of material in the waste stream.

Table 12.2. Percentage of the C&D Debris Stream Represented by the Major Recyclable Materials (from Chapter 8).

Waste Component	Percentage of the waste stream (by mass)
Concrete	56%
Wood	13%
Drywall	11%
Asphalt roofing materials	7%
Total	*87%*

12.2 Concrete

Concrete (portland cement concrete) is one of the most heavily recycled materials from C&D debris. When crushed, it can be used for road construction, concrete aggregate, drainage material, and rip-rap. Figure 12.1 depicts the uses of recycled concrete in the U.S. in 1997. There are currently a number of concrete recyclers in Florida. Perhaps the greatest potential market for crushed concrete is for the base course in roads. While the use of crushed concrete as base course material has been somewhat limited in Florida because of DOT specifications, it is commonly practiced elsewhere. A study performed by the University of Florida has shown that recycled concrete performs well as natural aggregates in base course for asphalt concrete roads (Romero-Monteiro 1997). Crushed concrete can also be used as fill for sinkholes, quarries, and other low areas. It can also be used as ballast or subballast in railroads. Large pieces can be used as riprap to prevent shoreline erosion (Cosper et al. 1994).

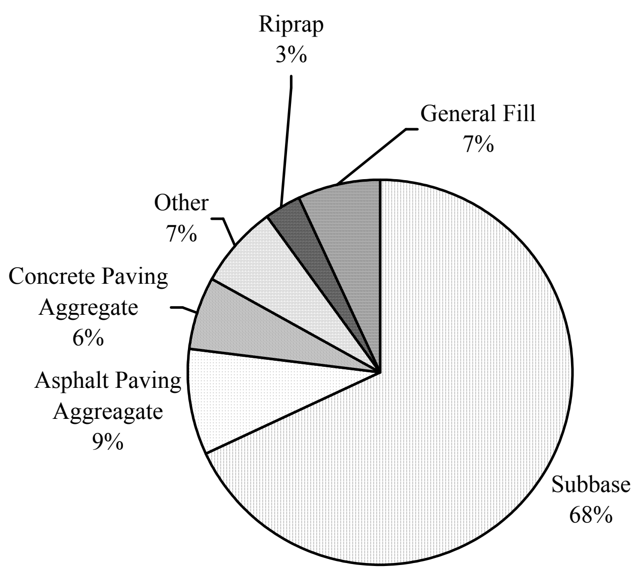


Figure 12.1. Uses of recycled concrete in 1997 in the U.S. (Turley 1997).

The amount of concrete recycled in Florida in 1999 was estimated at 74,223 tons (FDEP 2001). This is the amount reported by FDEP that originated from traditional waste haulers and is thus counted toward recycling goals. The total amount of concrete reported as recycled in 1996 was 390,950 tons. A number of non-permitted facilities also accept concrete. The amount of concrete waste generated (as determined in Chapter 8) was approximately 2,223,600 tons. When using the 1999 FDEP amended value for concrete recycled (74,223 tons), the recycling rate is three percent. When using the 1999 total reported concrete (390,950 tons), the recycling rate is 17 percent. The true fraction of the 2.3 million tons of concrete from building-related C&D debris that is recycled is difficult to estimate because some building-related concrete is recycled by non-permitted facilities while some of the permitted facilities likely report some non-building related concrete.

There is a significant market for recycled concrete in Florida. In 1999, approximately 98.9 million tons of crushed stone were purchased in Florida (Tepordei 2000). Table 12.3 lists all of the reported markets for the crushed stone in 1999 in Florida. Data on the demand for crushed stone did not exist for the year 2000 when this study was published. Figure 12.2 depicts the amount of waste concrete generated, the current recycled amount (total amount reported), and the amount that has the potential to be recycled. The potential amount to be recycled in Figure 5.2 only represents the amount that can be used in road construction. Florida has an extensive market for aggregates that could easily accommodate recycled concrete that originates from all construction and demolition activities, including road and bridge activity. The most promising of these markets is for road construction. Brick and tile can also be used for these purposes when ground in the same fashion as concrete. Since there were approximately 2,223,600 tons of the building-related waste concrete generated in Florida in 2000 (as calculated in Chapter 8) and the road base demand for crushed stone totaled 19,731,372 tons in 1999, the potential recycling rate for this market alone was 100 percent (FDEP 2001).

Table 12.3. Markets for Crushed Stone in Florida in 1999 (Tepordei 2000).

Use	Amount (tons)
Concrete Aggregate	28,108,938
Bituminous Aggregate	15,873,283
Roadstone and Coverings	19,731,372
Riprap and Railroad Ballast	165,347
Other Construction Uses	11,023,113
Cement Manufacture	4,299,014
Agricultural Uses	661,387
Other Uses	19,069,985
Total	*98,932,439*

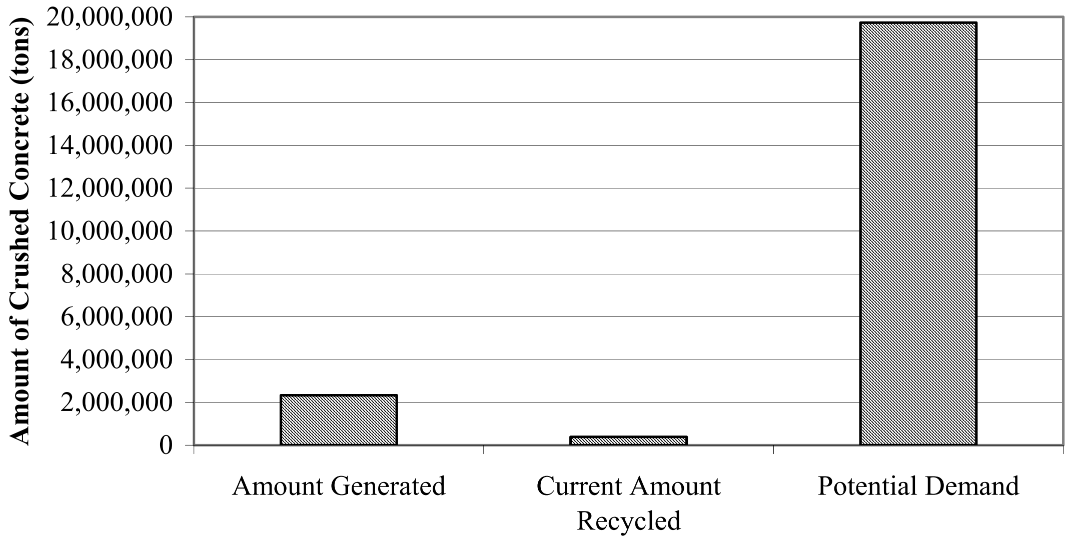


Figure 12.2. Amount of Concrete Waste Produced, Total Recycled and Its Potential Demand as Roadstone (FDEP 2001 And Tepordei 2000).

A primary reason that much of the concrete is not recycled, however, is the competitive mined aggregate market in South Florida. The price for recycled concrete is not much less than that of natural aggregates in this region of the state. Often, the concrete collected at recycling facilities in South Florida is used as lake fill. Many lakes were formed as the result of mining operations and crushed concrete is used to fill these lakes to form new real estate. Recycled concrete has a much better market in the north and northwest regions of the state. Natural aggregates are not easily acquired in these areas and a crushed concrete substitute is a cheaper alternative that can serve the same purpose.

12.3 Wood

Wood waste is currently being recycled two different ways in the state; process boiler fuel and mulch. In 1998, 401,587 tons of wood were reported to be used for process boiler fuel (FDEP 2000). A new red coloring method for wood mulch made the mulch from C&D more attractive for many consumers, and mulch dyeing became important for many recyclers. FDEP reported an amended recycling value of approximately 203,842 tons of wood waste in 1999 (FDEP 2001). The total amount of wood FDEP reported recycled was 224,307 tons. From the calculations in Chapter 8, it is estimated that 559,400 tons of wood are generated annually. This means that the recycling efficiency was approximately 36 percent if the amended value of recycled wood was used, 40 percent if the total value is used. It is uncertain how much of the 224,307 tons recycled was building-related C&D debris. It is likely that some of this wood was land-clearing debris, pallets, and non-building related construction wood.

In order to determine the potential recycling rate, it is important to determine the demand. The two promising markets for wood waste are mulch and boiler fuel. In 1998, 401,587 tons of wood, yard, and, paper wastes were used for process boiler fuel. No central agency or organization collects information on the demand for mulch.

To estimate the amount of mulch purchased by single-family homes, it is first necessary to know how many single-family housing units there are in Florida. This can be found from the U.S Census Bureau. The U.S. Census Bureau also collects information on the percentage of vacancies in Florida (U.S. Census Bureau 2001b). It was assumed that 25% of the occupied homes use mulch regularly. Data do not exist on the amount of mulch each home uses per year. The Mulch and Soil Council, however, estimates that each home uses about seven bags of mulch a year. Each bag weighs about 50 pounds (Lagosse 2001). The total demand for mulch, therefore, is approximately 200,000 tons. Equation 12.1 calculates the mulch annual demand in Florida.

Calculation of the annual mulch demand in Florida.

$$\mathrm{Q} = A \times B \times (1 - C) \times D \times E \times F \qquad \textbf{(12.1)}$$

where:

Q = Total amount of mulch demanded (tons)

A = Number of housing units in Florida, 2000 (U.S. Census Bureau 2001c)

B = Percentage of homes that are owned in Florida, 2000 (U.S. Census Bureau 2001c)

C = Percentage of homes that are vacant in Florida, 2000 (U.S. Census Bureau 2001b)

D = Percentage of homeowners that are regular customers

E = Number of bags of mulch each homeowner purchases annually

F = Approximate dry weight of each bag of mulch (lbs)

$$\text{Mulch Demand} = 7{,}302{,}947 \times 0.70 \times (1 - 0.03) \times 0.25 \times 7 \times 50 = 200{,}000 \text{ tons}$$

The demand of wood for boiler fuel can be determined by looking at the past demand and plant capacity for process boiler fuel. The Florida Department of Environmental Protection keeps these data and publish them in the “2000 Solid Waste Management Annual Report” (FDEP 2000). The total amount of yard, wood, and/or paper waste used in 1998 was 401,587 tons. The two facilities that used this waste were Okeelanta in South Bay and Ridge Generating Station in Polk County.

The potential total demand for wood in Florida, therefore, equals 601,587 tons. This amount is larger than the total amount of wood waste generated in Florida (approximately 559,400 tons). The recycling efficiency has the potential to be 100 percent. However, the plants using wood waste for process boiler fuel are located in the lower half of the state. It is unlikely that it would be cost effective to ship the wood waste from the Panhandle to these generating stations, especially when yard trash and paper can also be used as process boiler fuel.

Wood from demolitions and renovations has a higher risk of being contaminated with lead paint or other contaminants. Wood from these activities is not good for mulch but could be used for boiler fuel. Wood waste from construction projects would be better suited for use as mulch. If wood waste can be separated and used for different purposes, all of the estimated 295,400 tons of demolition and renovation wood waste and all of the estimated 264,000 tons of construction wood waste can be recycled. Figure 12.3 depicts the amount of wood waste that is generated, the total reported amount recycled, and the potential demand for construction, renovation, and demolition wood waste generated in 2000 in Florida.

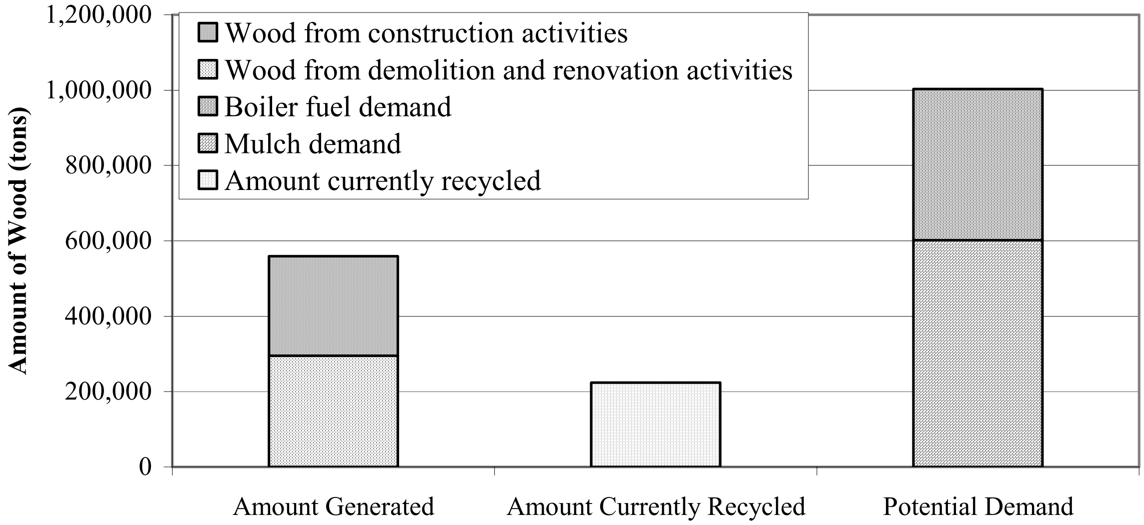


Figure 12.3. Amount of Wood Currently Generated, Recycled, and the Potential Demand for Recycled Wood in Florida (FDEP 2001 And FDEP 2000).

12.4 Asphalt Roofing Materials

Very few facilities recycle asphalt shingles in Florida. Usually, the only way they are recycled is if they are laid down as a temporary roads at landfills, providing friction on the landfill for the garbage trucks. Normally, aggregate (e.g. limerock) is laid down for this purpose; however, asphalt shingles provides a cheap alternative. This practice may not be considered true recycling. There were 3,058 tons of asphalt shingles recycled in 1999. The amount generated, as determined in Chapter 8, was approximately 282,593 tons. The current recycling efficiency is, therefore, approximately one percent. The market considered here is reuse in hot-mix asphalt production.

Asphalt shingles can be added to hot mix asphalt in the manufacture of asphalt (bituminous) concrete. This practice has proven effective in many states, including Florida. The shingles must be ground up and then added as five to ten percent of the mixture (Button et al. 1995, Grzybowski 1993, Mallick et al. 2000, Watson et al. 1998). The Florida Department of Transportation (FDOT) built 313 lane miles of roads and replaced 2,807 lane miles of roads in Florida last year; a total of 3,120 lane miles (FTC 2001). Each lane has an asphalt concrete thickness of about 0.30 feet and a width of about ten feet. Hence, the volume of asphalt concrete in one mile is approximately 48.6 million cubic feet. The density of asphalt concrete is approximately 145 pounds per cubic foot on average (Brown 1990). Therefore, the total weight of asphalt in one mile of road is approximately 1,130 tons. Since FDOT placed a total of 3,120 lane miles of road down, an approximate total of 3.53 million tons of asphalt were needed for road construction. If the asphalt shingle amount were ten percent (Grzybowski 1993), as shown in some studies, the amount of shingles that could be recycled would be about 352,610 tons. In most studies, however, the recommended amount of waste shingles used in hot-mix asphalt is five percent (Mallick et al. 2000, Button et al. 1995, Watson et al. 1998). If five percent is used, 200,000 tons of waste asphalt shingles could be recycled, which is 71 percent of the amount of shingles generated from C&D debris. Equation 12.2 presents this calculation. This calculation is only for state-built roads and does not include county, city, or privately built roads. The Florida Asphalt Contractors Association (FACA) estimates that the DOT uses 4.5 million tons of asphalt pavement (Warren 2001). Five percent of this amount is 225,000 tons, only 25,000 tons more than the estimate in Equation 12.2. Using asphalt shingles in asphalt for the construction or replacement of locally built roads would provide further markets for asphalt shingle waste. The FACA estimates that 15 million tons of asphalt pavement are used in Florida each year. The capacity for recycled asphalt shingles is approximately 750,000 tons. The potential recycling efficiency that factors in all roads in Florida is 100 percent. Figure 12.4 depicts the amount of shingles currently disposed and recycled and the potential demand for the entire state (FDOT and other local roads). The potential demand in Figure 12.4 represents the amount of shingles that could be recycled assuming five percent of new hot mix asphalt is asphalt shingles.

Calculation of the amount of shingles needed for asphalt manufacturing for one year in Florida.

$$Q = \left\lfloor (A + B) \times 5{,}280 \ \mathrm{ft}/\mathrm{mi} \right\rfloor \times C \times D \times E \times F \qquad \textbf{(12.2)}$$

Q = Amount of asphalt shingles (tons)

A = Length of road lanes that were built in Florida in one year (miles) (FTC 2001)

B = Length of road lanes that were replaced in Florida in one year (miles) (FTC 2001)

C = Thickness of asphalt concrete (feet) (Romero Monteiro 1997)

D = Width of one lane (feet)

E = Density of asphalt concrete (lbs/ft^3)

F = Percentage of asphalt concrete represented by asphalt shingles (Button et al. 1995, Mallick et al. 2000, and Watson et al. 1998).

$$Q = \left\lfloor (313 + 2{,}807) \times 5{,}280 \ \mathrm{ft}/\mathrm{mi} \right\rfloor \times 0.30 \times 12 \times 145 \times 0.05 = 200{,}000 \text{ tons}$$

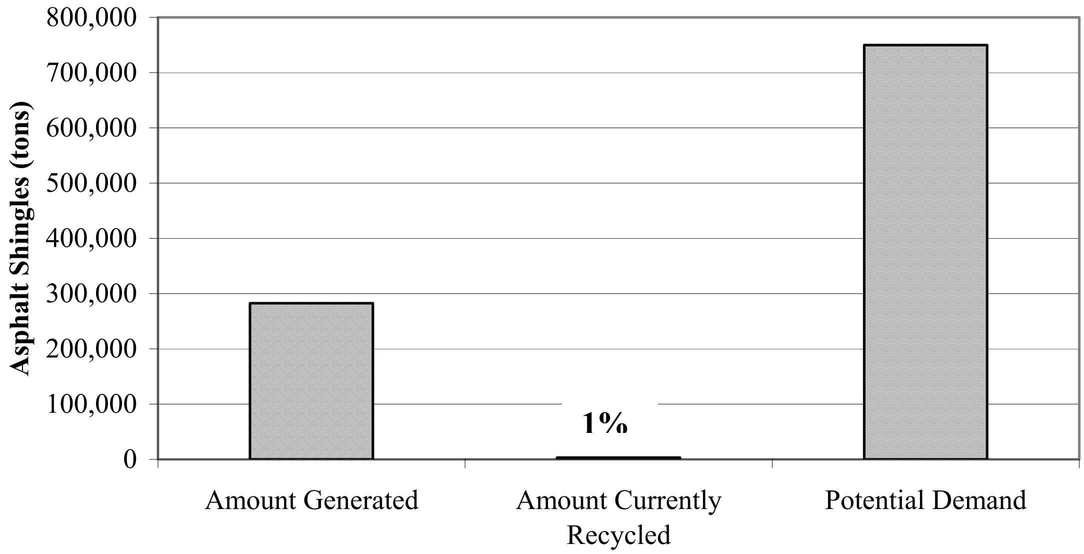


Figure 12.4. Current Amount of Asphalt Shingle Waste Generated and Recycled and the Potential Demand in Florida (FDEP 2001 and Warren 2001).

12.5 Drywall

Drywall is not currently heavily recycled in the state. Only one facility reported recycling the commodity in 1998, having recycled 519 tons. It was estimated in Chapter 8 that the total amount of drywall waste generated in Florida was approximately 470,790 tons. The current recycling efficiency, therefore, is less than one percent.

Drywall can be recycled in a number of ways. The potentially successful methods in Florida are as an agricultural amendment in soil, as an ingredient in cement, and as new drywall. As an agricultural amendment in soil, gypsum is needed as a calcium source in peanuts and other crops. There are a large number of peanut farmers in North Florida that currently use gypsum. In soil, it can also help buffer against acidity, a trait that is undesired in soils for agriculture. In cement, gypsum helps delay the setting time. Gypsum currently comprises between five and ten percent of the ingredients in cement. Since cement plants, located in Central and South Florida, produce a large quantity of cement, gypsum is also needed in large quantities. Gypsum from old drywall can also be used to make new drywall. Currently, the drywall manufacturers are already using recycled gypsum from their scrap piles and also from the phosphate mining industry. The market at present, therefore, is not promising for post-consumer waste drywall. This may change, however, as the drywall scrap piles diminish (Townsend et al. 2001).

Calculations performed by Allison Barnes in her thesis "Feasibility of Recycling Scrap Gypsum Drywall From New Construction Activities in Florida" determined that the capacity for waste drywall in Florida for these three markets is 639,000 tons (Barnes 2001). Figure 12.5 depicts the current amount generated, the current amount recycled, and the potential demand.

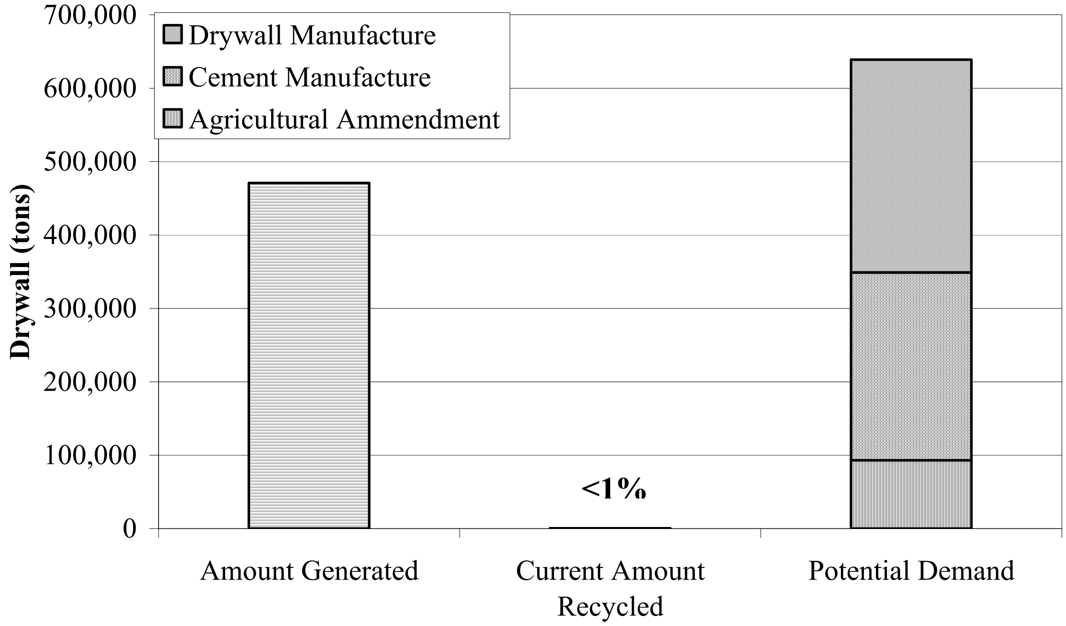


Figure 12.5. Current Amount of Drywall Waste Generated, Recycled, and Its Potential Demand in Florida (FDEP 2001 and Barnes 2001).

12.6 Summary

Figure 12.6 depicts the recycling rate for each of the four components discussed in this chapter. The wood-recycling rate is the highest. The amount of wood reported as recycled includes wood from other sources besides building-related C&D sources including land clearing debris, old fences, old telephone poles, and other non-building structures. Debris from these sources would not be accounted for in the estimations in Chapter 8, making the recycling efficiency in Figure 12.6 too high. The amount of concrete that is recycled does not include concrete from the demolition of large structures, such as stadiums. It can be assumed that the concrete recycling efficiency in the year 2000 was higher than is presented here.

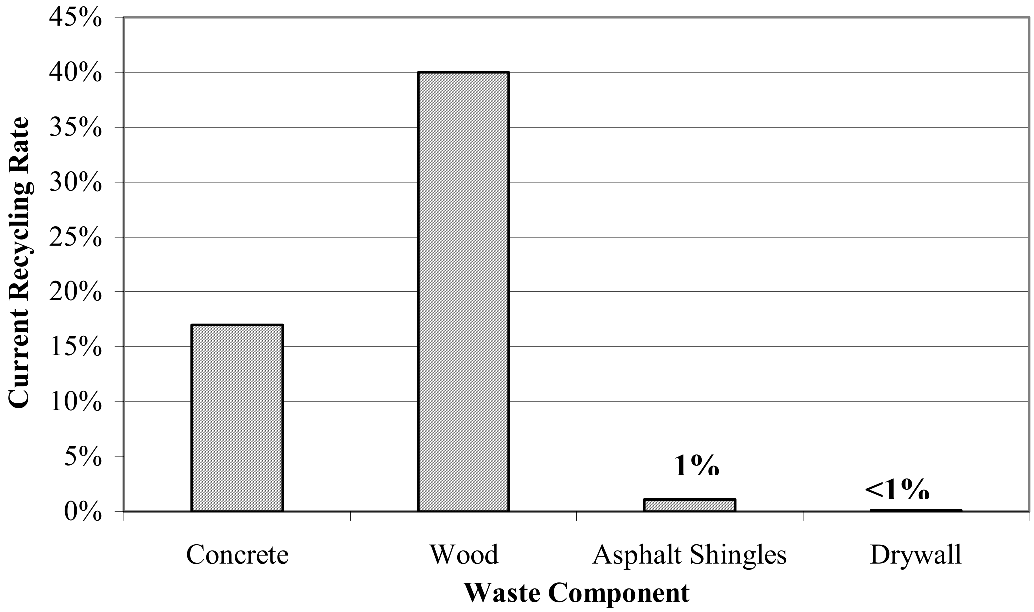


Figure 12.6. Current Recycling Rates of Four Major Components of C&D Debris.

12.7 Limitations to Recycling

Limitations to recycling exist for all of the waste components. Of course, the most limiting factor that applies to all materials is hauling costs. If hauling the material to where it can be recycled or where it can be used costs more than what it is worth, people will not recycle that material. Recycling must be beneficial in some respect for all parties involved in order for it to be successful.

Recycled concrete must compete with the large crushed stone industry in Florida, especially in South Florida where limestone is mined. In this region, the price of the recycled concrete will have to be less than that of crushed stone. Industries in North Florida do not have easy access to crushed stone. A recycled concrete program in this region might be more successful. Recycled C&D wood competes with land clearing and yard trash. Land clearing and yard trash can both be used in the same markets and have less risk of being contaminated with lead paint or arsenic (from CCA pressure treated wood). Post-consumer asphalt shingles (asphalt shingles from C&D debris activities) must compete with asphalt shingle manufacturer scrap waste. Manufacturer scrap waste is cleaner and is never contaminated with nails. Post-consumer asphalt shingles can be processed to have little or no contamination, but manufacturer scrap is guaranteed to have no contamination. Waste drywall must also compete with manufacturer scrap as well as synthetic gypsum sources, such as power plants that produce gypsum when removing sulfur in the air pollution control systems.

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