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Development of An OnSite Waste Management System and Recycling Infrastructure for Residential Construction in Florida

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This research project was sponsored by the Building Construction Industry Advisory Committee under a grant from the State of Florida Department of Education.

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Part 1: Residential Construction Prototype

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The overall purpose of this effort is to assist the construction industry in performing its waste management tasks in as environmentally friendly a manner as possible by diverting construction waste from landfills into recycled or reused products. In addition to the environmental advantages of this process, there are economic advantages as well. The combination of economic and environmental advantages include: (a) conservation of materials and energy, (b) reduction in the cost of waste disposal, (c) efficient use of construction materials, and (d) the good public relations value of responsible management of increasingly scarce resources. Additionally, the outcome of this effort will be programs that will initiate a movement within the construction industry to educate the broad spectrum of construction managers and trades to the need and importance for responsible materials management. This program begins with residential construction because the complexity of construction operations and the variety of materials utilized are considerably less complex than for commercial and industrial construction. Future efforts will extend the methods and technologies identified under the residential construction programs to these other construction sectors.

Construction and demolition (C&D) waste is clearly a major problem for the construction industry. It may be a cost problem for builders in areas of Florida where tipping or waste disposal fees are high, usually major metropolitan areas such as Miami, Jacksonville, Tampa, and Orlando. The evidence shows that only when the tipping fees exceed $50 per ton will builders consider construction waste to be a major problem. However, in many areas of Florida, due to a variety of circumstances, the cost of disposal is under $10 per ton and the cost significance to builders is very slight. The major problems that still remain are that the construction industry is perceived negatively with regard to the waste it generates and its lack of concern about the impacts on Florida's water and land resources. Results from a wide variety of sources show that builders can significantly reduce their generation of C&D waste, profit from

it financially, and receive positive publicity for their efforts. This is clearly a win-win situation, one that builders can and should take advantage of at every opportunity.

In this study, the researchers analyzed the waste generated for typical residential construction in Florida. It is hoped that this effort will result in further studies that assess construction waste, develop techniques for waste reduction, and create feedback from the industry to its materials suppliers. This feedback would help influence how vendors supply and package the materials flowing to construction sites as well as encourage them to develop products that utilize the waste generated from C&D activities. By implementing these changes, the building industry will support sustainable development through energy and resource conservation and landfill life extension.

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Chapter 1
Introduction

1.1 Introduction: The Construction & Demolition Waste Problem

Construction and demolition (C&D) waste is a major, obvious target for recycling efforts because it typically constitutes 15 to 20 percent of a community's waste stream volume (Apotheker, 1990). A systematic approach for builders to address their waste generation problems in a constructive manner does not currently exist in Florida. The creation of a system for builders to utilize to address this problem would have the advantage of moving the State closer to an era of "sustainable development" or "sustainable environment."

The relatively recent onslaught of Hurricane Andrew is an example of an extreme condition that illustrates just how serious the lack of a construction waste management scheme can be. The damage caused by Andrew generated a staggering quantity of waste in South Florida, resulting in the destruction of 75,000 homes. An average of 30 tons of waste debris had to be disposed of for each destroyed home, or 2.25 million tons of material (Kibert, personal communication). The tipping fees ranged from $20 per ton in Walton County to over $100 per ton in Monroe County, an average of $40 per ton. The cost was on the order of $100 million, simply for the disposal of this debris which includes destroyed homes, buildings, infrastructure, trees, and other debris. Not taken into account was the accelerated requirement for new landfill capacity in these counties as a result of the unforeseen utilization of capacity for this disaster. Additionally, the construction activities that rebuilding these communities will generate about 2.5 tons of waste per home. Clearly, a well-developed recycling infrastructure could have had enormous positive impacts because the vast quantity of waste being generated could have been reused with parallel benefits to the communities and local governments. Other disasters will inevitably strike Florida and the availability of a recycling infrastructure would greatly improve the situation the next time a hurricane occurs. Obviously this is an extreme scenario, but it does illustrate the scale of waste that can be created in a short period of time by an unexpected event such as a natural disaster.

1.2 Construction Waste Recycling System Components

On a daily basis, the existence of a complete construction recycling system consisting of the three M's: Methods, Machinery, and Markets, which are necessary in these times of decreasing landfill space, increasing material costs, and decreasing resources.

Methods:

The recycling of construction waste requires a standard methodology that all construction firms can follow. A major issue is whether the waste should be separated on-site or be delivered to a municipal materials recovery facility (MRF) or other processing site as mixed waste. Clearly, the possibility for selling separated materials is higher than for mixed waste. Additionally, the separation of mixed waste at the MRF can be a costly and time consuming process. A standard system of providing several on-site waste bins for separation of waste into major categories may be feasible. A significant portion of the method must be the actual conduct of construction by the work force. Their education and training is imperative in order to insure that materials are used in an optimal fashion. It should be noted that the methods that are developed as an outcome of this effort will have to be economically feasible. Ideally, it would be beneficial if the overall costs of waste disposal were reduced as a consequence of contractor participation in a recycling program. The pricing structure or other incentives built into the program should, in time, provide an opportunity for the contractors to be better compensated for their active participation.

Another waste management option is to make subcontractors responsible for their individual waste management during construction. This can be especially effective because subcontractors produce narrow categories of waste and do so on numerous jobsites. The subcontractors can be more effective in reducing their individual waste stream as well as in finding markets for materials they can recycle. For example, a residential dry wall contractor usually generates most of his waste within a seven to ten day period per home. This waste can easily be contained for resale/recycle on-site before it becomes commingled with the other C&D waste.

Machinery:

A construction waste recycling operation must have the appropriate technology available to it to enjoy successful operations. For example, a chipper for processing gypsum wallboard which constitutes up to 15% of C&D waste and which is perhaps the most troublesome material to recycle, has been developed. The chipper can process 120 tons per day (tpd) of wallboard into a material that can be used as an oil spill absorbent, cat litter, or soil amendment. Similar technology consisting of machinery and industrial/chemical processes are necessary to create a well-functioning recycling infrastructure for other types of C&D waste. This type of investment can be profitable for large drywall subcontractors.

Markets:

Perhaps the most difficult aspect of all recycling operations is closing the loop: finding markets for the output of the MRF or other processing facility. The typical waste of residential construction operations: asphalt shingles, gypsum wallboard, insulation, all have low market value in terms of recycling. Incentives for recycling these materials must be put into place. One method for causing a higher rate of recycling is the brute force approach of using legislation to achieve the desired effect. The Duty of Care provisions of the United Kingdom Environment Act of 1992 is an example of such an approach that could conceivably be taken to insure the markets are more responsible for the materials they are putting into buildings. This provision dictates that material suppliers are responsible for the disposal of their products, including the waste from construction and packaging of such materials.

1.3 Approach

The approach in this project to creating a system of waste management and recycling for residential construction will be as follows:

(a) Assess the existing Methods, Machinery, and Markets that have been identified in similar efforts in the U.S., Canada, and Europe.

(b) Determine the scope of the residential construction waste problem in Florida by assessing the categories and quantities of waste from home building.

(c) Examine current practices throughout Florida (C&D landfills and commercial recyclers) to determine their beneficial aspects and problems.

(d) Determine existing and potential markets for all components of the residential construction waste stream in Florida.

(e) Create a demonstration project with the cooperation of construction industry to test a prototype system that can be utilized throughout Florida.

The following is a detailed description of each of these steps.

(a) Assess the existing Methods, Machinery, and Markets that have been identified in similar efforts in the U.S., Canada, and Europe.

A shortage of landfill space has forced other countries and various regions of the U.S. to face up to the quantities of construction waste that were beginning to choke the few remaining landfill sites.

Perhaps the most advanced construction waste system in North America exists in Toronto, Ontario, Canada. A national blueprint entitled the "Green Plan" that provides comprehensive direction for the nation to follow in creating a sustainable environment was the starting point for Toronto's Build Green Program. The Canadians have declared that virtually all construction waste is, in fact, recyclable. Cooperation between construction industry, material suppliers, and local government has led to a number of innovative programs that further the direction of this program. A "Build Green" label is offered to manufacturers of construction materials that contain a recycled material content. A "Build Green Street" was included in the National Home Show in 1992. Its purpose was to teach construction industry, the general public, students, the media, and government about the possibilities for recycling various materials. A "Re-Uze Centre" was a prominent part of the program, showing how demolition materials such as brick, plumbing fixtures, piping and others could have a second life in other construction. On-site separation of construction waste into appropriate bins is now an accepted way of life in Toronto and both the citizens and construction industry are pleased with the outcome. The active participation of construction industry in this program has had the added benefit of vastly improving on its former image as a pillager of the land.

In Portland, Oregon the local multi-municipality agency, METRO, that is responsible for solid waste disposal, has started a number of positive initiatives to promote recycling of construction waste. Some level of construction waste recycling is occurring in Staten Island, NY; Brooklyn, NY; Cambridge, MA; Portsmouth, NH; Philadelphia, PA; Bridgeport, CN; and several other locations. With the exception of METRO in Portland, none of these programs are remotely as comprehensive as the Canadian efforts. Nonetheless these various approaches will be carefully studied to define the best features of each for incorporation into a strategy for Florida.

(b) Determine the scope of the residential construction waste problem in Florida. The methods of construction in Florida vary only slightly from other states or for that matter, from Canadian practices.

(c) Examine current practices throughout Florida (C&D landfills and commercial recyclers) to determine their beneficial aspects and problems.

A significant amount of experience with recycling of construction debris has occurred and continues to occur in Florida. There are a significant number of C&D landfill sites operated by private owners that, according to Florida statute, are permitted to accept clean construction site waste debris. At the present time Florida has about 800 of these C&D landfill sites. These private operations were quick to realize that the material entering their sites was in fact a valuable commodity. In addition to the C&D sites, a number of private recyclers have operations in Florida, the most prominent being Kimmins Recycling Corp. which operates MRF's in Miami, Tampa, Jacksonville, Lantana (near West Palm Beach) and Clearwater. Realco and KrushCrete operate combination C&D landfills and recycling operations in the Jacksonville area. It should be noted that of the C&D waste entering a typical Kimmins MRF, only about 50% is in fact recycled, with the remainder being landfilled (Table 1.1). A typical rule-of-thumb is that 6 tons of waste are created for each newly constructed house. Clearly, these quantities must be clarified in order to provide a better understanding of the material types and quantities flowing off residential construction sites. This information can also be used to determine the quantities of problematic material being generated, materials that will have great difficulty in being recycled or reused. In these cases cooperative work with materials suppliers may be required to improve the recyclability of their products. The bottom-line however is that the scope of the problem must be fully understood in order for detailed planning to occur.

Table 1.1 Composition of C&D Debris at a Kimmins Recycling Facility (Woods, 1992)

	Material Description	Volume %	% Recycled
WOOD	construction lumber	25.0	70
	pallets	2.0	95
	trees and stumps	5.0	100
PAPER	cardboard	17.0	75
	rolled paper	0.2	0
	misc.	0.6	0
CONCRETE	concrete block	1.0	0
	poured concrete sections	1.0	50
	plaster	0.3	0
	brick	0.2	0
PLASTICS	plastic pails	1.0	0
	plastic pipe	0.2	0
	polyethylene sheets/styrofoam	0.8	0
METALS	ferrous metals	5.0	95
	non-ferrous metals	2.0	95
ROOFING	shingles	3.0	0
	built-up roofing	5.0	0
	roofing insulation	5.0	0
EARTH	dirt	2.0	30
MISC	drywall	15.0	0
	broken glass/windows	0.1	0
	old doors and frames	0.1	0
	building insulation	4.0	0
	empty paint containers	0.8	0
	ceiling/floor tile	0.8	0
	carpet remains	2.0	0
	plumbing fixtures	0.1	0
	electrical fixtures	<0.1	0
UNACCEPTABLE	batteries	<0.1	100
	white goods	0.1	100
	tires	0.1	0
	furniture	0.2	0
	household garbage	0.2	0

The experiences of these various operations is important in addressing the C&D waste problem in Florida. Increasing the cooperation among these operations, construction industry, and local governments would be a major step in improving the handling of construction waste.

(d) Determine existing and potential markets for all components of the residential construction waste stream.

Perhaps the most essential but most neglected aspect of creating a recycling infrastructure is the development of an outlet for the raw materials and commodities emerging from the recycling operation. There have been numerous accounts of failed recycling efforts in other sectors that had simply fallen apart due to a lack of markets for their output. Municipalities have had the experience of collecting masses of newsprint and collect them in large warehouses only to have to incinerate or landfill them because there was no demand for them. Markets for recycled products can be extremely difficult to create and may ultimately be the limiting factor in any recycling venture. In some instances government involvement may be necessary to provide tax incentives, investment credits, or other stimuli for market development. Another difficulty is matching supply and demand for the recycled materials. If markets do in fact develop, either through market forces or via government incentives, it is necessary to assure a consistent flow of materials into the market. Again, other recycling efforts have failed due to an inability to supply the customer with products in a reliable manner. In Canada, the Toronto Home Builders Association has determined that virtually all construction waste is recyclable and that there are markets for the recycled waste. In Florida, for a residential construction waste recycling program to succeed, a similar careful assessment of market conditions will have to be made and any holes in the markets for specific waste products will have to be closed.

(e) Create a demonstration project with the cooperation of construction industry to test a prototype system that can be utilized throughout Florida.

After all the steps described above have been virtually completed, it will be necessary to test a prototype system on a reasonably large residential construction project. The construction industry, state and local governments, and other interested parties will be involved to design a system that is able to be as user friendly as possible. The concept of source separation on-site will be tried out using labeled disposal bins for the main waste components. Training of general contractors and subcontractors will be necessary to assure that all parties on the construction site fully understand the program. Cooperation of local government, C&D landfills and/or private recyclers, and material suppliers will all be enlisted for this program. An on-site analysis group from the University of Florida will conduct a detailed analysis of all waste materials created during the construction process and will classify all materials by weight and type. The program will be designed to be amended as experience dictates. At the termination of the demonstration stage of the program, a detailed manual of how to carry out a residential construction waste recycling program will be created. The manual will also contain details of how to analyze the economics of the program, how to identify and create markets, and how to develop a program that integrates the best interests of the contractor, community, and local government.

This then defines the scope of the overall research program to address the generation of C&D waste from residential, commercial, and industrial construction. In this particular project, only the characterization of residential waste was carried out to assess how residential construction waste generation in Florida compares to other states and locations.

Chapter 2
Background

2.1 Introduction

Abundant natural resources, availability of cheap land, and the evolution of building practices in the U.S. have resulted in construction materials and techniques that are both wasteful and unsuitable in terms of environmental impacts. The tradition of home ownership in some ways has further exacerbated the conflict between the built and natural environments as housing has been normally constructed in a manner that delivers the house at minimum first cost. This has resulted in widespread home ownership of buildings of low durability, that require high, continuous maintenance, and whose lifetimes are ultimately short. Production of speculative business developments has also created a situation where the cheapest methods and materials to deliver the facility were employed.

Several forces are converging that have the potential to rapidly change these historic trends. First, a strong environmental movement both in society and at all levels of government is forcing a re-examination of production techniques in all industries for their environmental impacts and suitability. Second, cheap land that had provided space for landfills and other sites for the disposition of trash from a "throwaway society" has become scarce, with some large metropolitan areas such as New York and Los Angeles having to export their trash considerable distances at high cost. Third, a vestigial movement within American construction industry is addressing the concept of a global sustainable environment from its perspective and beginning to consider the revision of traditional development and construction practices.

This movement toward sustainability is quickly forcing the revision of the traditional Engineering and Economics considerations to add a third "E": Environment. Construction materials, energy systems, water usage, facility siting, construction operations, Indoor Environmental Quality, and effects on plants and wildlife habitats are now part of a broad matrix of issues that are being evaluated. This research addresses one of these component trends in the U.S. : residential construction waste recycling.

2.2 Quantifying the Waste Stream

The construction process along with its associated land clearing and demolition activities is a considerable portion of the U.S. economy with a $500 billion dollar volume accounting for about 8% of U.S. economic activity. The waste generated from construction activities, although large in volume, amounts to only a relatively small cost to the builder, 0.5% of the cost of new homes.

No single study exists that comprehensively examines the size and scope of waste generated from construction and demolition activities (C&D) in the U.S. Several studies that have attempted to assess C&D waste have concluded that it comprises between 15 and 30% of total municipal solid waste (MSW) (Rathje, 1992; REIC, 1990). Two studies by the Massachusetts Institute of Technology in the late 1970s examined correlations between C&D waste generation and population levels, building and demolition activity and extraordinary projects, such as urban renewal activity or disaster clean-up efforts. Due to a lack of strong correlations and of accurate records on generation and disposal activities, the quantification of C&D waste has been extremely difficult (Apotheker, 1990). However, a sizable number of state and local studies give clues to the mass and volume of this waste stream.

A 1991 study conducted in the northeast U.S. classified this waste as rubble (50%), wood (25%), or other materials (25%). Rubble is defined as concrete, masonry, bricks, and dirt while other materials consist of drywall, plaster, metals, and tar-based materials such as roofing shingles, siding, and waterproofing materials (Donovan, 1991).

The generation of construction and demolition waste in one northeastern state, Vermont, amounted to 490,000 tons for a population of 567,000 people, resulting in a waste generation rate of 2.14 kg/person/day. About 41 percent is recycled, largely due to the high asphalt content of the waste stream, which amounts to about 46 percent of the total. After other recycling activities are factored in, about 36% or 0.77 kg/person/day must be disposed of in a landfill (Spencer, 1991).

In a report done by the Solid Waste Association of North America (SWANA), it was mentioned that C&D waste generation rates range from 0.05 to 1.60 kg/person/day from 14 references. These references dated from 1968 to 1991, and cover urban and city areas and the generation rates were derived from different sources (see Table 2.1).

The amount of C&D wastes generated and needing disposal depends on (Donovan, 1991) :

- the extent of growth and overall economic development, and the resulting level of construction, renovation and demolition
- periodic special projects, such as urban renewal, road construction and bridge repair programs
- unplanned events, such as the earthquake that severely damaged Los Angeles and the southern part of California in January 1994
- availability and cost of hauling and disposal options
- local, state, and Federal regulations concerning separation, reuse, and recycling of C&D waste
- availability of recycling facilities and the extent of end-use markets

There is no reliable technique to predict the precise amount of C&D waste generated in a specific community. However, it is possible to estimate generation and disposal by researching building permits, interviewing building contractors and demolition companies, visiting waste disposal facilities and talking with existing salvage and recycling companies.

Table 2.1 Published C&D Waste Generation Rates in U.S.
(Construction Waste & Demolition Debris Recycling - A Primer, 1993)

Generation Rate (Kg/Person/Day)	Developed by (or for) Source and Date of Data Used to Create the Rate
0.05	Unknown Listed in Franklin Associates Report - 1986
0.12	California Waste Management California Solid Waste Management Study- 1968 and Board for Population <10,000 Plan - 1970
0.18	Unknown New York State Solid Waste Management Plan - 1991
0.22	Gershman, Brickner & Bratton, Inc. Monterey Park, CA Source Reduction and Recycling Element - 1991
0.27	Metropolitan Planning Commission, Metropolitan Solid Waste Management and Recycling - Kansas City Region May 1971
0.29	Gershman, Brickner & Bratton, Inc. Town of Babylon, New York, Solid Waste Management Plan - 1991
0.31	California Waste Management Board California Solid Waste Management Study - 1968 and for population from 10,000 - 100,000 Plan - 1970
0.33	U.S. Environmental Protection Agency Listed in Franklin Associates Report - 1970 Urban average
0.34	Unknown New York State Solid Waste Management Plan - 1991
0.62	California Waste Management Board California Solid Waste Management Study - 1968 and Plan - 1970
0.65	Unknown New York State Solid Waste Management Plan - 1991
1.25	Boston, MA D.G. Wilson, "*The Treatment and Management of Urban Solid Waste*" - 1972
1.56	Wayne, NJ Quad City Solid Waste Project Interim Report - 1968
1.60	Washington, D.C. for 1968 D.C. Solid Waste Management Plan Status Report - 1970

Additional information from the Office of Solid Waste Management at the University of Illinois on C&D waste generation is shown in Tables 2.2 and 2.3 (Freeman, 1994). Table 2.2 indicates the demolition debris composition from a single large demolition site in Illinois.

Table 2.2 Construction Waste Production

6-Unit Apartment Building (9,000 sq. ft.)			Single Family Home (2,060 sq. ft.)	
Waste Type	Tons of Waste	% of Total	Tons of Waste	% of Total
Wood	7.40	44	3.40	46
Gypsum/ Dry Wall	4.25	25	1.88	25
Mixed Debris	3.00	18	1.13	15
Cardboard	1.08	6	0.40	5
Metals	0.52	3	0.44	6
Masonry	0.53	3	0.18	2
Total	**16.78**		**7.43**	

Table 2.3 Demolition Waste Composition

		Percentage of Material				
Building Type	No. of Bldgs	*Concrete*	*Brick*	*Wood*	*Paperboard*	*Steel*
Residential Wood	18	4	13	80	0	3
Residential Brick	4	0	73	23	3	2
Commercial Brick	9	20	71	12	1	3
Commercial Wood	3	7	18	73	0	3
Commercial Concrete	4	51	22	18	5	3

Waste generation on a square foot of construction basis is another method that has been tested in several construction projects with the result of a study conducted by Cornerstone Material Recovery shown in Table 2.4 (Cosper, Hallenbeck, and Brenniman, 1993). The quantity of construction waste per square foot for single family homes compares well with NAHB Research Center studies that have shown waste generation of about 6 lbs/ft^2. In the study shown in Table 2.4 and the NAHB studies, gypsum dry wall appears as a very problematical waste material, both in terms of its quantity (1 to 1.8 lbs/ft^2 of construction) and the lack of end uses for the waste.

Table 2.4 Construction Waste from Apartment and Single Family House				
	6 unit apartment building (9000 ft^2)		single family house (2060 ft^2)	
Waste Type	Tons	Percent	Tons	Percent
wood	7.40	44	3.40	46
gypsum/drywall	4.25	25	1.88	25
mixed debris	3.00	18	1.13	15
cardboard	1.08	6	0.40	5
metals	0.52	3	0.44	6
masonry	0.53	3	0.18	2
Total	**16.78**	100	**7.43**	100
Waste/ft^2	3.7 lbs/ft^2		7.2 lb/ft^2	

2.3 Management of C&D on Construction Projects

Most C&D waste is considered part of the municipal solid waste (MSW) stream and is disposed of in municipal landfills. Due to trends encouraging recycling and reuse and the more stringent constraints of MSW landfills, communities and contractors are increasingly targeting C&D waste for management other than disposal. A growing number of public and private organizations are formulating programs to separate C&D for recycling or other reuse projects. Because more segregated materials are available from a wide variety of C&D recovery activities, a growing number of companies are developing facilities to commercially recycle the materials generated. C&D waste is a target because it is both heavy and bulky, and therefore undesirable for disposal in landfills. On the other hand, many C&D materials have high potential for recovery and reuse. Recovering C&D waste can help communities reach their recycling goals and preserve space in their local landfills (Schlauder and Brickner, 1993). Recycling makes sense environmentally, and it is beginning to make economic sense in many parts of the U.S. C&D waste makes up roughly 25% of what goes into municipal landfills in the U.S. If local, state, and Federal landfills are included, C&D waste amounts to about 100 million tons a year, 90% of which can be recycled (Schlauder and Brickner, 1993).

For example, in Los Angeles in 1990, 400,000 tons of wood waste alone were taken to landfills. Translated to a *per capita* basis and applied to the entire country, enough wood is being thrown away in one year to provide the studs, joists, and rafters to frame 200,000 homes. About four tons of waste are generated during construction of an average single-family home.

However, depending on how well developed the local facilities and markets are, recycling will probably be more expensive at first than hauling everything to the dump. By starting a recycling program on the job-site, companies are making a good investment for the future. Even when it costs more, job-site recycling can give a company marketability with customers who are environmentally conscious. As public concern for the environment increases, constructors who recycle are looked on favorably by many owners. According to National Association of Home Builders (NAHB) Research Center, "The American public is now willing to incur *some* additional costs to make environmentally sound choices." And when more recycling facilities become available and the cost of recycling drops, contractors who already have a job-site recycling program in place will put themselves ahead of the competition.

The first step to job-site recycling is to do a waste audit to find out what kind of waste the projects are generating. The next step is to locate recyclers for each type of material. Finding markets for the waste and arranging for containers and transportation are the most important things to get the program started. There are several management measures that enhance job-site recycling.

- Training programs on waste management
- Source separation
- Getting sub-contractors to help
- Informing the customer

2.4 Construction Recyclers

In many locations of the U.S. C&D is disposed of in C&D landfills. Many states in U.S. are seeking to establish regulations for facilities which dispose of and recycle Construction and Demolition Debris (C&D). As defined by New York State, a C&D processing facility refers to "a recyclable handling and recovery facility which receives and processes construction and demolition debris and recovers recyclables in the process (Spencer, 1990)." Historically, local jurisdictions, in order to minimize large quantities of construction waste from entering and filling engineered landfills, have allowed private businesses to operate special landfills that could accept only the clean debris from construction activities. These private operations quickly realized the value of many of the materials being trucked onto their property for disposal and began separating materials that could be resold. Many of the firms that became involved in this business were in fact demolition contractors who were well aware of the high cost of disposing the debris they collected in their daily operations. A typical case is Wayne Gomez Construction of Denver, Colorado, a demolition contractor that had been paying $750,00 per year for disposal of C&D debris. This company invested in a state permitted site capable of accepting 600 tons/day of waste, consisting largely of wood, concrete, and asphalt. By charging their clients 50% of the cost of the municipal landfill ($2.00 versus $4.50 per cubic yard) they attract business and make a profit on their sales of recycled materials (Goldstein, 1992).

In the Northeast area, illegal disposal has become epidemic as landfills close and incinerators reject C&D materials. In response, Connecticut, New York, Rhode Island and Vermont have funded studies to evaluate C&D materials and their recycling potential, with an emphasis on end-use markets. California and many other states such as Florida have passed legislation to encourage markets for C&D materials. The Florida law requires that the Department of Transportation modify bid specifications for highway road base, sub-base and back-fill materials to include use of recycled materials, but without reducing quality of the construction (Spencer, 1990).

In other geographical areas the case is not so advantageous to the cause of recycling. In Miami, for example, the cost for processing C&D waste is $6/ton versus the tipping fee (landfill disposal fee) of $4/ton (Woods, 1992).

The rapid escalation in the costs of landfilling and social opposition to huge engineered landfills has forced state and local governments to consider methods to reduce the solid waste stream. The state of Vermont has a 10 year plan to recycle 40% of the solid waste stream by the year 2000. Part of their strategy is to stimulate recycling operations at C&D facilities. A study commissioned by Vermont indicated some of the levels of investment required for various types of C&D recycling facilities (Table 2.5) (Spencer, 1991). Vermont is considering a program that would provide low interest loans or subsidies to firms establishing solid waste processing operations.

Table 2.5 Investment costs for various levels of C&D recycling facilities

Type	Description	Capacity(ton/day)	Costs ($, x$10^6$)
Low Technology	Separates/salvages No on-site processing	50 - 500	0.5 - 1.0
Medium Technology	Accepts 1 or 2 types waste Some processing	100 - 500	1.0 - 3.0
High Technology	Accepts all C&D waste Extensive processing	500 - 1000	3.0 - 5.0
Integrated Waste	Accepts all solid waste Material recovery, recycling, landfilling	1000 - 2500	5.0 - 10.0

There are several technical problems that confront the operators of C&D recycling operations. C&D waste can have a wide variety of hazardous contaminants, making recycling a difficult proposition (Table 2.6) (Cosper, 1993). A sizable quantity of waste consists of various forms of wood from a wide variety of applications. Typically the wood has not been processed at the construction site and will have a significant quantity of nails, staples, and other embedded objects. Additionally the wood is mixed with other waste debris such as drywall, masonry, brick, concrete, and metals. Further because of its origin or manufacture, the wood product may be an unusable hazardous waste or may be allowed only for restricted uses (Table 2.7).

Table 2.6 Potential Hazardous Contaminants in C&D Waste

Acetone	Adhesives	Anti-freeze
Benzene	Carbon black	Caulking, sealants
Chromate salts	Cleaning agents	Coatings
Concrete curing compounds	Cutting oil	Diesel fuel
Etching agents	Fiberglass	Freon
Glues	Helium (in cylinders)	Hydrochloric acid
Kerosene	Lubricating oils	Methyl ethyl ketone
Mineral wool	Paint/lacquers	Paint stripper
Pentachlorophenol	Putty	Sealers
Solder flux	Solder	Sulfuric acid
Varnishes	Preservatives	Acetylene gas
Ammonia	Asphalt	Bleaching agents
Carbon dioxide (in cylinders)	Caustic soda	Chromium
Coal tar pitch	Cobalt	Creosote
De-emulsifier for oil	Diesel lube oil	Ethyl alcohol
Foam insulation	Gasoline	Greases
Hydraulic fluid	Insulation	Lime
Lye	Motor oil additives	Paint remover
Particle board	Floor polish	Resins/epoxies
Shellac	Solvents	Waterproofing agents

Table 2.7 Restrictions on wood waste at C&D recycling plants		
Material	**Hazardous content**	**Applications**
Shingles, siding	Asbestos	Unusable
Railroad ties Telephone poles Marine pilings	Creosote	Unusable
Wood from garages, barns, out-buildings	Ignitable petroleum distillates	Unusable
Wood with lead based paint	Lead	Unusable
Wood with mercury based paint content	Mercury	Unusable
Pressure treated lumber	Chromated copper arsenate	Restricted
Plywood, particleboard	Formaldehyde Phenol-formaldehyde Urea	Restricted
Laminated wood	Naphthalene	Restricted
Wood trim	Varnishes/stains	Restricted

The vast bulk of waste derived from construction and demolition debris in the U.S. is mixed waste as noted above. Neither existing regulations nor the overall economics of waste recycling dictate site separation of construction and demolition waste. This would clearly increase the value of the materials to be recycled. The time and expense to separate the waste materials at the C&D processing increase the cost of recycling, decrease their value due to residual contamination, and results in the rejection of substantial quantities of materials that could be recycled but that are too contaminated to be considered for this purpose.

2.5 Government Impetus for Recycling

The major force behind construction recycling originates from several key municipalities who offer advice and assistance in organizing recycling programs as well as motivating construction industry to become involved in sustainable or "green" construction programs. Some good examples of this are the cities of Minneapolis-St. Paul and Los Angeles, both of which publish detailed guides (Construction Materials Guidebook, 1993 and Construction and Demolition Waste Recycling Guide, 1994). Additional major programs of significance can be found in Portland, Oregon and Austin, Texas.

There is substantial opportunity to increase the marketability of the construction and demolition waste in the U.S. and Canada. This will help to decrease the amount of solid waste needing to be disposed and thus alleviate the burden of landfill sites. The private sector is responding quickly to the emerging C&D recycling trend. This is particularly true for portions of the waste stream that already have a relatively high value in end-use markets. However, given the emphasis on waste reduction, reuse, and recycling in many states, it is important that federal, state and local solid waste agencies assist public and private entities in developing and financing certain types of processing facilities. This assistance could be accomplished through a variety of measures, such as tax incentives, reduced-rate loans and risk-sharing programs. More than 17 state governments are encouraging recycling through a variety of tax incentives, including income tax credits, sales tax exemptions and property tax exemptions.

For example, the state of Florida offers a sales tax exemption on recycling machinery purchased after July 1, 1988. Tax incentives are also offered to encourage affordable transportation of recycled goods from collection points to sites for processing and disposal. In Kentucky, as an incentive measures for attracting recycling facilities to the state, property tax exemptions are offered to businesses and industries that recycle materials. In addition, as new and innovative techniques and equipment to process C&D materials develop, planning and regulatory agencies will be increasingly involved to determine the best ways to encourage, monitor, and regulate the processing activities (Donovan, 1991).

2.6 The Portland Success Story

Of all locations facing C&D problems nationwide, none has had quite the success in addressing the problem as has Portland, Oregon (Woods, 1996 and McPhee, 1996). The reasons for their success are multiple.

(1) Tipping fees have risen from $17.50 per ton in 1988 to $75 per ton today.

(2) All levels of government, from state down to local officials have aggressively targeted C&D waste.

(3) The regional government coordinates the local governments and dozens of C&D projects to include research efforts.

In addition, Portland's city government set a goal of diverting 60% of the waste stream by 1997 and enacted an ordinance effective January 1, 1996 that mandated that all construction projects of $25,000 or more must set up a recycling program for their C&D waste. This program has three tiers:

- For projects between $25,000 and $500,000, contractors must insure that as much wood, metals, and cardboard as possible are recycled.
- For demolition projects of more than $500,000, a recycling program for rubble, landclearing debris, metals, and wood must be set up.
- For construction projects of more than $500,000, a recycling program for rubble, metals, OCC, and wood must be set up.

In spite of this program, it is the $75 per ton tipping fee that is the driver because the economics of setting up recycling programs are excellent. Portland METRO, the metropolitan waste handling utility, discovered that $50 per ton was the crucial levy that forced a dramatic increase in the quantities of materials being diverted from landfills into the secondary materials markets.

2.7 Progress in Collier County, Florida

Although not as advanced as the progress in Portland, some local governments in Florida are having some measure of success in dealing with C&D waste. Collier County began looking at the situation in the late 1980's and decided to obtain bids for recycling C&D waste. After an initial experiment that proved the viability of recycling this waste, the County hired Modern Recycling, Inc. to set up and run the operation. As of 1995 Modern was processing 70,000 tons annually with the County paying $15.80 per ton diverted from the landfill (Beyond Landfilling, 1995).

2.8 Conclusions

Market and government forces and a decreased availability of landfill disposal space in many parts of the country are causing the serious consideration of recycling C&D waste. The first job-site recycling programs are beginning to appear in U.S. cities that have vigorous programs to assist construction industry in this effort. In the European Union (EU), countries will no longer be able to dispose of C&D debris in landfills after 2010 (DeGrane, 1995). The advent of "green" or sustainable construction efforts that place emphasis on recyclable materials and the use of recycled content materials will add further impetus to this trend. A combination of markets, tipping fees, and builder behavioral changes could dramatically change the situation in Florida and turn the C&D waste stream into raw materials, jobs, and new businesses.

Chapter 3
Methodology Development

3.1 Introduction

There is no generally accepted methodology in the U.S. for the characterization of C&D waste for residential construction. Therefore a methodology for determining the composition of construction waste for new residential houses had to be developed for this study. Depending upon the phase of construction, different waste categories are being generated. Due to the non-homogeneity of loads and the variance of waste categories generated in each construction phase, a statistical sample procedure cannot be readily used.

In this project, a C&D waste characterization methodology has been developed for new residential construction. However, it can be modified for all C&D waste sources to include residential, commercial, institutional, and industrial, both new construction and also remodeling and demolition.

3.2 Methodology Review

Current C&D waste composition studies are not adequate to generally characterize these waste flows. The lack of a common methodology in these studies for sampling and categorizing waste flows results in needless duplication and the creation of nontransferable data.

A methodology for the characterization of Municipal Solid Waste (MSW) was developed by Reinhart (1996). It outlines all the issues which need to be addressed in the planning and implementation phase of a MSW composition study. C&D waste is less homogeneous and more bulky than MSW. Due to their different natures, this methodology cannot be easily adapted to the needs of a C&D composition study. However, some of the main elements of this methodology are applicable and are used as a framework for the methodology describe below.

3.3 Study Plan

The determination of waste quantity and composition from construction of new residential houses can be very complex, since it involves coordination between builders, haulers, landfill operators and the work crew which samples and characterizes the waste. The study plan has to include clear objectives of the study, the waste stream categories, and the sorting site (construction or landfill). Careful preparation of the study plan ensures not only the accuracy and relevance of the data collected but also minimizes bias and creates a more cost effective study.

3.3.1 Define Waste Sources

New residential construction is assumed to be the only source for C&D materials in this methodology. An evaluation of current building practices should result in a breakdown of the major types of construction used to build residential homes (masonry/block, wood frame with brick or other siding). This will help with the determination of the number of homes of each type necessary for an effective composition study. If the waste comes from a multi-home development, some loads could contain the waste materials from more than one house. Prior to the initiation of the study, participating builders need to understand the conditions influencing the value of loads. For example, rainwater distorts the recorded weights of the material or mixed loads are unusable for characterization if the origin cannot be determined. To establish a profile of each house as a waste source generator, records regarding the individual structures, such as design details and square footage, need to be recorded.

3.3.2 Hauling Companies

Hauling companies, their drivers and the scale house workers are critical for load information for studies conducted at the landfill. Educating them about the importance of the study is a primary means of ensuring accuracy in data information. Pre-dump load identification (load origin and characteristics) can be incorporated on the scale house ticket given to the scale house worker by the hauler. While still in the roll-off container, the wastes should be checked for water, contamination and volume. The hauling company should be kept informed about the ongoing study, weighing procedures at the scale house, and the location for disposing loads at the landfill. If any change in scheduling occurs, the drivers need to be notified at once. Cultivating good relations with the hauling company and scale house employees benefits the study by creating informed parties capable of aiding recordkeeping on C&D wastes.

3.3.3 Worker Training

To ensure accurate results, participating workers must be informed of the purpose of the study and appropriately trained (Reinhard, 1996). They must be able to safely lift and maneuver heavy and hazardous materials. To better protect them and ensure accuracy, training sessions should be conducted to initiate new workers. A successful field study depends upon the participants understanding the following points from the training session:

- The waste composition study purpose, category definitions, significance of the collected data, and the need for precision in measurement.
- Sorting procedures and duties should be clear to all workers.
- The importance of safety. Occupational Health and Safety regulations require the use of safety equipment, and a planned policy for dealing with hazardous conditions must be followed. A site and study specific training manual for reference should be available.
- Means and methods of logging data into categories.

3.3.4 Safety Procedures

Health and safety procedures must be understood by all workers. Adequate supervision, training and planning are necessary to prevent accidents and injuries. Before each sorting session, workers need to be briefed on dangers in the field and in handling waste. A planning session before the day's activities should set the objectives for handling and sorting wastes. For safety, teams of workers can be as high as six individuals but no less than four. One person should be designated as a supervisor to monitor worker safety and log data. Health and safety policy should include:

- Procedures for safely handling wastes
- Site map and directions to medical facilities. Emergency numbers and contacts should also be posted
- Accessible communications equipment
- First aid and fire extinguisher locations
- Potable water for drinking and washing
- Designation of a shaded rest area
- Means of demarcation for waste sorting areas for crew visibility and protection from vehicular operations
- Smoking ban around all wastes
- Worker hygiene after touching waste to prevent ingestion or contamination.
- Respirators capable of filtering organic vapor, mist and dust need to be available to workers.

3.3.5 Define Waste Categories

A general list of waste categories was developed for this study (Appendix A). The key quality of a good category list is its flexibility. Subcategories for the general list may vary between studies depending on the objectives and local conditions. However, the general waste stream components should be consistent to allow comparison with other characterization studies.

The category list should be flexible enough to accept a broad range of C&D wastes under one material category. Specificity in the description of the wastes received can be developed in the study according to the composition objectives and the amount of time and money available. Waste categorization is never complete until all field data are collected. Actual field conditions may introduce subcategories that were unanticipated in the study plan but are also desirable to include in the category listing.

3.4 Sample Plan

A Sample Plan sets procedures for logging and identifying categorization data, waste handling and sorting, and measurement of weight and volume. The nomenclature for identification and record keeping is adaptable to a construction site or landfill site. A deposit of a full roll-off container at a landfill or a mound of C&D debris at the construction site is called a "load". Each load is identified by its origin such as name of the development and/or the address. Once a load is divided and weighed, the material is reflected in categories. Both loads and material categories have a descriptive hierarchy for identification in the study. A system of coding the residence, the load, and material categories prevents the loss or misrepresentation of data.

3.4.1 Development of Field Data

The Field Data Sheets are the primary means of ensuring accuracy and precision of the waste samples. The Data Sheet is both the quality control for field data recording and the principal means of data storage. Accuracy and efficiency in a thoughtful layout provides not only a speedy tool for recording data in the field, but makes the transferring of data into computer spreadsheets more efficient and allows expedient analysis. (See Appendix B)

Field conditions challenge the best sampling procedures. Categorization of C&D wastes should utilize both empirical measurements and visual estimations to overcome these field conditions. Visual estimation techniques for weight, volume and material condition can be added to the field data sheets. Estimation can provide qualitative information that explains variations in data because of contamination to the loads.

Field data sheets should be prepared prior to sorting. A spreadsheet layout is useful in logging and totaling successive data entries. Certain information may or may not be applicable to log on the field data sheets depending on the location of the study at either a landfill or construction site.

The cover sheet information for the load should include the entire list below unless solely specified for the landfill (lf) or construction site (cs):

- Contractor information with contact numbers
- Name of development and/or address of construction site
- Material origin information: material origin; type of construction; type of building
- Waste hauler and landfill with contact numbers (lf)
- Time of arrival at a landfill (lf)
- Pre-dump survey information collected from the scale house and driver (lf)
- Roll-off container conditions, total volume characteristics (loosely filled or compacted, full or nearly empty) (lf)
- General material weight information: weight of full roll-off and truck; weight of truck; weight of waste (lf)
- Space for any special notations or waste conditions
- Identification of the load number
- Workers participating and number of hours worked in sorting

Waste category field sheets should generally contain:

- Identification of load number with sorted category sequence and date of measurement.
- Specific conditions of waste characteristics (e.g. water or extraneous contamination).
- Category type.
- Weight of the filled container, dirt on scale, weight of empty container, and weight of waste.
- Volume of container, estimated percentage of container filled, and the actual volume of wastes in the container.
- Material density information for calculation of theoretical volume.
- Columns totaling all sample weight and volume measurements.
- Comments and annotation section.

3.4.2 Waste storage, handling and sorting

Wastes can be sorted at a C&D landfill or at the construction site. For handling and sorting, each location offers distinct advantages and tradeoffs in space, time and money. Protection of the waste during accumulation at the construction site, transportation, and sorting at the site are critical to insure valid weight and volume measurements.

Optimally, a paved surface (1,000 to 2,000 sq. ft.) at an elevation higher than its surroundings should be designated as the sorting area. A covered indoor area to protect workers and the wastes is always preferable to the outdoors. Facilities such as those provided for the NAHB C&D study are best for off- site storage and sorting.

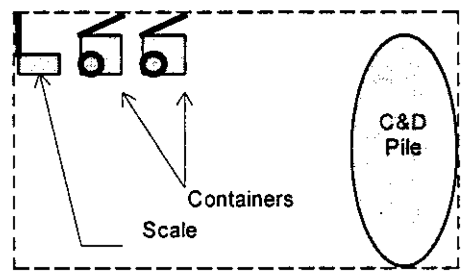
Simple precautions for open air storage of wastes, in lieu of covered containers or facilities, may be acceptable if followed consistently. At the sorting facility, C&D wastes should be placed in a location that is high, clean, and separate from other activities. If wastes are unprotected, the sorting should occur immediately upon arrival to prevent contamination by extraneous soils, moisture, and other wastes. In the event of precipitation or delays in sorting, every effort should be made to cover the load. Protection from the elements keeps materials free of contamination and isolated from other waste loads.

Sorting at the construction site assures greater accuracy by minimizing handling and contamination but has the disadvantage of more frequent sorting events due to space restriction. Travel time for the sorting crew due to more sorting events or sorting locations should be an additional consideration for selecting an appropriate sorting site.

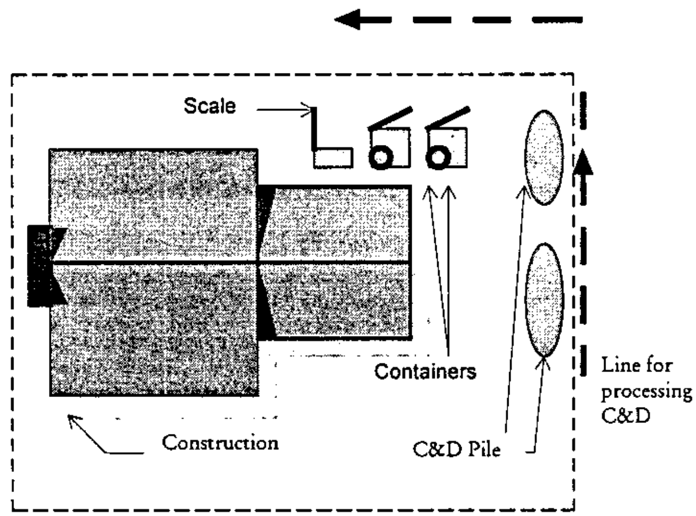
Depending on the scope of the study these factors must be weighed according to their time and cost benefits.

Sorting area

Layout of the sorting area may be different for the landfill and construction sites. Conditions at each of the two locations require not only different organization, but also distinct commitments to site management for work visits and tidiness.



Landfills usually have considerably more area for material sorting and transportation to and from the scale. The scale needs to be located near to the waste separating area with adequate space to line up filled containers. Weighing and sorting areas should not crowd each others' locations. Compared to a construction site, residual clean-up is minimal at a landfill.



Sorting at a construction site can be significantly constrained due to the density of activities, people and equipment. Site management is more rigorous, requiring frequent visits to prevent C&D waste build-up that could be unsightly for the contractor and dangerous to working conditions. Proximity of scale, containers, and sort crew may require a more linear layout, such that a "disassembly" line for C&D piles is formed.

3.4.3 Waste measurement

Upon arrival at the landfill, the truck is weighed with and without the construction waste material. From these two weights, the weight of the load is calculated. After sorting the load into the various categories and placing the material in containers (with known tare weight), the weight of the material is determined and added to previous weights for the same category of this specific load. If no mechanical assistance is available, the amount of material placed in the container must be of a manageable weight since heavy containers may be difficult to move.

3.4.4 Contamination

The load must be visually inspected for contamination by water and municipal solid wastes (MSW). MSW can be physically removed but water presents a special problem. Water either accumulates at the bottom of the container or is absorbed by construction material. The water content for each category can only be visually estimated and subtracted from the material weight. The estimate is based upon a scale of 1 to 5 in whole numbers where 1 is dry and 5 is complete saturation. Using simple laboratory analysis, unknown saturation levels in a given category could be determined. A weight modifier can then be deduced by weighing a sample of the material ultimately water logged and completely dry. To illustrate the amount of water absorbed, test samples were randomly selected and dried in an oven to determine their moisture content. The results of this analysis are shown in Appendix D.

3.5 Weight and Volume Measurement Considerations

Scale quality and the rigor of the weighing procedure greatly effect the accuracy and precision of the field data. The quality of the scale is determined by its capacity, accuracy and appropriateness for the study. A scale's maximum and minimum loads should be the first criteria of selection. Overall accuracy and the portability or condition of the scale are also important.

Individual characterization studies may require different scale qualities depending upon the objectives of the study. For mobile weight measurements it is recommended that the scale has the following characteristics:

- A maximum capacity of 1000 lbs. and a minimum accuracy of +or- 5 lbs.
- A low flat bed for weighing. This facilitates moving containers on/off.
- Relatively light and easily lifted by two workers.

- Wheels with a locking mechanism.
- A scale level is useful for irregular field conditions.

In preparation of measuring weight, the scales should be properly calibrated. Containers for the samples should be clean, dry and weighed. Any dirt on the scale should be removed.

3.5.1 Volume Measurement and Holding Containers

In the waste characterization study, the volume of the entire load and its components are the most variable factors. Waste placement, compaction, contamination, and the shape of the holding containers all influence the measured volume. Waste volume for each category is primarily influenced by the care of placement in the container. There are several methods for measuring the volume of the mixed waste and of the various categories:

- The mixed waste volume: This volume indicates the amount of container space needed during construction without recycling activities. It is also the volume this material would have in the landfill without compaction. Contamination can add volume to the waste categories. MSW is the easiest to eliminate, but dirt and water must be visually accounted for and/or estimated in the volume measurement.

- Volume of each waste category: This volume indicates how much container space for a specific category would have to be available if this material would be collected separately at the construction site. Different volumes will be measured depending on how the material is placed in the container. If it is thrown, more voids occur than when it is carefully placed. Voids can sometimes reach up to 50% of the container volume even if it stacked carefully. Container geometry may incidentally create voids or placement problems necessitating greater care of placement. Cumulatively this space can greatly exaggerate total material volumes. Compaction, careful placement, removal of contamination, and visual estimation are therefore critical.

- Theoretical volume: This is the amount of material without any voids. Theoretical volume determined through material density is a useful calculation for volume measurements. This calculation has no practical application as the total voids can never be removed from the waste category. However it provides an absolute base volume given complete compaction of materials. This volume qualifies and establishes the maximum estimated field density. Thus providing a range over which the materials that fill a container can vary.

Formula for calculation of material volume from material density and weight:

$$\frac{\text{Material Weight (lb)}}{\text{Material Density (lb/ft}^3\text{)}} \quad X \quad \underset{(1\ \text{yd}^3/27\text{ft}^3)}{\text{Conversion factor}} \quad = \quad \underset{(\text{yd}^3)}{\text{Theoretical Volume}}$$

In the data recording section of the summary sheets, the weights are tabulated in pounds and the volumes are provided in cubic yards. These units have been chosen due to the common usage by waste hauling companies in the United States. The word "None" in value box of the summary table indicates there was no recordable waste under that category/sub-category within a particular load. The term "Mixed" denotes that the sub-categories have not been sorted within its category. The annotation, N/A, represent the data was not available at the time of this report.

Chapter 4
Results

4.1 Introduction

The construction waste of four single family residential homes in north central Florida was analyzed in this study. The home selections were intended to represent the typical construction methods, materials, and layouts found in the State of Florida. All waste generated from each home was hauled from the building site to a C&D landfill where the contents of each roll-off container was separated and analyzed. The data collection started April 1996 and ended February 1997.

Throughout this chapter several key terms are used. "Load" refers to each separate roll-off container hauled from the construction site to the sorting and weighing facility. After sorting the load into categories and placing the material into containers, the weight of the material is determined. "Sample" weight is the term used for the weight of individual weighing groups with in the load. Each load is made up of many weighing "samples". The category and sub-category terms used in the text and summary tables throughout this chapter are defined in Appendix A.

4.2 Specific Residential Homes Studied

The general characteristics of the four homes studied are summarized in Table 4.1. All houses were constructed using a slab-on-grade foundation with asphalt shingles for roofing. Wall framing, wall and roof sheathing, and siding are described in the Table. The home located in "Villages of West End" was eventually excluded from the study and therefore no summary tables refer to this home.

Table 4.1 Construction Comparison of Homes

House	ft² (m²)	Foundation	Framing	Wall/Roof Sheathing	Siding	Roofing
Villages of West End	2,100 (195)	Slab-on-Grade	Wood	OSB	Hardi Plank & Brick	Asphalt Shingles
Jockey Club	3,808 (354)	Slab-on-Grade	Wood	OSB (Wall) Plywood (Roof)	Hardi Plank & Brick	Asphalt Shingles
Haile Plantation	4,688 (436)	Slab-on-Grade	Wood	OSB	Brick	Asphalt Shingles
Parker Place	2,995 (278)	Slab-on-Grade	Masonry Block Wood (Interior)	OSB (Roof)	Hardi Plank	Asphalt Shingles

4.2.1 Villages of West End

The first home studied was a 2,100 square foot home located in Gainesville, Florida in a subdivision called "Villages of West End". The home has a slab-on-grade foundation and wood framing for all walls and the truss system. The roof and wall sheathing material is oriented strand board (OSB). The exterior siding of the house is a combination of Hardi Plank and brick veneer. The entire construction process took approximately four months , starting in early April, 1996 and completed in mid-August, 1996.

The construction of this home required five 10 cubic yard roll-off containers to remove the construction waste. Since this was the first home analyzed in the study, several procedures were fine-tuned during the characterization: scheduling roll-off container pick up dates, communication with builder/supervisor of construction, load separation and weighing operations, and data organizing and logging. During the sorting of the first few loads, a comprehensive field data logging packet and protocol were assembled. Due to the fact that many procedures were established during this first analysis and one load was lost, the data for this house was not used in the study.

4.2.2 Jockey Club

The second home in the study is located in Gainesville, Florida in a development called, "Jockey Club". This 3,808 sq. ft. home is slab-on-grade, wood-framed construction. The framing material is standard southern yellow pine 2x4's, 16 inches on center. The wall sheathing is OSB and the roof sheathing used was plywood. The roof is surfaced with asphalt shingles. The exterior is sided with Hardi Plank with a decorative brick veneer on the front of the home. Construction of this home took approximately four months, commencing mid-April, 1996 and ending in mid-August, 1996.

The construction of the "Jockey Club" home required four 20 cubic yard and one 10 cubic yard roll-off container to haul away its waste. This home's waste data was collected in a standard manner, using a more refined separating and weighing method. A sample sheet in which the data was recorded is included in Appendix B. Although communication with the supervisor on the construction site had improved, the fourth load of waste hauled from the job was lost due the sudden and unforeseen change of the construction supervisor. This problem emphasizes the importance of constant contact with the project supervisor while conducting a study of this type. The total waste generated was calculated by adding the loads analyzed plus an estimated weight for the lost load (average of all comparable load weights recorded throughout the study).

Figure 4.1 Jockey Club house under construction.

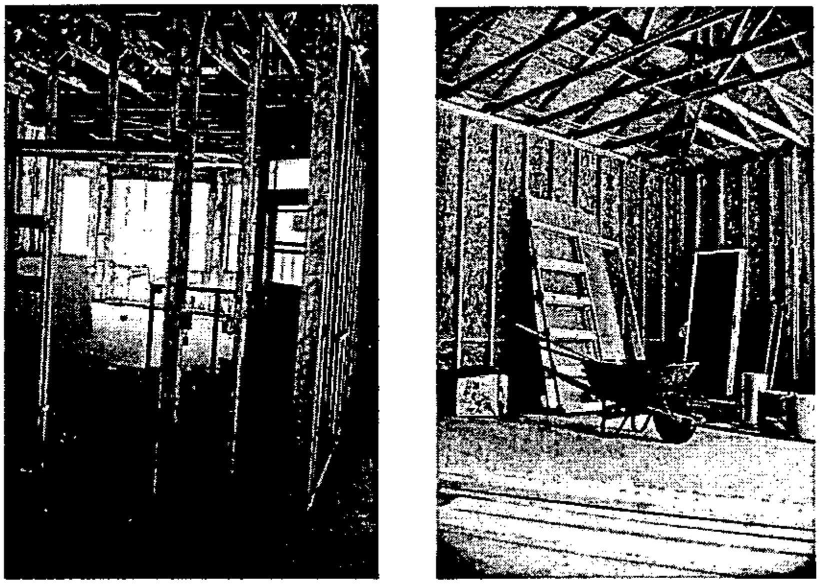


Figure 4.2 Inside the Jockey Club house.

4.2.3 Haile Plantation

The size of the third home examined in this study is 4,688 sq. ft. and is also located in Gainesville, Florida within a community named, "Haile Plantation". The construction method was similar to the previous homes with a poured slab-on-grade, framing of southern yellow pine 2x4 studs and a wooden truss system. The home's roof and wall sheathing was OSB, and the roofing material was asphalt shingles. The external siding is brick veneer. The construction of this home also took about four months to complete, starting mid-August, 1996 and finishing early-January, 1997.

The waste generated during the building process required four 20 cubic yard roll-offs. At the site the contractor furnished a two cubic yard container for municipal solid waste (MSW). This reduced the MSW entering the C&D trash container but did not eliminate it. There were three unique issues associated with the separation and weighing of this home's waste. First, the 20 yard roll-off used to collect the waste was divided into three separate compartments. The category labels used were wood, miscellaneous & masonry, asphaltic products, drywall and cardboard respectively. This allowed for presorting prior to arrival at the separation facility. Changing the labels on the segments of the roll-off to correspond with the progression of waste being generated through the construction process helped to separate the material at the landfill.

Second, the scale used to measure the various categories was changed after the first load due to the inaccuracy of the scale at the landfill. The drive-on scale located at the landfill measured in twenty pound increments, however, its sensitivity was such that it had an error range of plus or minus 100 pounds. In addition, trucks driving over the scale between weighing the various categories altered the dirt on the scale. Starting with the second load a transportable Fairbanks scale was used with a maximum capacity of 1,000 lb. and an accuracy of plus or minus five pounds.

Third, the drywall subcontractor for this house was responsible for his own waste. Therefore, no drywall waste was expected, however, the third load contained almost 3,000 lb. of it, which was about 60% of the total amount of drywall expected for a house this size.

Figure 4.3 Haile Plantation house under construction

4.2.4 Parker Place

The fourth home studied had a floor size of 2,995 sq. ft., and is located in Gainesville, Florida within a development called, "Parker Place". This house is slab-on-grade construction with concrete block exterior walls. The interior and truss system is framed with wood. The roof sheathing is OSB and the roof is topped with asphalt shingles. Construction of this home began in late August, 1996 and was completed in early February 1997.

This home required only three 20 cy roll-off containers of waste to be hauled off the job site. This construction site also has a two cubic yard container for MSW exclusively, however, MSW was still present in the C&D roll-off container. In addition, all three loads were contaminated with wastes of other homes being built within the same development. This problem was anticipated and discussed with the site supervisor, but since it happened anyway it was taken into consideration while the loads were sorted and measured. Also, the drywall contractor was responsible for his waste, so there was very little drywall disposed of in the roll-off container to measure.

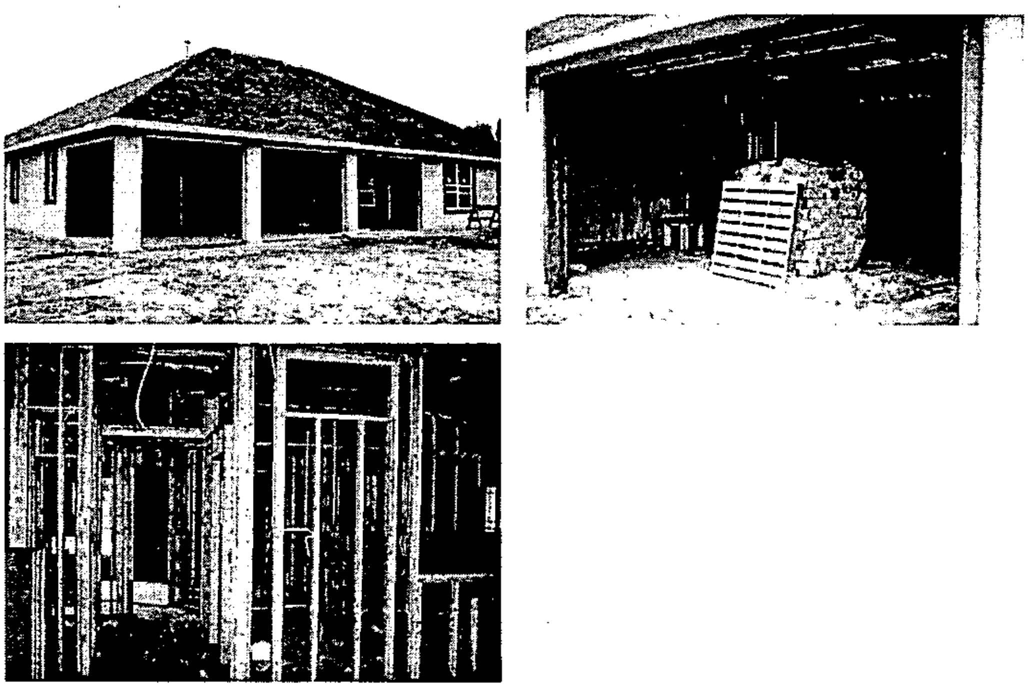


Figure 4.4 Parker Place house under construction.

4.3 Moisture Contamination

The roll-off containers analyzed were not all covered during construction. Considering the frequent rains in Florida, materials absorb water and skew the composition analyses results unless taken into account. The waste hauler involved with this study did not have any covered roll-offs. An attempt to cover the containers over night and during weekends with poly-ethylene sheeting was not successful. The plastic film was too weak to prevent anything but a light drizzle from entering the container without caving in. In addition, the workers were not consistent in keeping the container covered.

The water content was estimated on a scale of 1 to 5 for each sample. By averaging these values the moisture level for each load was determined. Further, the moisture content value representing the home's total waste is an average of the individual moisture content from each of its loads. The summary tables show weight-to-volume ratio variances due to this moisture infiltration problem. In order to further illustrate the water absorption rate of materials the chart in Appendix D shows the weight comparison of dry materials to wet materials sampled from the loads. The materials moisture content values for each load attempts to justify variations in materials weights. Due to the different moisture content in the measured weights for each category, they cannot be directly added for a load total without keeping the water saturation level in mind.

4.4 Summary Tables

The summary tables are located in Appendix C. Each table represents the measured construction waste generated from each of the three homes included in the study. The wastes were divided into categories with some having sub-categories within them. For each category, the weight, actual volume, and the theoretical volume are given. The weight was determined by weighing the separated waste on a scale and subtracting the weight of the container. The actual volume is determined by subtracting out the estimated void space around the material within the known volume of the weighing container. The actual volume value states how much volume that material takes up in a roll off when the material has been condensed and stacked in an orderly manner. This value for volume should be viewed to get an estimate of a container size required to haul the different materials. The theoretical volume is included in this study to use as a reference point, and it was calculated by dividing the material's weight by its density. In general, the theoretical volume expresses the volume a certain material should take up if the material in question was a solid mass within the weighing container.

Figure 4.5 Waste categorization at the landfill site.

4.5 Home Summary Charts

The summary charts illustrate the total waste weight, volume and weight of waste per square foot (lb/ft^2) of home under each category for each individual homes included in the study. The Residual Rubble estimate category was a visual estimate for the weight and therefore the volume is not available.

4.5.1 Jockey Club Summary Chart

Since the fourth roll-off container's contents were lost, the values are incomplete. However, the lost load's total weight and volume have been estimated respectively as 6,615 lb and 12 cy. The "Total" row includes this estimation in its values and calculations.

Table 4.2 Jockey Club (3,808 ft², 352 m²)

Category	Weight (lb)	Volume (yd³)	lb/ft²
Solid Wood	12,828	26.63	3.37
OSB	400	1.00	.11
Plywood	731	1.11	.19
Drywall	3,380	3.80	.89
Metals	201	.84	.05
Cardboard	686	3.02	.18
Paper	78	.48	.02
Plastics	194	1.44	.05
Concrete	1,994	2.40	.52
Brick	100	.10	.03
Asphalt Shingles	1,530	1.87	.40
Fiberglass Insulation	56	.67	.01
Hardi-Plank	1,428	1.59	.38
Miscellaneous	676	.72	.18
MSW	65	.30	.02
Residual Rubble Est.	1,150	N/A	.30
***Total :**	***32,112 lb**	***57.97 yd³**	***8.43 lb/ft²**
Total	**14,566 kg**	**44.32 m³**	**41.15 kg/m²**

4.5.2 Haile Plantation Summary Chart

Table 4.3 Haile Plantation (4,688 ft^2, 436 m^2)

Category	Weight (lb)	Volume (yd^3)	lb/ft^2
Solid Wood	3,927	10.04	.84
OSB	3,487	7.08	.74
Plywood	189	.43	.04
Drywall	2,864	6.81	.61
Metals	310	.51	.07
Cardboard	347	1.81	.07
Paper	218	1.33	.05
Plastics	173	1.13	.04
Concrete	5,515	2.94	1.18
Brick	3,501	2.09	.75
Asphalt Shingles	620	1.06	.13
Miscellaneous	13	.06	.00
MSW	63	1.31	.01
Residual Rubble Est.	4,050	N/A	.86
Total :	**25,277 lb**	**36.6 cy**	**5.39 lb/ft^2**
Total	**11,466 kg**	**28.0 yd^3**	**26.3 kg/m^3**

4.5.3 Parker Place Summary Chart

As mentioned in the text above most of the drywall waste was hauled away by the drywall contractor.

Table 4.4 Parker Place (2,995 ft², 278 m²)

Category	Weight (lb)	Volume (cy)	lb/ft²
Solid Wood	3,569	6.71	1.19
OSB	1,306	3.62	.44
Plywood	42	.05	.01
Drywall	184	.29	.06
Metals	50	.02	.02
Cardboard	424	2.27	.14
Paper	80	.27	.03
Plastics	75	.53	.03
Concrete	5,403	4.56	1.80
Clay Tile (Floor)	200	.16	.07
Asphalt Shingles	681	1.03	.23
Fiberglass Insulation	118	1.28	.04
Hardi-Plank	162	.24	.05
Miscellaneous	475	1.84	.16
MSW	42	N/A	.01
Residual Rubble Est.	1,650	N/A	.55
Total :	**14,461 lb**	**22.87 yd³**	**4.83 lb/ft²**
Total	**6560 kg**	**17.49 m³**	**23.6 kg/m³**

4.6 Home Total Summary Chart

Table 4.5 illustrates the individual home's unsorted total waste weights and volumes. Since the fourth load of waste from the Jockey Club was lost the total weight must be noted as an estimate.

Table 4.5 Home Total Weight & Volume Summary Chart

Home	ft^2 (m^3)	Wood Waste lb/ft^2 (kg/m^3)	Drywall Waste lb/ft^2 (kg/m^3)	Total Waste lb/ft^2 (kg/m^3)	Total Waste Weight
Jockey Club	3,808 (354)	3.67 (17.88)	0.89 (4.33)	8.43 (41.15)	*32,112 lb 14,566 kg
Haile Plantation	4,688 (436)	1.62 (7.91)	0.61 (2.98)	5.39 (26.60)	25,277 lb 11,466 kg
Parker Place	2,995 (278)	1.64 (8.02)	0.06 (2.88)	4.83 (23.60)	14,461 lb 6560 kg
Average	3830 (356)	2.31 (11.27)	0.52 (3.40)	6.22 (30.45)	23,950 lb 10,864 kg

Chapter 5
Market Analysis

5.1 Introduction

Establishing a successful construction/demolition (C&D) recycling business in Florida is a very difficult proposition at present. To actually initiate processing of the incoming waste, at least two acres of clear space for processing equipment, incoming waste stockpiles, recycled materials, and minimal maneuvering room for mobile equipment and operations are required. Reasonable quality, reliable equipment suitable for these operations will generally cost between $300,000 and $750,000 for a 400 to 500 ton per day operation. At present operators of these facilities make a profit almost solely on tipping fees, with the recycling operation functioning mostly to maintain materials throughput. Markets for the recycled products made from C&D waste are very soft, the result being that many operators experience a net loss on the recycling portion of their operations. The lower the C&D landfill tipping fee in the jurisdiction, the more difficult it is for the recycling operation to survive. The presence of C&D landfills with capacity makes the feasibility of establishing a recycling operation almost impossible because the purely landfill operations do not have materials processing costs. The operator must also contend with the high disposal cost of unrecyclable or undesirable materials from the recycling process that must be transported to a suitable engineered landfill. In addition to all these difficulties, the operator must also find and train productive crews to process the materials and find markets for the recycled materials. The net result is that only experienced operators with adequate financial capacity and extensive knowledge of the marketplace for recycled materials have a real chance of surviving in this highly competitive and highly regulated business.

Restrictions on disposal, environmental regulations, and other factors have motivated some construction/demolition landfill operations in Florida to consider converting their businesses into recycling operations. This section describes the requirements for

C&D landfill operations in Florida to make a transition from landfilling to recycling. It also provides other important background information for use in determining the probability of success in converting from a C&D landfill to a recycling business.

5.2 Background

C&D recycling businesses face many obstacles to success, among them competition from C&D landfill operations and the high cost of disposing of materials that cannot be recycled. At the present time there are no C&D recycling operations in Alachua County and just a few C&D landfills in the area. The prices charged by various landfills in Alachua County is shown in Table 5.1. The tipping fee is the amount of money per unit quantity that must be paid to the landfill operation or recycling operation to dispose of the incoming C&D waste materials from construction operations.

Table 5.1 Typical C&D Operations and Tipping Fees in Florida

Location	Operator	Tipping Fee/Ton
Alachua County	Alachua County Landfill	$60
Hillsborough County	Kimmins Recycling MRF	$29
Alachua County	Florence Landfill	$18
Palm Beach County	Palm Beach County Landfill	$37
Duval County	Realco MRF	$20-$30

The tipping fee charged by the Class I landfill is particularly important because it is the price a C&D recycling operation will generally have to pay to dispose of what is left over from their materials processing operations, the "residue." The large differential between tipping fee costs for a C&D recycling operation and a Class I landfill is perhaps the key element in determining the success of the recycling operation. The smaller the difference the more likelihood there is of success. Conversely for a large difference, the chances of success are greatly diminished.

5.3 Requirements for a Successful C&D Recycling Operation

Table 5.2 indicated the requirements for starting and operating a profitable C&D recycling business.

Table 5.2 Seven Determining Factors for Success of a C&D Recycling Business
1. Good site and site location
2. Proper equipment
3. Experience in C&D recycling operations
4. Trained supervisors and employees
5. Knowledge of secondary materials markets
6. Business / financial capacity
7. Knowledge of environmental and safety regulations

Site and Site Location

The site must have adequate space for the C&D processing equipment, an area for the incoming waste materials, and space for the processed materials. The total space must be sufficient to account for mismatches in the rate of incoming versus outgoing materials. For a nominal operation, an allocation of 1 acre for equipment and at least 1 acre for processed materials would be a minimum requirement for materials handling and throughput. The location must also be satisfactory in terms of where it is situated in the jurisdiction it serves. It must be able to be permitted and must be in reasonable proximity to the construction operations it serves to be competitive with other C&D landfills or recyclers.

Proper Equipment

Experienced C&D operators have learned that it pays to have the proper equipment for the job, preferably equipment made specifically for C&D recycling operations or for a similar business such as quarrying operations. The result of using makeshift equipment or other equipment not specifically designed for handling and separating mixed C&D waste is breakdowns, downtime, and loss of revenue. The equipment must also be able to be maintained by the operators. This includes good knowledge of the equipment, technical information about the equipment, and access to spare parts. The older the equipment, the more chance there is that parts will be unavailable or that the manufacturer will be out of business. Functional equipment is absolutely essential because the tight operating margins of C&D recycling force a high throughput and reliable, rugged equipment. The equipment must be able to produce secondary materials of sufficient quality to meet market demands. The equipment needed to operate a 400 to 500 ton per day recycling operation will range up to $750,000 in cost for a complete set of new machinery including mobile equipment down to $300,000 if the operator has mobile equipment and can obtain used equipment in good condition.

Experience in C&D Operations

Unlike other salvage operations, C&D is a waste stream that has only a few components of real value mixed in with many materials with little or no value. Understanding the equipment, separation techniques, quality control issues, and other essential features of C&D operations are key to the success of the recycling business. The recovery rate of secondary materials or percent of the incoming waste stream converted to secondary materials is the quantity that can make or break a C&D operation. A high recovery rate indicates a successful operation able to technically handle the problems of separating mixed materials. The disposal costs of the non-recovered or residue materials can be very high as the only disposal option for these truly waste materials is a Class I landfill. Some materials such as concrete, masonry, and rock may have to be cleaned prior to processing to meet the quality requirements of the secondary materials markets. This requires good knowledge of the equipment and process needed to accomplish cleaning as well as other quality control procedures. Cross-contamination of materials is another quality control issue that an experienced C&D operator will recognize and have the technical capability to solve. The operator must have knowledge of how to set both tipping fees and secondary materials prices.

Trained Employees

As with any other business, the employees at a C&D recycling operation must be well trained to operate equipment, know the general business, understand the value of the various materials, and be able to function safely in a hazardous environment. The variety of equipment such as front end loaders, conveyors, trommel screens, wood chippers, crushers, hoppers, hammermills, and others require a number of relatively skilled workers who can operate, maintain, and repair a variety of equipment. In addition to knowing the operations and equipment the employees need to be trained as a team to maximize their productivity, maintain availability of equipment, and produce a high quality output.

Knowledge of Secondary Materials Markets

The primary goal of present day C&D recycling operations in Florida is to maximize the throughput of materials through the site to earn tipping fees and to sell the recovered materials to the secondary materials markets. This requires an aggressive marketing effort to locate markets and sell materials at the highest possible prices. The present rather low level of market development means that significant time and money must be invested in establishing relationships, keeping track of pricing changes, and becoming a reliable supplier of materials. In order to insure a continuous intake of C&D materials the operator also has to locate and develop relationships with demolition and general contractors with projects in the area to sell their C&D recycling business as the disposal option of choice for the contractors. This latter effort includes keeping tipping fees low and service high.

Business / Financial Capacity

A C&D recycling operation requires a relatively expensive system of equipment and conveyors for proper, reliable operation. The operator has to have the finances to acquire the appropriate equipment and startup the operation. Startup costs are always significant because the entire function must undergo a shakedown period during which productivity will be low. Additionally markets for products will be only partially developed and sales of the operation's output will be initially slow. During slower economic times the operation may see both a decrease in C&D intake as well as a decrease in sales of secondary materials. Liability considerations are such that a C&D operation should be well insured to protect itself due to product or other liability problems. All these matters related to finances require the operator to have an assured source of funds to survive the wide variety of problems that face this and any other business operation. As with any other business the operator must have good business skills to deal with employees, customers, regulatory agencies, banks, neighbors, and many other forces impacting on the operation. The operator must know how to survive and make a profit in a competitive marketplace in a business with thin profit margins.

Knowledge of Environmental and Safety Regulations

C&D operations must follow strict safety and environmental guidelines to operate in a manner which protects the public from air and water contamination as well as excessive noise and other nuisances. OSHA safety regulations are such that heavy penalties can be levied on operators whose workers are functioning in a risky environment and who are untrained in safety issues specific to the C&D operation. Environmental regulations produce another group of concerns for the C&D recycling operator, resulting in another set of costs in terms of penalties for violating environmental standards.

5.4 Cost Considerations for Establishing a C&D Recycling Operation

The major difficulty C&D recycling operations encounter when setting up an operation is a failure to perform a detailed cost analysis of the proposed operation. A reasonably complete analysis would include the following cost categories shown in Table 5.3.

Table 5.3 Cost Considerations for C&D Recycling Business Startup and Operation

Capital Costs	Operations and Maintenance (O&M)
Land	Labor
Site Preparation	- Supervision
Buildings	- Operators
Equipment	- Laborers
Mechanical/Electrical Installation	Utilities
Rolling Stock	- Electricity
Engineering	- Water
Startup	Fuel
Contingencies	Parts & Supplies
	Outside Maintenance
Other Costs	
Services	
- Legal	
- Accounting	
Insurance	
Marketing	
Residue Disposal	
Permits	

The recycling business operator has to carefully consider the stream of materials that will be flowing into the site to prepare the operation for processing the waste into secondary materials with reasonably high value. Table 5.4 shows a breakdown of C&D experienced at a typical Florida recycling operation receiving mixed C&D waste. The composition of C&D waste will vary from site to site and from time to time depending on the ratio of commercial to residential construction as well as the proportion of demolition activities taking place in a given jurisdiction. Some C&D operators restrict their intake to items such as concrete and asphalt from road construction operations, providing a more specialized and profitable operation.

However for the typical operation the quantities in Table 5.4 are realistic. The noteworthy quantity is the percentage of materials that had to be rejected because of a lack of value or markets for the secondary materials. In the particular example shown, only 55% by volume were recoverable while the remainder had to be disposed of in suitable landfills.

Table 5.4 Composition of Mixed C&D Debris Entering Typical Florida Recycling Operation

Material	% Volume	% Recycled	% Landfilled
Construction wood	25.0	70.0	30
Trees/Stumps	5.0	100.0	0.0
Cardboard	17.0	75.0	25.0
Misc Paper	0.8	0.0	100.0
Concrete/Masonry	2.5	20.0	80.0
Plastics	2.0	0.0	100.0
Metals	7.0	95.0	5.0
Roofing Materials	13.0	0.0	100.0
Dirt	2.0	30.0	70.0
Gypsum Wallboard	15.0	0.0	100.0
Glass	0.1	0.0	100.0
Building Insulation	4.0	0.0	0.0
Misc*	5.8	0.0	0.0
Unacceptable**	0.8	0.0	0.0
Overall	**100.0**	**55.0**	**45.0**

* Miscellaneous materials
** Batteries, paint cans, and similar

The markets for secondary materials from C&D recycling operations are good for some materials and virtually non-existent for others. Metals have traditionally had strong demand. Wood chips have outlets as mulching materials, bedding for animals, and fuel for power plants. Recycled concrete aggregate for sub-grade has established markets and cardboard prices make it a salable commodity. On the other hand materials such as insulation, roofing materials, spackle buckets, tiles, and flat glass do not have markets and must be landfilled.

5.5 Economics of C&D Operations

C&D landfills produce income by charging a fee for allowing construction operations to deposit the debris from site clearing, demolition, and construction to be dumped on land owned by the C&D landfill operator. The fee is called a tipping fee. The tipping fee is the primary income for these operations. In general C&D landfills are private operations, many of which have pits where sand or other materials have been mined. The C&D waste serves the somewhat useful function of filling up these pits, allowing potential reuse of the land for other purposes. In some cases, there is no pit and the waste is simply piled up on open ground to limits set by the local jurisdiction. Eventually physical or legal restrictions force the C&D operators to seek ways of ridding their sites of materials so they can continue earning money via tipping fees. Having to move material off the site means the operator must now separate the mixed loads coming onto the site and find markets for salable products and dispose of the residue materials. These separated salable products are sometimes called recycled or secondary materials in contrast to primary or virgin materials that are extracted from nature.

C&D operations that are forced to convert over to recycling by circumstances find a much more complicated economic picture than when they were solely a C&D landfill. Markets for secondary materials in Florida vary from locale to locale but in general the markets are soft due to the relatively low cost of primary materials. At the upper end of value in the secondary materials market are metals at about $60.00 per ton (steel) to $1,000.00 per ton (aluminum), crushed concrete at $5.00 to $10.00 per ton, and wood fuel chips for which a price of $6.00 to $10.00 per ton can be earned. Cardboard currently receives up to $110.00 per ton. On the lower end are wood chips for mulch, glass and dirt, receiving about $3.00 to $5.00 per ton in the market place. In fact, dirt products are often given away as landfill cover in some jurisdictions. Materials such as plastics, asphalt shingles, and drywall have virtually no markets.

To get to a point to be able to recover these materials, a C&D recycling operation must also invest in expensive machinery that can separate the mixed waste stream with sufficient quality for the materials to be resold. In the terms of a recycling operation, quality means minimizing contamination from other materials to keep the secondary materials stream as pure as possible. A good C&D recycling operation with high throughput and a high quality product will have a processing cost of $8.00 to $10.00 per ton of incoming materials.

An additional consideration for the C&D recycler is the need to consider the disposal of waste materials for which there is no market, much of which must be disposed of in an expensive Class I landfill. In Orange County the current price for Class I landfill disposal is $30.65 per ton. This does not include the cost of loading and hauling the materials which adds another $5.00 per ton or more to the cost of disposal.

An expression that states the relationship between all these economic factors is:

$$I = Q\,[I_t + r\,I_s - C_p - (1\text{-}r)\,C_d]$$

where:

I = gross income, \$
Q = C&D materials intake, tons
C_p = processing cost, \$/ton
C_d = disposal cost, \$/ton
I_t = tipping fee, \$/ton
I_s = income from secondary materials sales, \$/ton
r = recovery rate of secondary materials from waste, %

An example using a medium high recovery rate of 80%, a tipping fee of $7.50/ton, a disposal cost of $35.00/ton, a processing cost of $10.00 per ton, and an average market price of $9.00 per ton gives:

$$I = Q[\$7.50 + (0.8)\ \$9.00 - \$10.00 - (1 - 0.8)\ \$35.00]$$

or:

$$I = Q\ (\$7.50 + \$7.20 - \$10.00 - \$7.00)$$

$$= Q\ (-\$2.30)$$

This simple example indicates a loss of $2.30/ton under the given circumstances. The only way to operate profitably is to increase the recovery rate which simultaneously decreases the cost of disposal, decrease processing costs, and find higher prices for secondary materials. The tipping fee is unlikely to rise due to local competition. If for example the recovery rate would rise to 90%, a very high rate, we would have

$$I = Q[\$7.50 + 0.9(\$9.00) - \$10.00 - (1 - 0.9)\ \$35.00]$$

$$= Q\ (\$7.50 + \$8.10 - \$10.00 - \$3.50)$$

$$= Q\ (\$2.10)$$

With a high recovery rate and all other conditions remaining the same, the operator can now make $2.10 per ton of incoming material. However a 90% recovery rate is exceptionally high and only a very few, well-organized operators with highly constrained intake are able to achieve this level of recovery. In some locations C&D operations are able to charge much higher tipping fees, for example in Duval and Hillsborough counties where $30.00 to $40.00 per ton are achievable. In these latter jurisdictions the lack of C&D landfills and limited space has allowed and even forced recycling operations to take hold. In Orange County the tipping fees are relatively low, making C&D operations of any type marginal businesses.

5.6 Conclusions

A properly functioning C&D recycling business must earn much of its money from tipping fees. The current economics of recycling operations are not very favorable. Recycling serves more to maintain throughput on sites with diminished capacity to landfill incoming waste than to be a profitable, stand-alone business. An operation restricted in its on-site disposal possibilities has a difficult situation because it must carefully balance the intake of C&D waste with the sale of secondary materials. The business must have a high recovery rate in order to maximize the quantity of secondary materials and minimize the residue which will have to be disposed of in a Class I landfill, an expensive proposition. A high recovery rate, high productivity, and a high throughput require good equipment and a well trained crew of supervisors, equipment operators, and laborers for a profitable business. The markets must be developed by the business both to insure a continuous intake of C&D waste as well as to sell the secondary materials produced. As with any business, experience in C&D recycling and the construction secondary materials markets gives the operator a significant advantage in becoming a successful enterprise. The net result is that establishing a viable C&D recycling operation is a difficult undertaking requiring a wide range of skills and experience to be successful. Without the operator having extensive background and experience, good financial capacity, and sound planning, successfully establishing a C&D recycling business is very unlikely.

Chapter 6
Conclusions and Recommendations

6.1 Introduction

Construction and demolition (C&D) waste is a serious problem in Florida as well as nationwide. It takes valuable land out of use due to the need for landfill space, causes environmental problems due to leaching of contaminants into groundwater, and is indicative of a wasteful approach to construction. The value of the materials thrown away during the construction process is surprisingly high, on the order of several hundred dollars per house for residential construction. Tipping fees, while not significant in most areas of Florida, are rising, and will eventually affect the bottom line of home builders. The study conducted in this effort was limited largely to wood frame construction in North Florida where the costs of waste disposal are very low.

One of the major products of this research is the development of a methodology for analyzing C&D waste (Chapter 3). Prior to this effort, there was no standard methodology for researchers seeking to determine the quantity and distribution of C&D waste. During the conduct of this research, a wide range of problems were encountered in trying to analyze the waste and these are addressed in the methodology. Although determining the weight of the waste is reasonably straightforward, calculating the volume is a far more difficult problem. Procedures for estimating C&D waste volume are presented in this report.

6.2 Conclusions

Residential construction industry in Florida has a waste pattern similar to other States. The National Association of Home Builders (NAHB), in a major recent study, concluded that construction of the average home resulted in 6 pounds per square foot of construction waste or 6 tons of construction waste for a 2,000 square foot home. Drywall comprised 1 pound per square foot of waste in the NAHB study. The results of this study conclude that waste was on the order of 6.2 pounds per square foot with drywall comprising approximately 0.80 pounds per square foot. It should be noted that the tipping fees in Alachua County for C&D waste are on the order of $18-$20 per ton, among the lowest in the State of Florida and perhaps the nation. The result is that residential builders and their subcontractors have no incentives for reducing their output of waste nor is the cash differential between landfill costs and recycling profit sufficient to support a materials recovery facility (MRF).

6.3 Recommendations

The following are the principal recommendations resulting from this study:

- The Florida Home Builders Association (FHBA) should promote and educate their membership on waste management, waste reduction, and recycling to help home builders not only reduce their environmental impacts, but also increase their profitability.
- A follow-on study should examine the effects of builder and subcontractor training in waste management techniques and planning should be conducted to determine the impacts of these measures on the generation of construction waste from residential home building.
- A standard waste management system for residential construction in Florida should be developed, tested, and adopted. This system of waste management should be adopted by the FHBA and disseminated to its membership via Continuing Education Unit (CEU) training which is mandated by the Construction Industry Licensing Board (CILB) of Florida.
- This study focused principally on wood framed home construction in Florida and other studies that examine waste from block construction, steel framing, and other construction systems should be conducted.
- Additional studies should be conducted to examine the current materials used in construction to determine where materials and products should be changed or redesigned to reduce the current level of waste in residential construction.

- Future efforts should focus on commercial construction as well as residential construction to determine its waste generation rates.
- A study should be made to determine the relationship between tipping fees and waste generation rates.
- For all future waste characterization studies of C&D waste it is recommended that the waste is only collected in closed containers and the separation be conducted under a roof to avoid contamination by water.

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Appendix A

Waste Categories

Category & Sub-category Definitions

This section explains what type of materials comprises each category heading in the summary tables.

- **Wood:**
    - **Solid Sawn Wood:** Dimensional lumber, Trim, Palates
    - **OSB:** Oriented strand board
    - **Plywood:** Interior and exterior grade, T1-11
- **Gypsum Wallboard:** Normal sheet.
- **Metals:** Steel packaging bands, Tofit cladding, drywall edging, nails. (Mixed ferrous and non-ferrous- there was never enough non-ferrous to separate out)
- **Cardboard:** Boxes (Packaging)
- **Paper:** Non composite bags (Packaging)
- **Plastics:** Poly-ethylene sheething, straps (Packaging and work site material cover)
- **Masonry:**
    - **Concrete:** Pre-mix concrete, CMU
    - **Brick:** Red veneer siding brick
- **Asphaltic Products:** Roofing shingles and tar paper
- **Insulation:** Fiberglass wall/attic bats, ridged insulated duct board
- **Hardi-Plank:** Composite wood/cement siding
- **Miscellaneous:** Plastic/paper composite bags for cement and plaster, paint cans, caulking tubes
- **MSW:** (Municipal Solid Waste) Food containers and bags, drink cans and bottles
- **Residual Dirt & Rubble Estimate:** A visual estimation of scattered debris left on the working floor at the weighing facility
- **Standing Water Estimate:** An estimation of water collected at the bottom of the roll-off before the load is dumped at the weighing facility

Appendix B
Sample Field Data Sheet

Construction and Demolition Waste Composition Study Data Sheet

Sorting Facility

Name of Waste Facility: Florence Landfill **phone:** (352) 375-9919 **fax:** (352) 375-5299

Contact Name: Paul & Joni Florence

Address of Waste Site:

Street: 3003 SE 15th St. **Zip:** 32641

City: Gainesville **County:** Alachua **State:** FL

Accuracy of tipping scale: 20lb

On Site Containers: Weight/Volume
760 lbs/4 cy 42 lbs/0.48 cy 10 lbs/0.12 cy
On Site Equipment: Model/Weight/Bucket Volume
Ford 555(backhoe)/13,640 lb/1cy
John Deere 644V(front end loader)/27,920 lb/3cy

Material Origin

1. Origin of Loads: ☐ Commercial ☑ Residential ☐ Institutional ☐ Public ☐ Other

2.Type of Construction: ☑ New ☐ Remodeling ☐ Maintenance ☐ Demolition

3. Type of Building: ☑ Wood Frame ☐ Masonry ☐ Steel

Builder Company: Dibros Homes

Development: Jockey Club (Load 3)

Contact Name: Luis / Patti Diaz **phone:** (352) 374-4150 **fax:** (352) 374-8293

Address of Builder:

Street: 2630-A NW 41st Terr. **Zip:** 32606

City: Gainesville **County:** Alachua **State:** FL

Square Footage:	
Living Area	2,762
Garage	646
Patio	400
Total:	3,808

Name of Site Manager: Brad Danlovich

Address of construction site: **Lot#:** 88

Street: 136 SW 134th Terr. **Zip:** 32669 **phone:** (mobile) (352) 491-4302

City: Gainesville **County:** Alachua **State:** FL **fax:** Same as office

Separating Container Supplier

Co. Name of Waste Hauler: City of Gainesville Solid Waste

Contact Name: Gina Hawkins (Recycling Coordinator)

Address of Supplier: **phone:** (352) 334-5040 **fax:** (352) 334-2213

Street: City of Gainesville, P.O. Box 490, Station 10

City: Gainesville **County:** Alachua **State:** FL **Zip:** 32602-0490

C&D Waste Hauler

Co. Name of Container Supplier: Browning-Ferris Industries (BFI)

Contact Name: Dan McGinnis (District Manager) **phone:** (352) 375-3908 **fax:** (352) 372-9637

Address of Supplier:

Street: 5002 SW 41st Blvd. **PO Box:** 140908

City: Gainesville **County:** Alachua **State:** FL

Container Number: N/A **Zip:** 32614

Material Composition

Mixed Waste from Roll-off

	Load 1	Load 2	Load 3	Load 4	Load 5	Load 6	Total
Arrival Date at Sorting Facility:			2-Aug				
Arrival Time at Sorting Facility:			12:02				
Truck Number:			409				
Ticket Number:			N/A				
Roll-off Conditions							
Load Size: 10/20/40 cy./ other:			20 cy				
Standing Water in Roll-off ?:			N/A				
Was the Roll-off Cover Used?:							
During Construction?:			No				
During Transportation?:			No				
Material Volumes							
Percentage of Roll-off filled:							
Compaction of Waste in Roll-off: Loose<-------------------->Dense 1 2 3 4 5			3				
Material Weights (lb.)							Total
Weight of Full Roll-off & Truck:			37,540				
Weight of Empty Roll-off & Truck:			31,620				
Weight of Waste:			5,920				5,920 lb
Total People-hours:			15 hr.				15 hr.
People-hours/1 lb. of Waste:			.003 hr.				.003 hr.

Separated C&D Waste

Load(3) Wood

Solid Sawn Wood	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug	13-Aug					
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	4	4					
[Total Weight] Container + Waste + Dirt:	3,520	2,100					
Weight of Dirt on Scale (lb):	900	900					
Weight of Container/Vehicle (lb):	760	760					
Waste Weight (lb):	1,860 lb	440 lb					2,300 lb
Total Container Volume (cy):	4.00	4.00					
Estimated % of Container Filled:	0.90	0.30					
Actual Volume of Container Filled:	3.60 cy	1.20 cy					4.80 cy
Density of Solid Sawn Wood:[36 lb/ft^3]							
Theoretical Volume by Material Density:	1.91 cy	.45 cy					2.36 cy

Notes: This is the first home to have all wood types sorted.
The second sample are pallets.

Pressure Treated Wood	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Pressure Treated Wood:							
Theoretical Volume by Material Density:							

Notes: None

Plywood	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	5						
[Total Weight] Container + Waste + Dirt:	2,320						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	760						
Waste Weight (lb):	660 lb						660 lb
Total Container Volume (cy):	4.00						
Estimated % of Container Filled:	0.25						
Actual Volume of Container Filled:	1.00 cy						1.00 cy
Density of Gypsum Wallboard:[39 lb/ft^3]							
Theoretical Volume by Material Density:	0.63 cy						0.63 cy

Notes: Gypsum Wallboard only. See OSB below.

Load(__)**Gypsum Wallboard**	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Gypsum Wallboard:							
Theoretical Volume by Material Density:							

Notes: None

Load(3)Metals

Ferrous	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
[Total Weight] Container + Waste + Dirt:	1,000						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	42						
Waste Weight (lb):	58 lb						58 lb
Total Container Volume (cy):	0.48						
Estimated % of Container Filled:	0.80						
Actual Volume of Container Filled:	0.38 cy						0.38 cy
Density of Ferrous Metal:[472 lb/ft^3]							
Theoretical Volume by Material Density:	.005 cy						.005 cy

Notes: Combined ferrous and non-ferrous. Mostly steel strapping.

Non-Ferrous	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Aluminum:							
Theoretical Volume by Material Density:							

Notes: Combined ferrous and non-ferrous.

Load(3)**Cardboard**	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	5						
[Total Weight] Container + Waste + Dirt:	1,060						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	42						
Waste Weight (lb):	118 lb						118 lb
Total Container Volume (cy):	0.48						
Estimated % of Container Filled:	0.95						
Actual Volume of Container Filled:	0.46 cy						0.46 cy
Density of Cardboard:[43 lb/ft^3]							
Theoretical Volume by Material Density:	0.10 cy						0.10 cy

Notes:

Load(3)**Paper**	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	5						
[Total Weight] Container + Waste + Dirt:	1,020						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	42						
Waste Weight (lb):	78 lb						78 lb
Total Container Volume (cy):	0.48						
Estimated % of Container Filled:	1.00						
Actual Volume of Container Filled:	0.48 cy						0.48 cy
Density of Paper:[58 lb/ft^3]							
Theoretical Volume by Material Density:	.05 cy						.05 cy

Notes:

Load(3)Plastics

Film	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	3						
[Total Weight] Container + Waste + Dirt:	962						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	42						
Waste Weight (lb):	20 lb						20 lb
Total Container Volume (cy):	0.48						
Estimated % of Container Filled:	1.00						
Actual Volume of Container Filled:	0.48 cy						0.48 cy
Density of Plastic Film:[N/A]							
Theoretical Volume by Material Density:	N/A						N/A

Notes:

Plumbing Pipe/Fittings	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Plastic Pipe:							
Theoretical Volume by Material Density:							

Notes: None

Construction and Demolition Waste Composition Study Data Sheet

Vinyl Siding / Trim	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Vinyl Siding:							
Theoretical Volume by Material Density:							

Notes: None

Load**(3)Masonry**

Concrete	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	3						
[Total Weight] Container + Waste + Dirt:	15,240						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	13,640						
Waste Weight (lb):	700 lb						700 lb
Total Container Volume (cy):	1.00						
Estimated % of Container Filled:	0.80						
Actual Volume of Container Filled:	0.80 cy						0.80 cy
Density of Concrete :[144 Bs/ft^3]							
Theoretical Volume by Material Density:	0.18 cy						0.18 cy

Notes: A fraction of the bricks were not weighed. (120 lb. est.)
Combined masonry and brick.

Brick	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Brick:							
Theoretical Volume by Material Density:							

Notes: Combined masonry and brick.

Clay Tiles/Ceramics	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Clay Shingles:							
Theoretical Volume by Material Density:							

Notes: None

Load(3)Asphalt Products

Asphalt Shingles	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug	13-Aug					
[Total Weight] Container + Waste + Dirt:	1,318	1,242					
Weight of Dirt on Scale (lb):	900	900					
Weight of Container/Vehicle (lb):	42	42					
Waste Weight (lb):	376 lb	300 lb					676 lb
Total Container Volume (cy):	0.48	0.48					
Estimated % of Container Filled:	0.85	0.80					
Actual Volume of Container Filled:	0.41 cy	.38 cy					0.82 cy
Density of Asphalt Shingles :[86 lb/ft^3]							
Theoretical Volume by Material Density:	0.16 cy	.13 cy					0.29 cy

Notes:

Load(__)Insulation

EPS / XPS Ridged Board	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
Visual Moisture Content: Dry<-------------->Saturated 1 2 3 4 5							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of EPS / XPS :							
Theoretical Volume by Material Density:							

Notes: None

Fiberglass	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:							
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5							
[Total Weight] Container + Waste + Dirt:							
Weight of Dirt on Scale (lb):							
Weight of Container/Vehicle (lb):							
Waste Weight (lb):							
Total Container Volume (cy):							
Estimated % of Container Filled:							
Actual Volume of Container Filled:							
Density of Fiberglass :							
Theoretical Volume by Material Density:							

Notes: None

Load(3) Hardi Plank	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	4						
[Total Weight] Container + Waste + Dirt:	1,060						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	42						
Waste Weight (lb):	118 lb						118 lb
Total Container Volume (cy):	0.48						
Estimated % of Container Filled:	0.45						
Actual Volume of Container Filled:	0.22 cy						0.22 cy
Density of Hardi Plank:[40 lb/ft^3]							
Theoretical Volume by Material Density:	.11 cy						.11 cy

Notes:

Construction and Demolition Waste Composition Study Data Sheet

Load(3) OSB	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	4						
[Total Weight] Container + Waste + Dirt:	2,060						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	760						
Waste Weight (lb):	400 lb						400 lb
Total Container Volume (cy):	4.00						
Estimated % of Container Filled:	0.25						
Actual Volume of Container Filled:	1.00 cy						1.00 cy
Density of plywood:[39 lb/ft^3]							
Theoretical Volume by Material Density:	0.38 cy						0.38 cy

Notes:

Load(3)Miscellaneous	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------->Saturated 1 2 3 4 5	4						
[Total Weight] Container + Waste + Dirt:	1,000						
Weight of Dirt on Scale (lb):	900						
Weight of Container/Vehicle (lb):	42						
Waste Weight (lb):	58 lb						58 lb
Total Container Volume (cy):	0.48						
Estimated % of Container Filled:	0.17						
Actual Volume of Container Filled:	0.08 cy						0.08 cy

Notes: Composite paper/plastic mortar bags.

Load(3) **MSW**	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------>Saturated 1 2 3 4 5	2						
[Total Weight] Container + Waste + Dirt:	N/A						
Weight of Dirt on Scale (lb):	N/A						
Weight of Container/Vehicle (lb):	N/A						
Waste Weight (lb):	30 lb						30 lb
Total Container Volume (cy):	0.15						
Estimated % of Container Filled:	1.00						
Actual Volume of Container Filled:	0.15 cy						0.15 cy

Notes: Visual estimation of residual volume
Coke cans, food wrappers, garbage...ect.

Load(3) **Residual Rubble Est.**	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotal
Date Measured:	13-Aug						
Visual Moisture Content: Dry<------------>Saturated 1 2 3 4 5	3						
Waste Weight (lb):	450 lb						450 lb

Notes: Visual estimate of dirt and rubble left on ground of weighing area.

Material Weight and Volume Summary: Load 3

Material	Measure	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Subtotals
Wood								
Solid Sawn	Weight:	1,860 lb	440 lb					2,300 lb
	Actual Volume:	3.60 cy	1.20 cy					4.80 cy
[Density: 36 lb/ft³]	Theoretical Volume:	1.91 cy	.45 cy					2.36 cy
OSB	Weight:	400 lb						400 lb
	Actual Volume:	1.00 cy						1.00 cy
[Density: 37 lb/ft³]	Theoretical Volume:	.40 cy						.40 cy
Plywood	Weight:	660 lb						660 lb
	Actual Volume:	1.00 cy						1.00 cy
[Density: 39 lb/ft³]	Theoretical Volume:	.63 cy						.63 cy
Gypsum Wallboard								
	Weight:	None						None
	Actual Volume:	None						None
[Density: 44 lb/ft³]	Theoretical Volume:	None						None
Metals								
Ferrous & Non-Ferrous	Weight:	58 lb						58 lb
	Actual Volume:	.38 cy						.38 cy
[Density: 472 lb/ft³]	Theoretical Volume:	.005 cy						.005 cy
Cardboard								
	Weight:	118 lb						118 lb
	Actual Volume:	.48 cy						.48 cy
[Density: 43 lb/ft³]	Theoretical Volume:	.10 cy						.10 cy
Paper								
	Weight:	78 lb						78 lb
	Actual Volume:	.48 cy						.48 cy
[Density: 58 lb/ft³]	Theoretical Volume:	.05 cy						.05 cy
Plastics								
Film	Weight:	20 lb						20 lb
	Actual Volume:	0.48 cy						0.48 cy
[Density: N/A lb/ft³]	Theoretical Volume:	N/A						N/A
Masonry								
Concrete	Weight:	700 lb						700 lb
	Actual Volume:	.80 cy						.80 cy
[Density: 144 lb/ ft³]	Theoretical Volume:	0.18						0.18

Construction and Demolition Waste Composition Study Data Sheet

		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Totals
Brick	Weight:	Mixed						Mixed
	Actual Volume:	Mixed						Mixed
[Density: 125 lb/ ft³]	Theoretical Volume:	Mixed						Mixed
Asphaultic Products								
Shingles & Tar Paper	Weight:	376 lb	300 lb					676 lb
	Actual Volume:	.41 cy	.38 cy					.79 cy
[Density: 86 lb/ft³]	Theoretical Volume:	.16 cy	.13 cy					.29 cy
Insulation								
Fiberglass	Weight:	None						None
	Actual Volume:	None						None
[Density: 4.1 lb/ft³]	Theoretical Volume:	None						None
Hardi Plank								
	Weight:	118 lb						118 lb
	Actual Volume:	.22 cy						.22 cy
[Density: 40 lb/ft³]	Theoretical Volume:	.11 cy						.11 cy
Miscellaneous								
	Weight:	58 lb						58 lb
	Actual Volume:	.08 cy						.08 cy
MSW								
	Weight:	30 lb						30 lb
	Actual Volume:	.15 cy						.15 cy
Residual Dirt & Rubble *Est.								
	Weight:	*450 lb						*450 lb
	Actual Volume:	N/A						N/A
House Subtotals:		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Totals
Seperated Material Weights:		4,926 lb	740 lb					5,666 lb
Seperated Materials Actual Volumes:		9.08 cy	1.58 cy					10.66 cy
Moisture Level of Materials:		4	4					4

Appendix C

Summary Tables

Material Weight and Volume Summary: (Jockey Club)

		Load 1	Load 2	Load 3	Load 4	Load 5	Subtotals
Wood							
Solid Sawn	Weight:	4,870 lb	5,140 lb	2,300 lb	Lost	518 lb	12,828 lb
	Actual Volume:	12.60 cy	8.80 cy	4.80 cy	Lost	.43 cy	26.63 cy
[Density: 36 lb/ft^3]	Theoretical Volume:	5.01 cy	5.29 cy	2.36 cy	Lost	.53 cy	13.19 cy
OSB	Weight:	Mixed	Mixed	400 lb	Lost	None	400 lb
	Actual Volume:	Mixed	Mixed	1.00 cy	Lost	None	1.00 cy
[Density: 37 lb/ft^3]	Theoretical Volume:	Mixed	Mixed	.40 cy	Lost	None	.40 cy
Plywood	Weight:	Mixed	Mixed	660 lb	Lost	71 lb	731 lb
	Actual Volume:	Mixed	Mixed	1.00 cy	Lost	.11 cy	1.11 cy
[Density: 39 lb/ft^3]	Theoretical Volume:	Mixed	Mixed	.63 cy	Lost	.07 cy	.70 cy
Gypsum Wallboard							
	Weight:	None	None	None	Lost	3,380 lb	3,380 lb
	Actual Volume:	None	None	None	Lost	3.80 cy	3.80 cy
[Density: 44 lb/ft^3]	Theoretical Volume:	None	None	None	Lost	2.85 cy	2.85 cy
Metals							
Ferrous & Non-Ferrous	Weight:	58 lb	45 lb	58 lb	Lost	40 lb	201 lb
	Actual Volume:	.24 cy	.12 cy	.38 cy	Lost	.10 cy	.84 cy
[Density: 472 lb/ft^3]	Theoretical Volume:	.005 cy	.004 cy	.005 cy	Lost	.003 cy	.02 cy
Cardboard							
	Weight:	176 lb	76 lb	118 lb	Lost	316 lb	686 lb
	Actual Volume:	.96 cy	.86 cy	.48 cy	Lost	.72 cy	3.02 cy
[Density: 43 lb/ ft^3]	Theoretical Volume:	.15 cy	.07 cy	.10 cy	Lost	.27 cy	.59 cy
Paper							
	Weight:	None	None	78 lb	Lost	None	78 lb
	Actual Volume:	None	None	.48 cy	Lost	None	.48 cy
[Density: 58 lb/ ft^3]	Theoretical Volume:	None	None	.05 cy	Lost	None	.05 cy
Plastics							
Film	Weight:	58 lb	58 lb	20 lb	Lost	58 lb	194 lb
	Actual Volume:	.48 cy	.24 cy	.48 cy	Lost	.24 cy	1.44 cy
[Density: N/A lb/ ft^3]	Theoretical Volume:	N/A	N/A	N/A	Lost	N/A	N/A
Masonry							
Concrete	Weight:	620 lb	674 lb	700 lb	Lost	None	1,994 lb
	Actual Volume:	1.00 cy	.60 cy	.80 cy	Lost	None	2.40 cy
[Density: 144 lb/ ft^3]	Theoretical Volume:	.16 cy	.17 cy	0.18	Lost	None	.51 cy

		Load 1	Load 2	Load 3	Load 4	Load 5	**Subtotals**
Brick	Weight:	Mixed	Mixed	Mixed	Lost	100 lb	100 lb
	Actual Volume:	Mixed	Mixed	Mixed	Lost	.10 cy	.10 cy
[Density: 125 lb/ ft^3]	Theoretical Volume:	Mixed	Mixed	Mixed	Lost	.03 cy	.03 cy
Asphaultic Products							
Shingles & Tar Paper	Weight:	280 lb	216 lb	676 lb	Lost	358 lb	1,530 lb
	Actual Volume:	.36 cy	.34 cy	.79 cy	Lost	.38 cy	1.87 cy
[Density: 86 lb/ ft^3]	Theoretical Volume:	.12 cy	.09 cy	.29 cy	Lost	.15 cy	.65 cy
Insulation							
Fiberglass	Weight:	None	56 lb	None	Lost	None	56 lb
	Actual Volume:	None	.67 cy	None	Lost	None	.67 cy
[Density: 4.1 lb/ft^3]	Theoretical Volume:	None	.51 cy	None	Lost	None	.51 cy
Hardi Plank							
	Weight:	None	932 lb	118 lb	Lost	378 lb	1,428 lb
	Actual Volume:	None	1.23 cy	.22 cy	Lost	.14 cy	1.59 cy
[Density: 40 lb/ft^3]	Theoretical Volume:	None	.86 cy	.11 cy	Lost	.35 cy	1.32 cy
Miscellaneous							
	Weight:	160 lb	60 lb	58 lb	Lost	398 lb	676 lb
	Actual Volume:	.18 cy	.10 cy	.08 cy	Lost	.36 cy	.72 cy
MSW							
	Weight:	Mixed	Mixed	30 lb	Lost	35 lb	65 lb
	Actual Volume:	Mixed	Mixed	.15 cy	Lost	.15 cy	.30 cy
Residual Dirt & Rubble Est.							
	Weight:	500 lb	200 lb	450 lb	Lost	N/A	1,150 lb
	Actual Volume:	N/A	N/A	N/A	Lost	N/A	N/A
House Subtotals:		Load 1	Load 2	Load 3	Load 4	Load 5	***Totals**
Separated Material Weights:		6,722 lb	7,457 lb	5,666 lb	*6,615 lb	5,652 lb	32,112 lb
Separated Materials Actual Volumes:		15.82 cy	12.96 cy	10.66 cy	*12.00 cy	6.53 cy	57.97 cy
Moisture Level of Materials:		3	3	4	Lost	5	3.75

Material Weight and Volume Summary:(Haile Plantation)

		Load 1	Load 2	Load 3	Load 4	Subtotals
Wood						
Solid Sawn	Weight:	2,720 lb	806 lb	323 lb	78 lb	3,927 lb
	Actual Volume:	7.40 cy	1.70 cy	.65 cy	.29 cy	10.04 cy
[Density: 36 lb/ft³]	Theoretical Volume:	2.80 cy	.83 cy	.33 cy	.08 cy	4.04 cy
OSB	Weight:	2,140 lb	1,282 lb	65 lb	None	3,487 lb
	Actual Volume:	4.80 cy	2.15 cy	.13 cy	None	7.08 cy
[Density: 37 lb/ft³]	Theoretical Volume:	2.14 cy	1.28 cy	.07 cy	None	3.49 cy
Plywood	Weight:	None	71 lb	None	118 lb	189 lb
	Actual Volume:	None	.14 cy	None	.29 cy	.43 cy
[Density: 39 lb/ft³]	Theoretical Volume:	None	.07 cy	None	.11 cy	.18 cy
Gypsum Wallboard						
	Weight:	None	None	2,864 lb	None	2,864 lb
	Actual Volume:	None	None	6.81 cy	None	6.81 cy
[Density: 44 lb/ ft³]	Theoretical Volume:	None	None	2.41 cy	None	2.41 cy
Metals						
Ferrous & Non-Ferrous	Weight:	198 lb	17 lb	95 lb	None	310 lb
	Actual Volume:	.22 cy	.02 cy	.27 cy	None	.51 cy
[Density: 472 lb/ ft³]	Theoretical Volume:	.02 cy	.01 cy	.01 cy	None	.04 cy
Cardboard						
	Weight:	198 lb	114 lb	18 lb	17 lb	347 lb
	Actual Volume:	.46 cy	.96 cy	.15 cy	.24 cy	1.81 cy
[Density: 43 lb/ft³]	Theoretical Volume:	.17 cy	.10 cy	.02 cy	.02 cy	.31 cy
Paper						
	Weight:	None	75 lb	143 lb	None	218 lb
	Actual Volume:	None	.53 cy	.80 cy	None	1.33 cy
[Density: 58 lb/ ft³]	Theoretical Volume:	None	.05 cy	.09 cy	None	.14 cy
Plastics						
Film	Weight:	10 lb	163 lb	None	None	173 lb
	Actual Volume:	.12 cy	1.01 cy	None	None	1.13 cy
[Density: N/A lb/ ft³]	Theoretical Volume:	N/A	N/A	None	None	N/A
Masonry						
Concrete	Weight:	None	528 lb	2,887 lb	2,100 lb	5,515 lb
	Actual Volume:	None	.30 cy	1.45 cy	1.19 cy	2.94 cy
[Density: 144 lb/ ft³]	Theoretical Volume:	None	.14 cy	.74 cy	.54 cy	1.42 cy

		Load 1	Load 2	Load 3	Load 4	Subtotals
Brick	Weight:	None	Mixed	3,501 lb	None	3,501 lb
	Actual Volume:	None	Mixed	2.09 cy	None	2.09 cy
[Density: 125 lb/ ft^3]	Theoretical Volume:	None	Mixed	1.04 cy	None	1.04 cy
Asphaultic Products						
Shingles & Tar Paper	Weight:	198 lb	16 lb	406 lb	None	620 lb
	Actual Volume:	.22 cy	.05 cy	.79 cy	None	1.06 cy
[Density: 86 lb/ ft^3]	Theoretical Volume:	.09 cy	.01 cy	.17 cy	None	.27 cy
Miscellaneous						
	Weight:	None	None	None	13 lb	13 lb
	Actual Volume:	None	None	None	.06 cy	.06 cy
MSW						
	Weight:	25 lb	14 lb	15 lb	9 lb	63 lb
	Actual Volume:	.56 cy	.30 cy	.27 cy	.18 cy	1.31 cy
Residual Dirt & Rubble Est.						
	Weight:	300 lb	500 lb	3,000 lb	250 lb	4,050 lb
	Actual Volume:	N/A	N/A	N/A	N/A	N/A
House Subtotals:		Load 1	Load 2	Load 3	Load 4	**Totals**
Separated Material Weights:		5,789 lb	3,586 lb	13,317 lb	2,585 lb	25,277 lb
Separated Materials Actual Volumes:		13.78 cy	7.16 cy	13.41 cy	2.25 cy	36.6 cy
Moisture Level of Materials:		4	2	2	2	2.5

Material Weight and Volume Summary: (Parker Place)

		Load 1	Load 2	Load 3	Subtotals
Wood					
Solid Sawn	Weight:	982 lb	2,093 lb	494 lb	3,569 lb
	Actual Volume:	2.53 cy	3.42 cy	.76 cy	6.71 cy
[Density: 36 lb/ft^3]	Theoretical Volume:	1.01 cy	2.15 cy	.51 cy	3.67 cy
OSB	Weight:	1,255 lb	51 lb	None	1,306 lb
	Actual Volume:	2.55 cy	1.07 cy	None	3.62 cy
[Density: 37 lb/ft^3]	Theoretical Volume:	1.26 cy	.05 cy	None	1.31 cy
Plywood	Weight:	None	None	42 lb	42 lb
	Actual Volume:	None	None	.05 cy	.05 cy
[Density: 39 lb/ft^3]	Theoretical Volume:	None	None	.04 cy	.04 cy
Gypsum Wallboard					
	Weight:	None	184 lb	None	184 lb
	Actual Volume:	None	.29 cy	None	.29 cy
[Density: 44 lb/ft^3]	Theoretical Volume:	None	.15 cy	None	.15 cy
Metals					
Ferrous & Non-Ferrous	Weight:	12 lb	38 lb	None	50 lb
	Actual Volume:	.01 cy	.01 cy	None	.02 cy
[Density: 472 lb/ft^3]	Theoretical Volume:	.001 cy	0.003 cy	None	.004 cy
Cardboard					
	Weight:	95 lb	54 lb	275 lb	424 lb
	Actual Volume:	.77 cy	.36 cy	1.14 cy	2.27 cy
[Density: 43 lb/ ft^3]	Theoretical Volume:	.08 cy	.05 cy	.24 cy	.37 cy
Paper					
	Weight:	18 lb	37 lb	25 lb	80 lb
	Actual Volume:	0.05	.12 cy	.10 cy	.27 cy
[Density: 58 lb/ ft^3]	Theoretical Volume:	.01 cy	.02 cy	.02 cy	.05 cy
Plastics					
Film	Weight:	None	35 lb	40 lb	75 lb
	Actual Volume:	None	.18 cy	.35 cy	.53 cy
[Density: N/A lb/ ft^3]	Theoretical Volume:	None	N/A	N/A	N/A
Masonry					
Concrete	Weight:	4,000 lb	353 lb	1,050 lb	5,403 lb
	Actual Volume:	2.67 cy	1.00 cy	.89 cy	4.56 cy
[Density: 144 lb/ ft^3]	Theoretical Volume:	1.03 cy	.09 cy	.27 cy	1.39 cy

		Load 1	Load 2	Load 3	Subtotals
Clay Tile (Floor)	Weight:	None	None	200 lb	200 lb
	Actual Volume:	None	None	.16 cy	.16 cy
[Density: 125 lb/ ft^3]	Theoretical Volume:	None	None	.04 cy	.04 cy
Asphaultic Products					
Shingles & Tar Paper	Weight:	641 lb	40 lb	None	681 lb
	Actual Volume:	.99 cy	.04 cy	None	1.03 cy
[Density: 86 lb/ ft^3]	Theoretical Volume:	.28 cy	.01 cy	None	.29 cy
Insulation					
Fiberglass	Weight:	68 lb	37 lb	13 lb	118 lb
	Actual Volume:	.86 cy	.23 cy	.19 cy	1.28 cy
[Density: 4.1 lb/ft^3]	Theoretical Volume:	.61 cy	.33 cy	.12 cy	1.06 cy
Hardi Plank					
	Weight:	125 lb	37 lb	None	162 lb
	Actual Volume:	.19 cy	.05 cy	None	.24 cy
[Density: 40 lb/ft^3]	Theoretical Volume:	.12 cy	.03 cy	None	.15 cy
Miscellaneous					
	Weight:	200 lb	250 lb	25 lb	475 lb
	Actual Volume:	.86 cy	.90 cy	.08 cy	1.84 cy
MSW					
	Weight:	10 lb	25 lb	7 lb	42 lb
	Actual Volume:	N/A	N/A	N/A	N/A
Residual Dirt & Rubble Est.					
	Weight:	700 lb	650 lb	300 lb	1,650 lb
	Actual Volume:	N/A	N/A	N/A	N/A
House Subtotals:		Load 1	Load 2	Load 3	**Totals**
Separated Material Weights:		8,106 lb	3,884 lb	2,471 lb	14,461 lb
Separated Materials Actual Volumes:		11.48 cy	7.67 cy	3.72 cy	22.87 cy
Moisture Level of Materials:		3	3	2	2.67

Appendix D
Moisture Content of C&D Components

Moisture Content of Sorted Building Materials

OSB	30.5 %
Gypsum Wallboard	10.5 %
Cardboard	41.6 %
Tar paper	20 %
Hardi-Plank	22.8 %

(Moisture levels of new building materials have not been taken into account. Data represent only a snapshot rather than the mean of several samples.)