CITRUS COUNTY, PUTNAM COUNTY, OKALOOSA COUNTY

AND THE

NEW RIVER SOLID WASTE ASSOCIATION

1998-1999 INNOVATIVE GRANT PROJECT

RECYCLING OF DISCARDED GYPSUM DRYWALL IN FLORIDA

FINAL REPORT TO THE FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

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SUBMITTED BY:

CITRUS COUNTY GOVERNMENT

THE NEW RIVER SOLID WASTE ASSOCIATION

AND

OKALOOSA COUNTY GOVERNMENT

PREPARED BY:

UNIVERSITY OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL ENGINEERING SCIENCES

TIMOTHY G. TOWNSEND

ALLISON H. BARNES

KIMBERLY M. COCHRAN

JENNA JAMBECK CARLSON

This project was a collaboration of many parties, including Susan J. Metcalfe and Frank Wentzel from the Citrus County Solid Waste Management, Darrell O'Neal from the New River Solid Waste Association, Jim Reece from the Okaloosa Solid Waste Department, Charles McLendon and Thomas Edwards from R.W. Beck, and Judy DeVita from Jones, Edmunds, and Associates. The principal investigator on the project was Timothy G. Townsend from the University of Florida Department of Environmental Engineering Sciences. Allison H. Barnes, Kimberly M. Cochran, and Jenna R. Jambeck Carlson from the University of Florida Department of Environmental Engineering Sciences prepared this report.

RECYCLING OF DISCARDED GYPSUM DRYWALL IN FLORIDA

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CHAPTER 1
INTRODUCTION

OVERVIEW

This report presents the combined results of three Innovative Recycling Grants conducted on discarded gypsum drywall in Florida during 1999 and 2000. The grants were awarded by the Florida Department of environmental Protection (FDEP). The University of Florida, Department of Environmental Engineering Sciences, collected and compiled information gathered by all three grant recipients, as well as additional information on the subject, to produce this comprehensive report.

MOTIVATION

Construction and demolition (C&D) waste results from the construction, demolition and renovation of buildings, bridges, roads and other structures. Gypsum drywall represents one of the more common components of the C&D waste stream along with concrete, asphalt, wood, metal, cardboard, plastic, and soil. As Florida's population grows and C&D related activity continues at a rapid pace, large amounts of C&D waste are generated. Construction and demolition waste accounts for approximately 24 percent of the municipal solid waste (MSW) stream in Florida (FDEP, 2000). The large contribution of C&D waste to the overall waste stream, combined with possible environmental impacts when disposed and a relatively low recycling rate, have placed renewed attention on this often overlooked material.

Gypsum drywall stands out as one component of C&D waste that warrants additional attention. Gypsum drywall represents the largest material found in C&D waste that currently does not have an established market in Florida. Concrete and wood are certainly larger components of the C&D waste stream, but markets for recycled concrete and wood do exist. Successful gypsum drywall recycling programs operate in other areas of North America. Gypsum drywall also merits special attention because of its possible impact on the environment during disposal. When disposed in a landfill, conditions often develop that result in the biological transformation of gypsum to hydrogen sulfide, a foul-smelling gas that is toxic at high concentrations. Many C&D waste landfills suffer from this problem. One factor limiting landfill operators from minimizing the amount of drywall that is disposed is the lack of available recycling markets.

PROJECT OBJECTIVES

Waste reduction experts with the FDEP recognized the need to develop the gypsum drywall recycling market in the state and awarded three of the 1999-2000 Innovative Recycling Grants to counties that addressed this issue. Grants were awarded to the team of Citrus and Putnam Counties, The New River Solid Waste Association (Baker, Bradford and Union Counties), and Okaloosa County (See Figure 1-1).

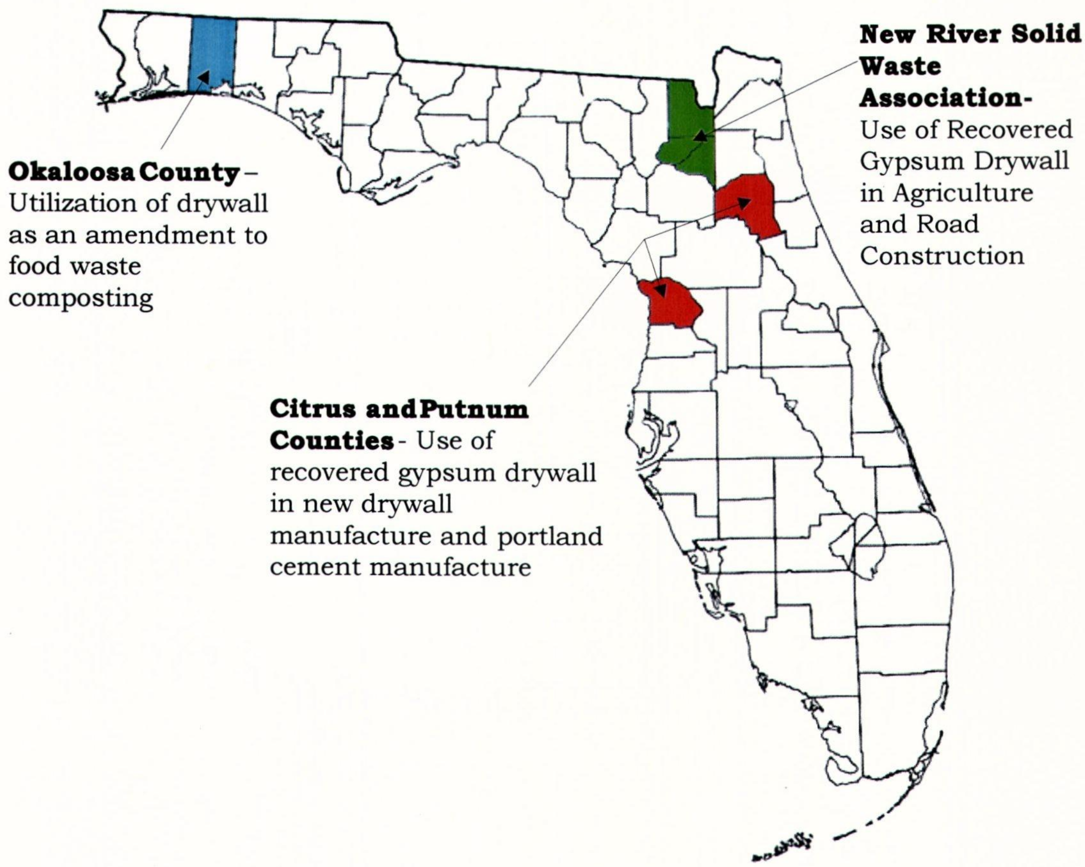


Figure 1-1. Innovative Grant Recipient Locations

Each grant focused on different end-use markets. The grant recipients did, however, participate during the process by holding joint information dissemination meetings, evaluating several combined processing trials, and sharing information for one final report. The specific objectives and the participants of each grant are presented in Table 1-1.

Table 1-1. Innovative Recycling Grants and Objectives

Grant Recipient	Other Participants	Objectives
Citrus/Putnam	R.W. Beck Agri-Cycle, Ltd. Florida Crushed Stone Southdown	• Assess the amount of drywall in the C&D waste stream • Implement and evaluate drywall collection and processing systems • Investigate markets of recycled drywall for remanufacture into new drywall and in the production of Portland cement
NRSWA	IFAS JEA Homes of Merit	• Implement and evaluate drywall collection and processing systems • Investigate markets of recycled drywall as a soil amendment for agriculture in two separate experiments • Investigate the uses of recycled drywall as a material for stabilizing road base
Okaloosa	IFAS R.W. Beck Eglin Air Force Base	• Investigate markets of recycled drywall for two composting methods: windrow method and in-vessel method (AgBag)

ORGANIZATION OF THIS REPORT

This report documents the grant activities and summarizes the results. Additional background information common to all grants is also presented. The report is organized into seven sections. Appendices and references are also included. The sections and appendices included in the report are outlined and summarized in Table 1-2.

Table 1-2. Report Organization

Section	Description
1.0	• Introduction
2.0	• Background on gypsum • Drywall as a component of the C&D waste stream • Environmental impacts
3.0	• Markets for recovered gypsum • Collection and processing of drywall • Existing recycling programs
4.0	• Citrus/Putnum Innovative Recycling Grant
5.0	• NRSWA Innovative Recycling Grant
6.0	• Okaloosa Innovative Recycling Grant
7.0	• Drywall Recycling Feasibility • Economics • Policy
Appendices	• Appendix A – Information Dissemination • Appendix B – Putnam County Class III Waste Sort • Appendix C – Weight-Based Composition Study Data Collection Sheet • Appendix D – Stakeholder Meeting I & II Notes and Economic Analysis • Appendix E – IFAS Agricultural Trial I (SVREC-Live Oak) • Appendix F – IFAS Agricultural Trial II (Macclenny) • Appendix G – AgBag Composting Made Simple

CHAPTER 2
BACKGROUND ON GYPSUM DRYWALL

THE MINERAL GYPSUM

Gypsum is a non-metallic mineral composed of calcium sulfate ($CaSO_4$) and water (H_2O). Gypsum is also called hydrous calcium sulfate ($CaSO_4 \cdot 2H_2O$). Natural gypsum deposits formed as a result of evaporating seawater from ancient seabeds (Kessler, 1994). Today, gypsum is mined from these deposits as a raw material for many different manufacturing, industrial, and agricultural uses. The United States leads the world in gypsum mining and production with 18% of the global output. The majority of the gypsum mined in the U.S. (72%) comes from the following states (in descending order): Oklahoma, Iowa, Texas, Michigan, California, Nevada, and Indiana (USGS A, 2000). A number of industrial processes produce synthetic gypsum as a byproduct, including phosphate fertilizer production and desulfurization of combustion gases (Harler, 1996). Figure 2-1 presents the distribution of the raw gypsum supply in the United States. The majority comes from mines in the U.S., however a fraction is imported (primarily from Canada, Mexico, and Spain), and another fraction is derived from byproducts of the industrial processes listed above.

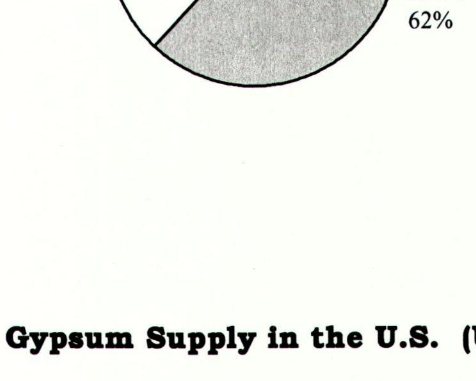


Figure 2-1. Gypsum Supply in the U.S. (USGS A, 1998).

Processed gypsum is classified as *calcined* (part of the water is driven off) or *uncalcined*. Calcined gypsum is used in the production of drywall and plaster of paris. Uncalcined gypsum is used for portland cement manufacture, agriculture, and fillers in consumer products. The amount of gypsum products produced in the United States amounts to more than 37 million metric tons (USGS A, 2000 and USGS A, 1998). Cement production accounted for more than five million metric tons, and agricultural applications accounted for more than three million metric tons. The remainder was primarily used for drywall manufacturing. Figure 2-2 presents the major gypsum markets and their relative distribution. Federal funding authorized in 1998 for road repair and construction will likely increase the need for gypsum in cement production. The average price per ton of crude uncalcinated gypsum is $7.20, while calcined gypsum is priced at $18.00 per ton on average (USGS A, 1998). The United States produced 19,400,000 tons of calcined gypsum in 1998, valued at $302 million. Florida alone produced 1,230,000 tons, valued at $26.6 million (USGS A, 1998).

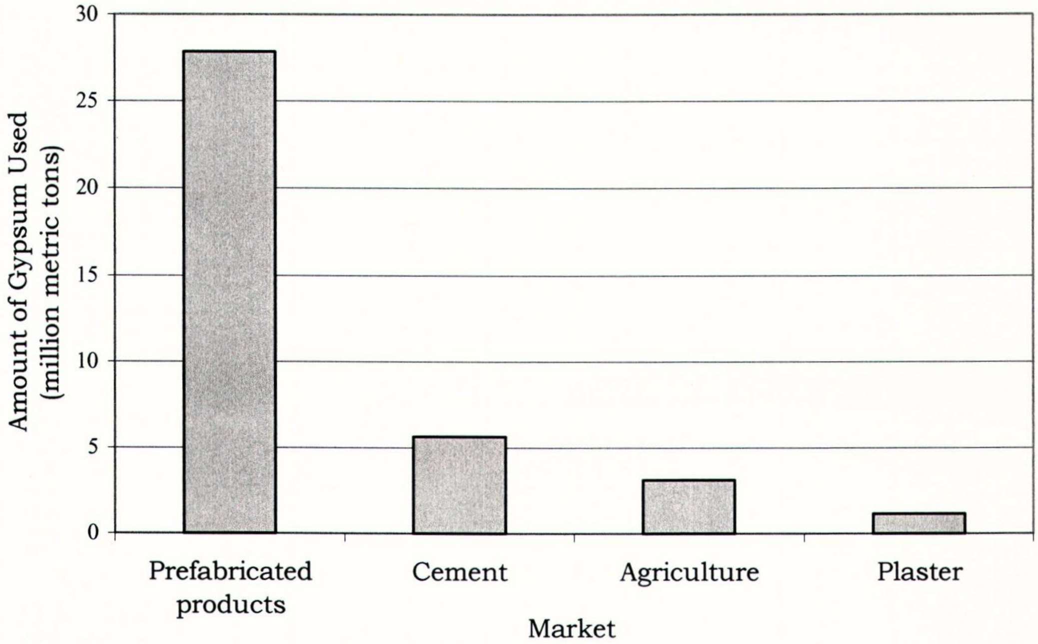


Figure 2-2. Gypsum sold for production and use in the U.S. (USGS A, 1998).

GYPSUM DRYWALL

Gypsum is naturally fire resistant, which makes it a popular building material. There are 65 drywall-manufacturing plants in the United States that produce and sell 29.1 billion square feet of drywall per year. The drywall manufacturing process begins with the mined gypsum. After the gypsum is transported from the mines, it is crushed. Any rock larger than two inches in diameter is size reduced. The crushed gypsum is fed into a "rock dryer," a kiln that evaporates any moisture on the rocks. Then it is ground into a fine powder, which is often called "land plaster." The wallboard manufacturing process uses calcined gypsum. The calcination process involves heating the "land plaster" (hydrous calcium sulfate), removing approximately three-quarters of the water to form calcium sulfate hemi-hydrate ($CaSO_4 \cdot 1/2H_2O$). The powder is heated to remove 75% of the water that makes up the actual chemical structure of the gypsum. This process turns the powder into stucco, a very dry powder that will harden quickly when mixed with water. The stucco is fed into a pin mixer and mixed with water and other ingredients, depending on the type of drywall being made. This slurry is spread onto a moving continuous sheet of paper, then sandwiched with a top paper, forming the wallboard. This continuous sheet of wallboard travels on conveyor belts for four minutes in order to allow the slurry to harden. It is then cut into panels and sent to a kiln for final drying. It is trimmed to the exact length and bundled, ready for shipment (National Gypsum Company, 1999). Figure 2-3 summarizes the drywall manufacturing process.

Manufactured fire resistant (Type X) drywall

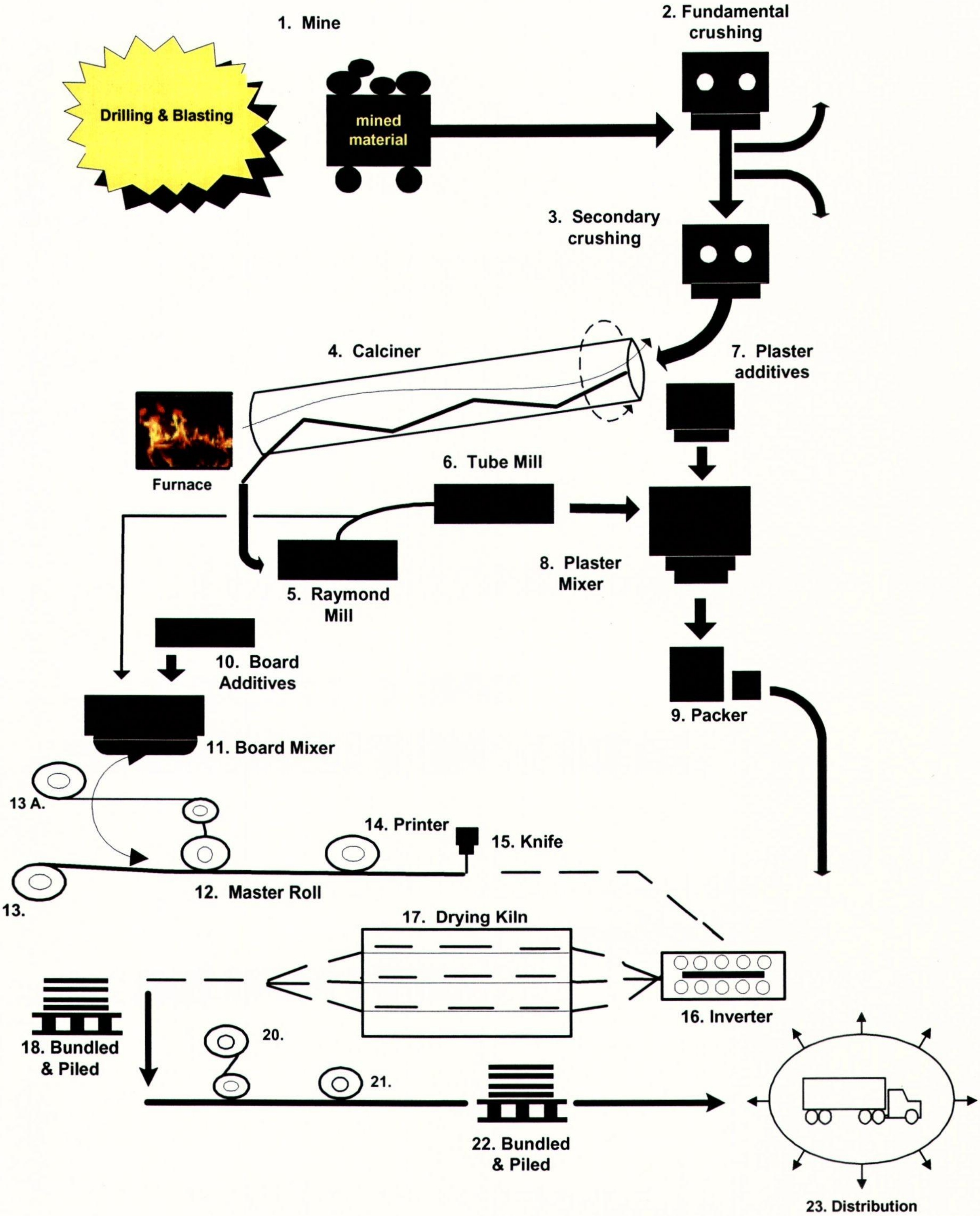


Figure 2-3. The Drywall Manufacturing Process at a Typical Gypsum Plant. Source: U.S. Gypsum, 1999

Drywall comes in many different types and sizes to meet very specific needs in a residential home or commercial building. Figure 2-4 presents the relative amounts of prefabricated (drywall) products that are produced from gypsum. Regular gypsumboard is the most common type of drywall produced followed by Type X, which is fire resistant. Other types include water resistant board and drywall produced specifically for mobile homes. The most common types of drywall produced, sizes, and applications are summarized in Table 2-1.

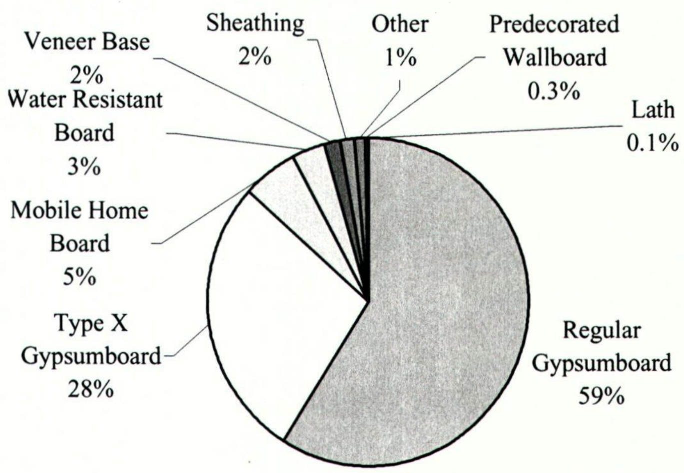


Figure 2-4. Prefabricated products made from gypsum

Table 2-1. Typical drywall sizes and applications (Source: U.S. Gypsum, 2000)

Drywall Description	Thickness	Width	Length
Regular Gypsum Drywall	¼"	4'	8-12'
Used for interior walls and ceilings, with sound and fire resistant properties	3/8"	4'	8-12'
depending on the thickness and assembly	½"	4'	8-16'
	5/8"	4'	8-12'
Fire Resistant (Type X)	½"	4'	8-16'
Used in ceilings, floors and interior walls because of the non-combustible core	5/8"	4'	6-16'
Water Resistant Used for backing in bathroom and shower areas	½"	4'	8-12'
Type X Water Resistant	½"	4'	8'
Both fire and water resistant and used in similar applications	5/8"	4'	8-12'
Wide Board Used for large applications such as ceilings and eliminates the need for a filler strip	½"	4.5'	8-12'

GYPSUM DRYWALL IN CONSTRUCTION AND DEMOLITION WASTE

C&D waste consists of building related waste (construction, demolition and renovation), roadway related waste, land-clearing debris, and inert debris waste. Drywall is a typical component of the building related waste. Construction debris consists primarily of scraps from trimming and cutting pieces of wood, drywall, roofing material and masonry work. Demolition waste can be 20 to 30 times the amount of construction waste generated on a per building basis (U.S. EPA, 1998). Renovation waste is a combination of both demolition and construction waste. Typically, C&D waste is sent to a landfill or a materials recovery facility (MRF).

The amount of drywall in the building related C&D waste stream may range from 4% to 76%, depending on whether the waste comes from construction, demolition or renovation activities. The percentage of drywall in the C&D waste stream will vary by size and type of the building and construction materials used. No National or statewide estimate of C&D waste composition currently exists, but waste composition studies have been performed on different C&D waste streams. This section further examines the percentages of drywall generated from these building related activities.

DRYWALL IN CONSTRUCTION DEBRIS

Construction debris is generated from residential and non-residential building related activities. Residential new construction comprises 5% and non-residential comprises 3% of the building related C&D waste generated in the U.S. as a whole (U.S. EPA, 1998). This percentage is likely higher in Florida because of the state's rapid growth and relatively new infrastructure. Waste audits characterizing the composition of residential and non-residential new construction debris have been performed by several entities including the National Association of Homebuilders (NAHB) Research Center, the Metropolitan Service District in Portland, Oregon, the Metro Waste authority in Des Moines, Iowa, Cornell University and the University of Florida.

The NAHB conducted waste assessments of four residential construction sites. These sites were in Largo, Maryland; Anne Arundel County, Maryland; Portland, Oregon; and Grand Rapids, Michigan. The percentage of drywall in the waste stream from the residential study ranged from 24% to 31% (NAHB, 1995). A series of audits were undertaken by the Metropolitan Service District in Portland, Oregon (METRO). Assessments took place at several residential and non-residential construction, demolition and renovation sites. The percentage of drywall waste from the residential audits ranged from 11% to 28% (METRO, 1992-1995).

Drywall was found to be 16% of the waste from residential construction and 7% from non-residential construction in a 1995 study performed in Des Moines, Iowa by the Metro Waste Authority and Gershman, Brickner & Bratton, Inc. (GBB). A waste composition study of construction sites in Alachua County, Florida found residential construction to contain 30% drywall and non-residential construction to contain 11%. The pie charts in Figure 2-5 present the average waste compositions of the four sites examined by the NAHB, the average of the three sites examined by METRO, and both the residential and non-residential waste audits performed in Iowa.

Drywall installation at a residential construction site (left) and drywa the roll-off at a commercial construction site (right).

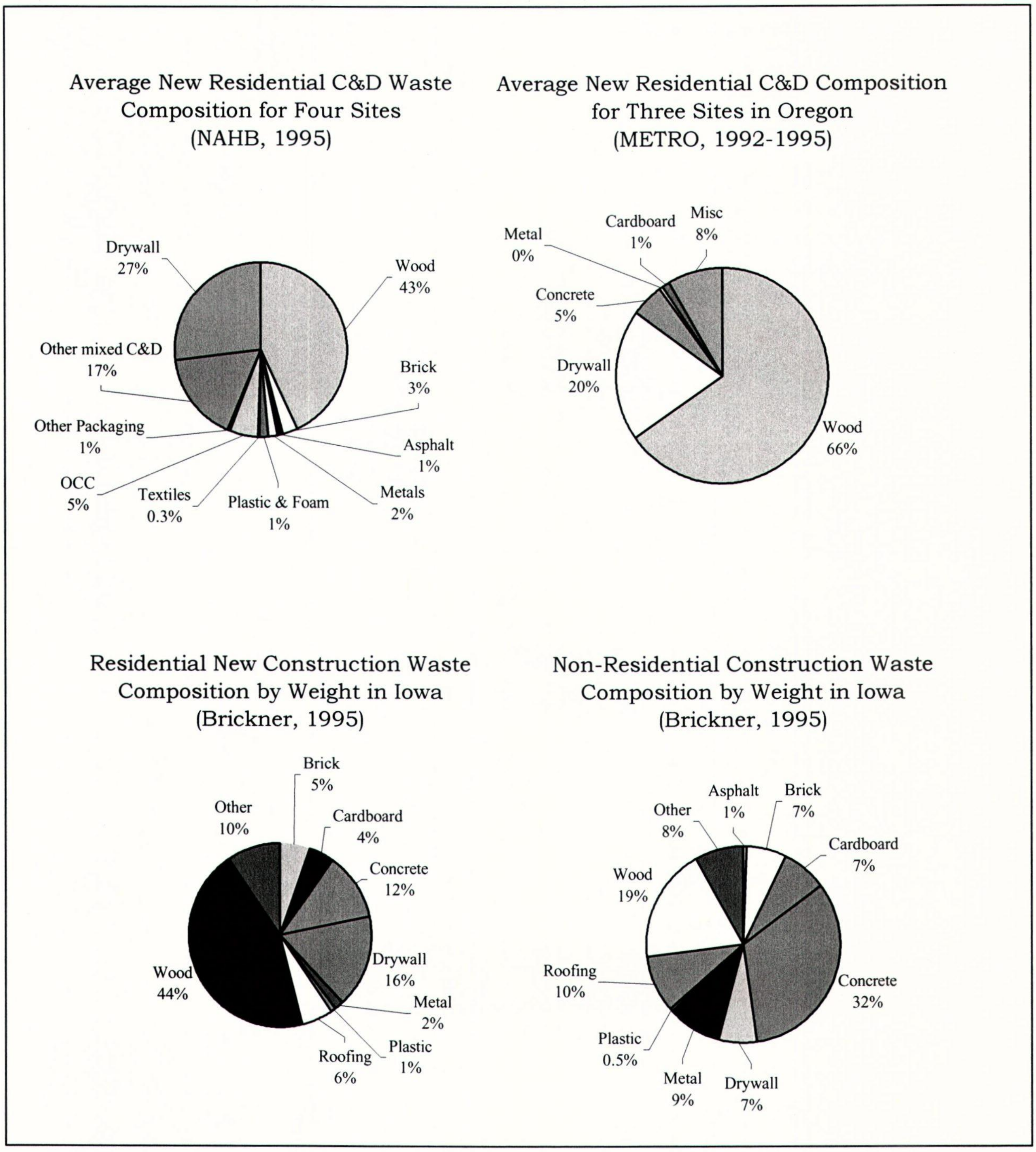


Figure 2-5. Constnction C&D Waste Compositions

DRYWALL IN DEMOLITION DEBRIS

Residential demolition debris comprises 15% and non-residential demolition debris comprises 33% (the largest fraction) of C&D waste produced from building related activities (U.S. EPA, 1998). In 1998, the U.S. EPA estimated that 19.7 million tons of residential demolition debris and 45.1 million tons of non-residential demolition debris are generated per year. As homes ending their life cycle are being demolished, more modern construction materials are entering the demolition C&D waste stream like drywall, treated wood and composite materials.

A C&D composition study focusing on demolition debris was completed by the Metro Waste Authority and GBB in Des Moines, Iowa (Brickner, 1995). Both residential and non-residential buildings were assessed. Drywall was found to compose 10% of the residential and 20% of the non-residential demolition waste. A demolition contractor, R.W. Rhine, in Tacoma, Washington, performed waste audits on 19 non-residential demolition sites in the northwest area. The waste characterization from these combined demolitions, was composed of 41% drywall. In 1997, the NAHB Research Center performed a deconstruction project (the Riverdale Case Study). A multi-family (4-plex) building was systematically dismantled for the purpose of recovering and recycling the demolition waste (NAHB A, 1997). Drywall composed 17% of this waste stream. The pie charts in Figure 2-6 present the waste compositions of the residential and non-residential demolition waste audits performed in Iowa, the combined waste composition of the 19 demolition sites in Washington and the waste composition from the Riverdale Case Study.

A non-residential demolition site

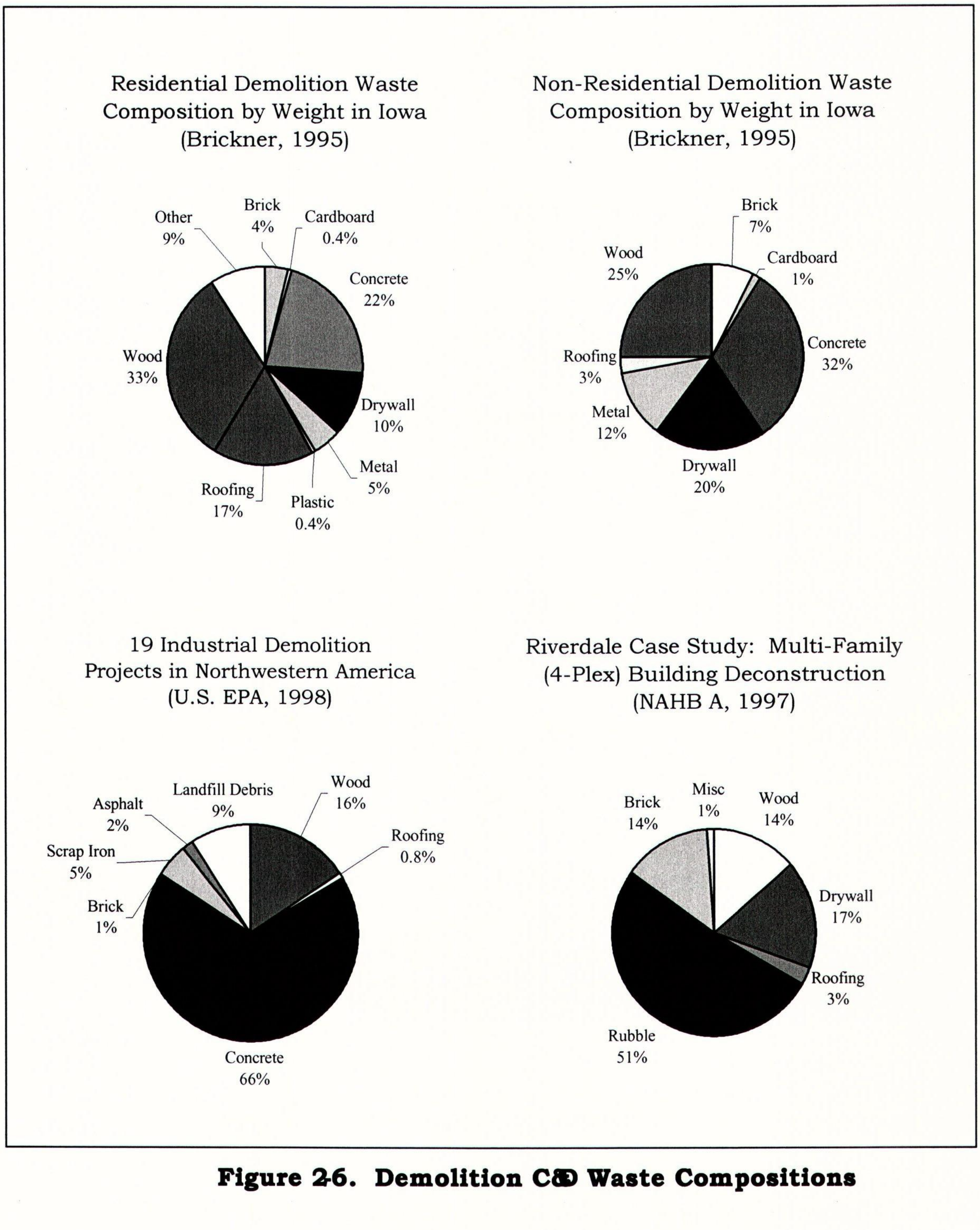


Figure 2-6. Demolition C&D Waste Compositions

DRYWALL IN RENOVATION DEBRIS

Renovation debris is a combination of C&D debris and is much more variable than either. Residential renovation waste comprises 23% and non-residential waste comprises 21% of the C&D waste generated from building activities. In 1998, the U.S. EPA estimated that 31.9 million tons of residential renovation debris and 28.04 million tons of non-residential renovation debris are generated per year.

The METRO Oregon C&D composition study also included a renovation waste audit. Drywall was found to comprise 76% of the waste generated from kitchen renovation activities (METRO, 1992-1995). The C&D composition completed in Des Moines, Iowa also included renovation data. Drywall composed 16% of the C&D waste stream from a non-residential renovation (Metro Waste Authority, 1995). The pie charts in Figure 2-7 present the percent composition of the waste stream from both these renovation audits.

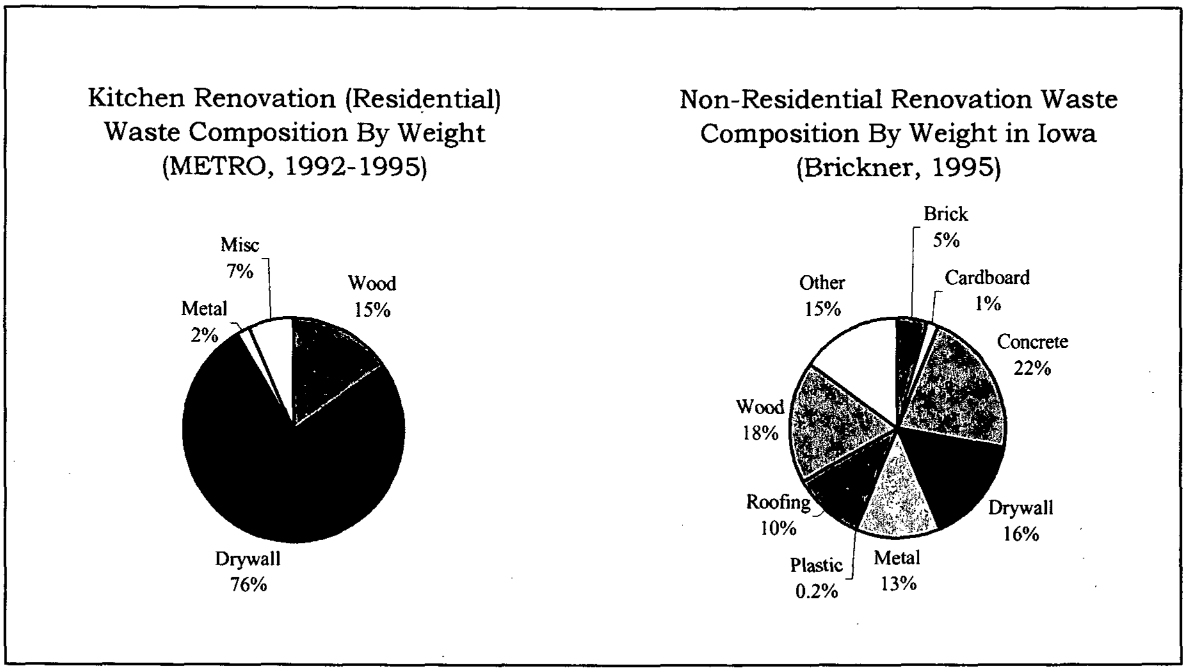


Figure 2-7. Renovation C&D Waste Composition

ENVIRONMENTAL IMPACTS OF GYPSUM IN CONSTRUCTION AND DEMOLITION DEBRIS

A number of environmental issues are associated with the disposal of gypsum drywall in C&D debris landfills. These issues arise when gypsum drywall is subjected to certain conditions including an anaerobic environment, a specific pH range, and adequate moisture after disposal. In an unlined landfill, water from precipitation or groundwater intrusion allows calcium sulfate from the drywall to be released (leached) into solution. Aqueous sulfate is included in the secondary drinking water standards. Secondary drinking water standards are not health-based, but were developed for aesthetic and taste conditions in water. Drinking water standards are used as groundwater protection standards in the state of Florida. Leaching of sulfate from drywall has the potential to exceed the groundwater protection standard for sulfate (Jang and Townsend, 2001).

Another environmental issue is the generation and then release of hydrogen sulfide gas. Hydrogen sulfide is a toxic, colorless gas with a distinctive "rotten egg" odor. Many landfills throughout Florida and the United States have had complaints from surrounding residents about "rotten egg" odors coming from the landfill (Lee, 2000). In May of 1995, the St. Petersburg Times reported neighbors of the Sunset Landfill in Pasco County, Florida had problems associated with hydrogen sulfide. Residents near the landfill had been evacuated twice because of hydrogen sulfide odor problems. Hydrogen sulfide monitoring was completed at Pine Ridge Recycling and Disposal Facility in Orange County, Florida in response to complaints from residents concerning health and safety issues. Odor complaints were also made against G.E.L. Corp. C&D Recycling Facility in Volusia County, Florida (Burns, 1997) and at an MSW landfill in Collier County, Florida (Moore, 1998).

The production of hydrogen sulfide occurs when calcium sulfate is reduced to the hydrogen sulfide gas. Sulfate reducing bacteria accept electrons to reduce sulfate and hydrogen sulfide is produced through the process shown below.

$$SO_4^{-2} + \underset{\text{(e.g. Drywall paper backing)}}{\text{Organic Matter}} \xrightarrow[\text{reduction}]{\text{Assimilatory sulfate}} H_2S$$

The rate at which hydrogen sulfide is generated depends on the concentration of organic matter, concentration of dissolved oxygen in the leaching solution, the pH and the temperature.

GYPSUM DRYWALL REGULATIONS/LEGISLATION

In an effort to compile the latest available information on current drywall legislation, programs, and processors, the Department of Environmental Protection or equivalent agency for each of the United States was contacted (Appendix A). In addition to the U.S., international agencies were also contacted to provide some insight into how other parts of the world are addressing the issue of drywall disposal and recycling.

UNITED STATES

To date, no U.S. state has banned the disposal of gypsum drywall in landfills. Some states do limit which landfills can receive gypsum drywall. In Washington, the definitions of demolition and inert wastes found in the "Minimum Functional Standards for Waste Handling" (ch. 173-304 WAC) excludes gypsum wallboard waste. This exclusion limits where wallboard waste may be sent for disposal. Wallboard may be only disposed of in landfills permitted to accept gypsum waste. New Mexico does not allow drywall to be disposed as "clean fill." Tennessee has proposed regulations concerning drywall disposal. Tennessee State Senator James Kyle has proposed legislation to prohibit drywall disposal in Class 3 and Class 4 landfills.

Two states, Nebraska and New Jersey, have regulations restricting drywall reuse. Use of drywall is prohibited in land improvement projects due to concerns about general groundwater contamination in Nebraska Title 132, Integrated Solid Waste Management Regulations, Chapter 2, Sections 002.01A and 002.01K. Use of drywall as a soil amendment is prohibited due to concerns about heavy metals in the paper of drywall in New Jersey regulations NJAC7:26-1.7 (g). Drywall is banned from land application in other states as well. In Oklahoma the recycling of any product as a land application is not allowed. Michigan has general recycling regulations; however, drywall recycling has not been approved to date. The State of Connecticut is currently drafting a guidance document for drywall recycling.

Other states do not have stringent guidelines for drywall disposal or recycling. In Kansas, drywall used at construction sites can be used on site as a soil conditioner. Kentucky, Maine, Florida and New Mexico allow drywall to be buried on site at construction sites. In addition, New Mexico allows drywall to be beneficially reused in soil treatment, sludge bulking, dirt and clay settling in turbid water, leaching sodium salt on salt treated roads, and odor reduction for animal waste. The State of New York has general beneficial reuse regulations with drywall reuse requiring approval on case specific basis. Reuse projects that have been approved previously include use in spill absorption, composting, calcium and sulfur additives in agricultural fields, new drywall, and plaster.

CANADA

Some regions of Canada have instituted bans on the landfilling of gypsum drywall. Environment Canada, the Canadian version of the Environmental Protection Agency, does not have national legislation banning gypsum drywall from landfills. The bans are also not in place at the Provincial and Territorial level. A number of cities or districts have implemented bans. The most notable is the ban on landfilling gypsum drywall, instituted in 1990, by the Greater Vancouver Regional District. This ban was placed as a result of several landfills that experienced severe hydrogen sulfide odor problems. The ban was implemented, however, with the knowledge that a gypsum drywall recycling firm was under operation in the area (New West Gypsum, 2000). Other locations in Canada have implemented bans, including the city of Guelph in Ontario.

CHAPTER 3
RECYCLING OF GYPSUM DRYWALL

MARKETS FOR GYPSUM

For gypsum drywall recycling to be successful, it is essential to have a reliable end-user market. Virgin gypsum is cheap and abundant, so there must be a competitive price or an economic benefit for recycled material to be used in its place. The economic viability of drywall recycling depends on factors such as collection, processing, transportation, landfill tipping fees and the value that end-user markets place on recycled gypsum products. Several end-user markets are identified in Table 3-1 and further explored in this chapter.

Table 3-1. Potential markets for recovered gypsum drywall

Market	Use
Manufacture	New drywall
	Portland cement
	Flea powder
Agriculture	Plant nutrient
	Improving soil structure
	Reclamation of sodic soils
	Correction of subsoil acidity
	Animal bedding
	Plant disease prevention
	Reducing phosphorous leaching from manure-loaded soils
	Compost
Construction	New construction soil amendment
	Road construction
	Construction materials
Other	Bulking and drying agent
	Settlement of dirt and clay particles in turbid water
	Absorbent for greases

The primary markets for recycled drywall identified in this chapter include agriculture, Portland cement manufacturing, composting, and new drywall. A brief section on other recycling markets is also included. This chapter reviews these markets in detail. Also included in this chapter are sections on processing gypsum drywall waste and other existing recycling programs.

REUSE OF GYPSUM IN THE MANUFACTURE OF NEW DRYWALL

Gypsum from waste drywall can be recycled back into new drywall. Many wallboard manufacturers will only use their own off-spec materials because of quality requirements they must adhere to. Paper content also dictates how much recycled material may be used due to concerns about flammable properties of the new wallboard product. Usually, only about 10 to 20% of the new product consists of recycled gypsum. The recycled gypsum is combined with virgin rock and fed into the process. It must contain less than 2% paper and cannot contain any metal fragments such as nails and screws (CWC, 1995). To prepare for reuse, the drywall scraps must go through a process to have the paper backing removed. All of the ferrous pieces are removed from the discarded drywall by a magnet. See Chapter 2 for a description of how drywall is made.

Byproduct gypsum is also used in the manufacture of new drywall. Gypsum by-products are produced from the manufacture of several acid manufacturing industries, such as phosphoric, hydrofluoric, and citric acid. It is also formed from flue gas desulfurization processes, such as those at coal-fired power plants. During the desulfurization process, compressed air is blown into reaction tanks where limestone slurry absorbs SO_2 that is released from burning coal. Synthetic gypsum is produced from this process and can be dehydrated to make new gypsum drywall (Bench Mark, 1999). Byproduct gypsum from flue gas desulfurization is either landfilled on site or sold for the manufacture of new drywall (Wolsiffer and Wedig 1997, Barsotti and Kalyoncu, 1996).

GYPSUM USE IN THE MANUFACTURE OF PORTLAND CEMENT

Cement binds sand and gravel together to form concrete. Concrete is the most widely used construction material in the world. It is used to build a large variety of structures and construction products, including dams, bridges, pipes for water, foundations, blocks, and utility poles. Concrete consists of crushed stone, sand, water, cement, and air. The percentages of these ingredients in concrete are illustrated in Figure 3-1.

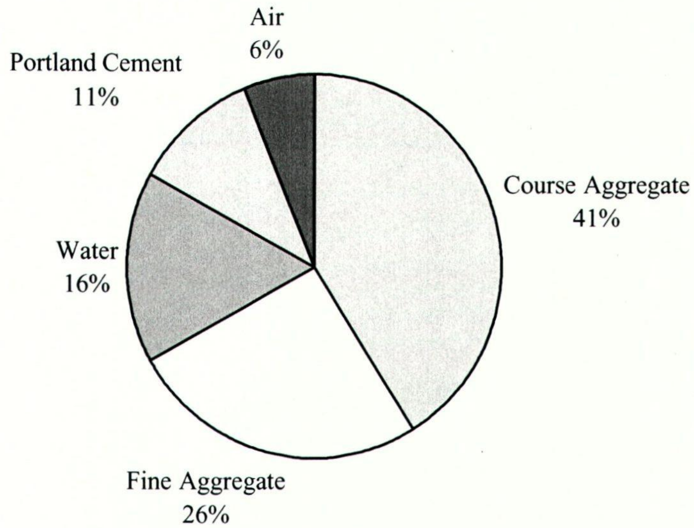
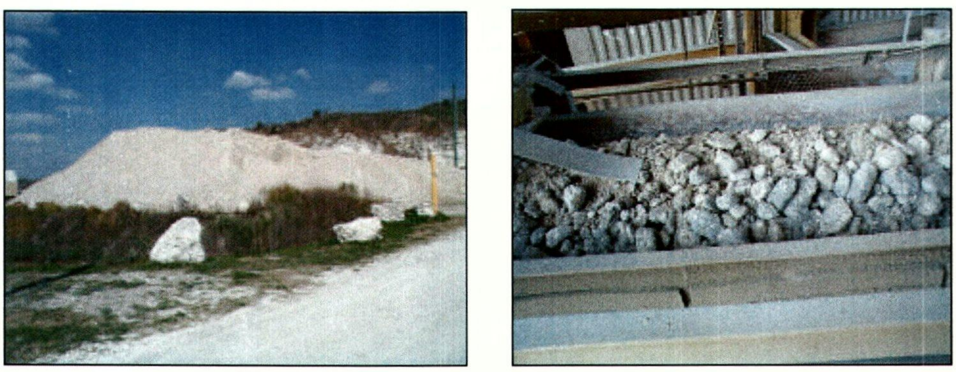


Figure 3-1. Composition of concrete by volume (Portland Cement Association, 2000)



A gypsum stack (left) and raw gypsum on a conveyor belt (right) at Florida Crushed Stone in Brooksville, Florida.

Any type of cement that hardens under water is known as hydraulic cement. This includes Portland cement, which is the most commonly used type of cement. Portland cement is made from limestone, sand, clay, shale, water, and gypsum. Figure 3-2 describes the chemical composition of cement by volume. All of these components are derived from the limestone, sand, clay, shale, water, and gypsum.

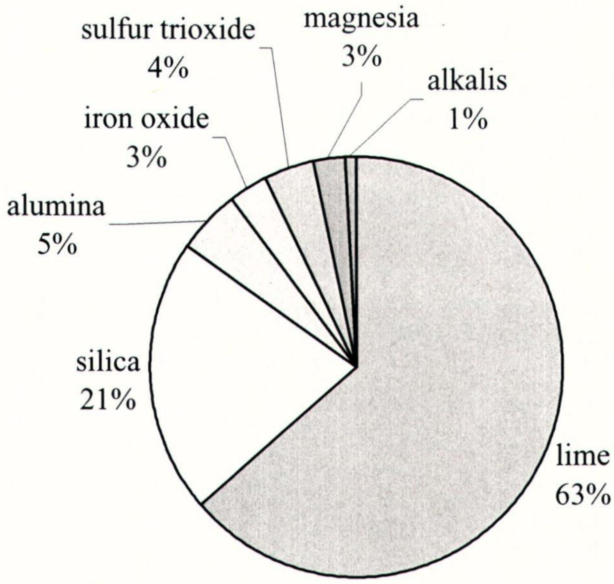


Figure 3-2. Composition of cement by volume (MarketPlace Cement, 2001)

When water is added to cement, it triggers a chemical reaction called hydration. This reaction forms a gel that hardens and binds sand and gravel into a solid mass. Although most of the strength develops in the first few days, the cement can continue to harden for years if moisture is present. The rate of hydration controls the concrete's setting time. Different additives, including gypsum, are used to control the setting time. Different amounts of additives are used, depending on the specific application of the concrete. Gypsum comprises 6% (or 120 lbs.) of every ton of cement produced at Florida Crushed Stone (Wheeler, personal communication, 2000). This percentage may vary elsewhere from 5 to 10%. Temperature affects the setting time, so special considerations are needed if the cement is to be used in the summer versus the winter. Concrete is used in residential and non-residential buildings, highways, streets and bridges, maintenance and repair, water and waste infrastructure, non-construction purposes, and for other applications, as shown in Figure 3-3.

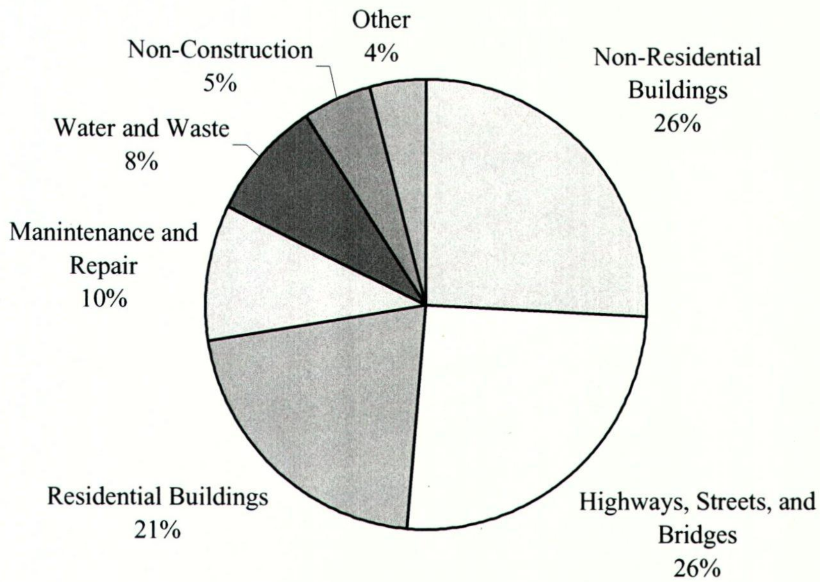
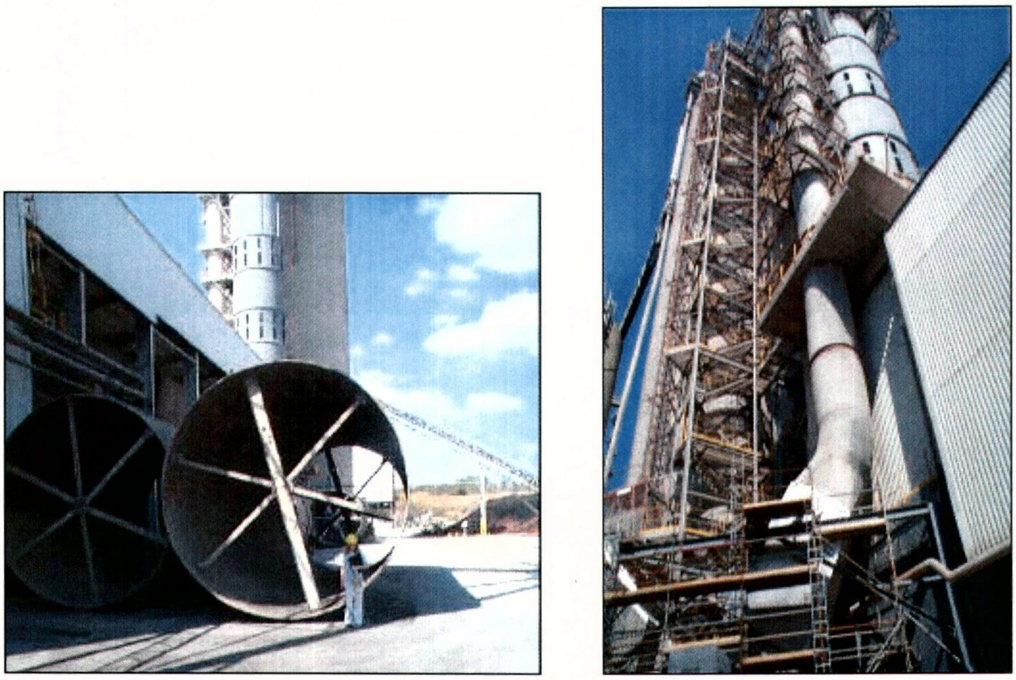


Figure 3-3. Major uses of concrete (Portland Cement Association, 2000)

The process of making cement starts with limestone mining. Limestone is crushed to the size of gravel. After this limestone has been transported to the cement plant from the quarry, it is crushed into a powder and blended with other minerals, such as sand, clay, iron ore, or shale. Then cement manufacturers use either a dry or wet process to produce clinker. Most manufacturers use a dry process and the wet process is used mainly by older factories. In the dry process, the powder is placed directly into the preheater. In the wet process, water is first added to form slurry. The raw material, either in the form of a powder or as slurry, is heated up from 20°C to about 900°C in a preheating tower. The preheater tower, more than 200 ft high, is the largest feature on the cement manufacturer's property. The raw material goes through a series of cyclones on its way to the rotary kiln. Along the way, the water is evaporated and 95% of the calcination occurs. Calcination is the process of driving off carbon dioxide from limestone (calcium carbonate) to form lime (calcium oxide). The lime is then fed into a rotary kiln. This kiln is a horizontally sloped cylinder that turns about one to three revolutions per minute. In this kiln, it is heated from 600°C to about 1450°C. From this extreme heat, it undergoes a chemical reaction to form clinker. In the calcining zone, which heats from 600°C to 900°C, calcination is completed. The material then goes to the burning zone (Wheeler, personal communication, 2000)



Old rotary kiln (left) and preheater (right) at Florida Crushed Stone, Brooksville, Florida.

In the burning zone, where the kiln is heated from 1200°C to 1450°C, the lime reacts with silica and other materials to form dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite. Tricalcium aluminate and tetracalcium aluminoferrite, when in liquid state, meld solids into clinker. The rest of the lime reacts with the dicalcium silicate and forms tricalcium silicate. The materials are in the hottest zone at the end, at a temperature of 1480°C, and the materials are partially molten. The clinker that is produced is then rapidly cooled by air blown through large fans as it passes over a grate. This hot air is returned to the kiln or preheater in order to save energy. It is ground and a small amount of gypsum is added. Gypsum is added to improve the properties of the concrete and to control the setting of concrete. The mixture is sent to a ball mill and ground to a very fine powder with particles as small as 1/25,000 of an inch. The cement manufacturing process is then complete and it can be either stored in silos or transported in road tankers. Figure 3-3 presents an overview of the dry cement making process (FCS, 2000).

The amount of cement produced in the United States has been constantly changing in the past 30 years. This 28-year trend of production and demand is represented in Figure 3-4. In 1970, the demand for cement in the United States was about 69 million metric tons. Of that, 66 million tons was produced in the U.S. In 1998, the demand was about 81 million metric tons, and almost 80 million tons was produced in the U.S. Demand was at a minimum in 1982 at 58.6 million metric tons and peaked in 1987 at 82 million tons. The industry has been trying to keep with this trend, but as shown in figure 3-4, it is not always able to.

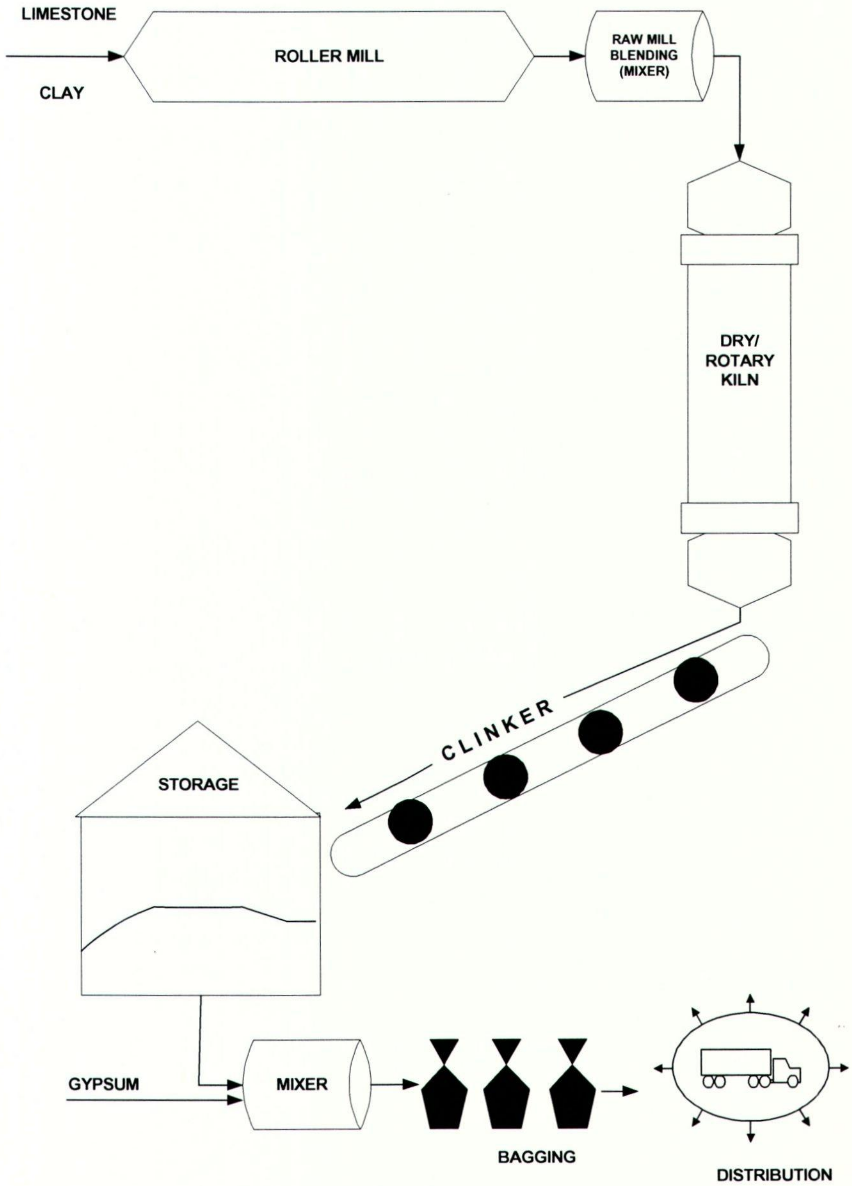


Figure 3-3. The dry portland cement making process (FCS, 2000).

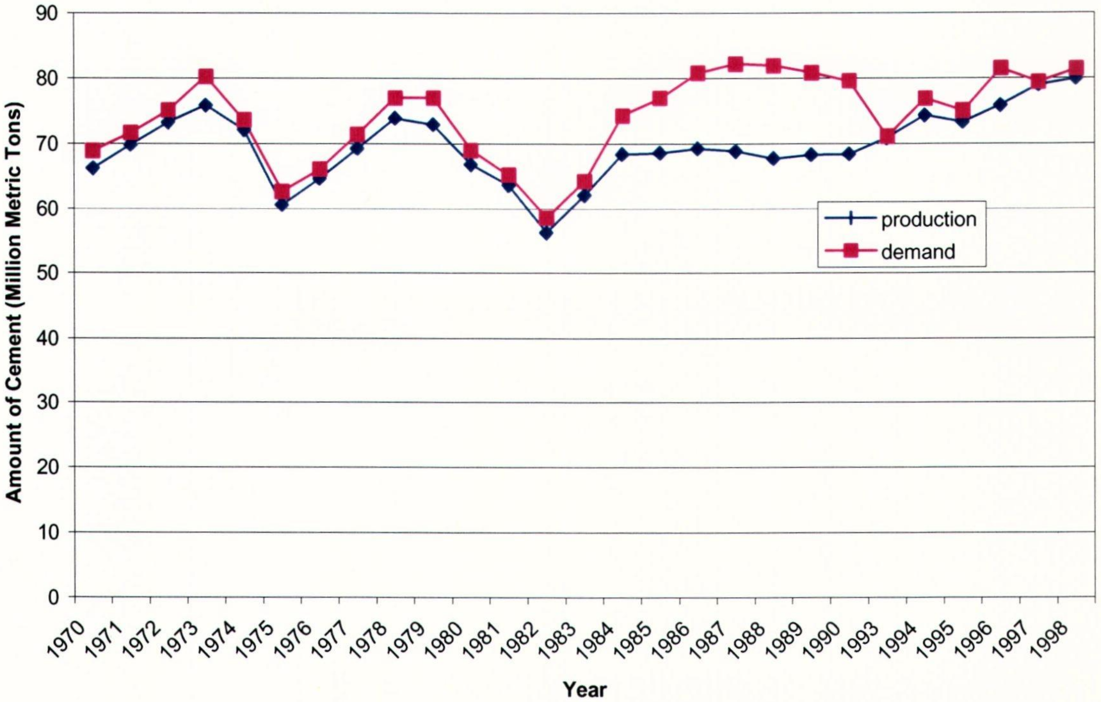


Figure 3-4. U.S. Demand and production levels for portland cement (USGS, 1991, 1996-1999)

There are seven active cement plants in Florida (see Figure 3-5). Tarmac and Rinker are located in Miami. Lafarge Corporation has two plants, one in Palmetto and one in Tampa. Florida Crushed Stone and Southdown are located in Brooksville and Florida Rock Industries is located in Newberry.

In 1998, 9,401,388 tons of C&D waste were collected in the state of Florida and 6,112,923 million tons, or 65%, were disposed. That same year, 1,881,566 tons of concrete were recycled. That amounts to 20% of all C&D waste that was collected. Concrete is the most recycled C&D product, comprising 57% of the total amount of C&D material that is recycled (FDEP H, 1999).

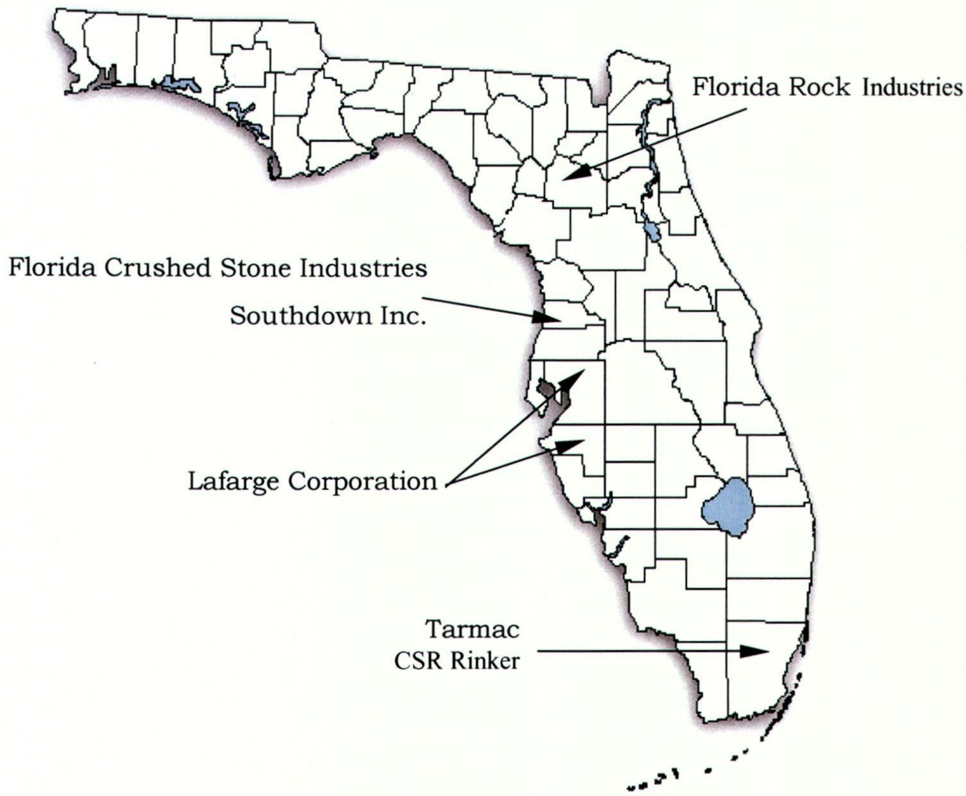


Figure 3-5. Cement plants in Florida

GYPSUM USE IN AGRICULTURE

The primary potential uses for gypsum in agriculture are

- As a source of plant nutrients
- Improving soil structure
- Reclamation of sodic soils
- Correction of subsoil acidity

Mined or by-product gypsum may be used in agriculture. Mined gypsum, also referred to as raw or virgin gypsum, has been used in agriculture for over 200 years for supplying calcium and sulfur to soils. By-product gypsum is produced during the manufacture of phosphoric, hydrofluoric, or citric acid manufacturing. The gypsum by-products are also produced by the pollution control systems, such as flue gas desulfurization at coal-fired power plants. Since the by-product gypsum is often produced in reasonably pure form, typically greater than 90%, it would be suitable for use as a soil amendment or in the manufacture of new gypsum drywall. However, land application of by-product gypsum has raised environmental concerns because of the presence of trace amounts of impurities from the neutralization of waste acids.

There are currently no prescribed formulas for calculating scrap gypsum application rates for soils. Ranges of application have fallen between eight (NAHB, 1999) and 22 tons per acre (Burger, 1993). Ritchey et al. (1995) notes that chemical, mineralogical, climatic and physical factors should be included when determining such a number, and further concluded that there was no current method for determining application rates of gypsum for agricultural benefits.

BENEFITS OF GYPSUM IN AGRICULTURE

Gypsum is inexpensive and easily obtainable, making it the most widely used soil amendment for reclamation (Shainberg et al., 1989). Reclamation or amelioration refers to the exchange of calcium for sodium in sodic soils. Sodic or saline soils are those that contain soluble salts and exchangeable sodium at levels that interfere with the growth of most crops. Gypsum has also been used as a soil amendment because of its beneficial effect on the physical and chemical properties of soil. It can improve filtration, increase rooting in acid subsoils and supply calcium and sulfur to plants (Korcak, 1996). In addition to being used as a soil amendment, gypsum has also been studied to determine its effects on crop production and yield. Gypsum has been applied to a variety of crops, such as peanuts (Alva et al., 1989), brussels sprouts (Carter and Cutliffe, 1990), soybeans (Alva and Sumner, 1989), corn (Burger, 1993) and cotton (Caldwell et al., 1990). A comprehensive list of gypsum's benefits in agriculture are outlined by Wallace (1994). The following subsections will detail the benefits of using gypsum in agriculture.

A biological "quick" test to identify soil situations where gypsum application would be beneficial was developed to identify soil calcium deficiency and/or aluminum toxicity (Ritchey et al., 1989). The test compares root lengths of 4-day seedling growth in a soil alone or amended with limestone as a calcium source. Growth of 30% or more shows that a beneficial result could occur from treatment and 15% or less growth shows that limited benefit could be expected from treatment. This method is good because it is simple and does not require analysis by an analytical laboratory. This test was not performed using scrap gypsum drywall.

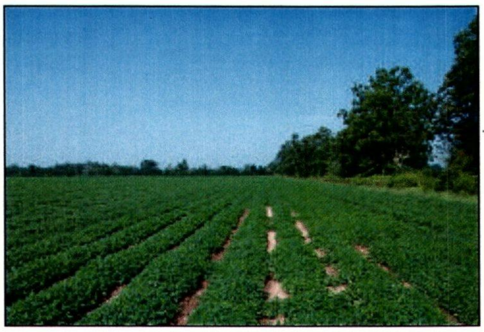
GYPSUM AS A PLANT NUTRIENT

Gypsum is calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). Since calcium and sulfur are among the 16 essential plant nutrients, experiments have been conducted based on the hypothesis that clean gypsum drywall waste would be beneficial to crops as a source of both calcium and sulfur where needed. Calcium is needed for cell wall strength and enzyme activity in plants and sulfur is used to build proteins. Certain crops require more calcium and sulfur than others and these are presented in the following paragraphs.

Vegetables such as tomatoes, peppers, watermelon, escarole lettuce, celery, cauliflower and cabbage all require calcium or they will show deficiencies. Calcium plays a role in the development of cells of plants, keeps cell membranes intact and hormones functioning properly, helps to deter the toxic effects of aluminum. Vegetable crops that have a calcium deficiency can display symptoms such as restricted growth of shoots and roots, blossom end rot of tomatoes, peppers and watermelon, brownheart of escarole, celery blackheart, and cauliflower or cabbage tipburn (Maynard and Hochmuth, 1999). These symptoms usually occur on strongly acidic soils or during severe droughts in Florida. Most crops do not show such severe symptoms, however, the yield could be reduced just because the crop did not grow up to its potential.

The class of vegetables called legumes includes: beans, peas, lentils and garbanzo beans, or chickpeas. People have been eating legumes for thousands of years and these foods are the main source of protein for people in many developing countries. Peanuts, which are also legumes, require a great deal of calcium to ensure proper growth. Even a slight deficiency can prevent correct pod formation, creating a significant loss in yield. According to the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida, peanuts need calcium to ensure proper growth and prevent certain plant diseases (IFAS, 2000).

Gypsum is typically used to supply the calcium to peanuts for effective fruit development (Harun, 1985). Gypsum insures pod growth, reduces pod rot caused by imbalances of other nutrients, and improves the viability of peanuts produced for seed. In a study by Harun (1985), it was found that gypsum reduced the damaged kernels percentage and peanut pod rot percentage, significantly increased calcium levels in the fruiting zone, and was more effective in increasing the calcium levels in the fruiting zone during fruit development than lime.



Peanut crop grown with gypsumamended compost. Field (left), peanut plant (right).

The peanut is the major crop in the southeast for which calcium requirements are most crucial. Gypsum should be applied to peanuts no later than early flowering, which occurs about 30 days after planting. Gypsum is typically applied at the rate of about 600 - 800 pounds per acre (Breman, personal communication, 2000). The maximum gypsum rate recommended for peanuts in the Southeast is 1720 pounds of gypsum per acre. However, since farmers typically grow peanuts in a three-year crop rotation to increase their profits, this amount decreases to 573 pounds of gypsum per acre on an annual long-term basis. Gypsum is used as the calcium source because it doesn't raise pH and is highly soluble. Gypsum is a neutral salt, and according to Shainberg et al. (1989) has a solubility of 2.5 g/L or 15 mM. Salts such as calcium carbonate and calcium chloride are either less soluble or more soluble, respectively (Shainberg et al., 1989). Because some soils require different amounts of calcium, proper soil testing can evaluate the recommended levels of gypsum to be applied to a specific type of soil. Application rates of gypsum are based on levels of exchangeable sodium present in the soil (Miller, 1995).

Cucurbits, which include crops such as cucumber, summer squash, cantaloupe, pumpkin, and watermelon require calcium during a growth period called fruit fill to prevent "blossom end rot". It may also affect tomatoes and peppers. This is a physiological degeneration and secondary fungal infection when insufficient soluble calcium especially during dry weather cause fruits to have fruit curl or have pointed tips, and these fruits cannot be sold as US 1 or US 2 grade (Breman, personal communication, 2000). These grades attract the highest price on the market, so it is desirable for the fruit not to show these characteristics.

Blossom end rot on tomato plant (left) and pepper plant (right).

Vegetable crops that have a sulfur deficiency show a general yellowing of younger leaves and reduced growth. This occurs on very sandy soils that are low in organic matter. Soils that follow continued use of sulfur-free fertilizers and areas that receive little atmospheric sulfur show occurrences of sulfur deficiencies most frequently (Maynard and Hochmuth, 1999).

Burger (1993) found that application of ground drywall waste to test plots increased corn yield, soil fertility and concentrations of calcium, magnesium and sulfur in corn ear leaves. The test plots consisted of 15 plots with 5 treatments of three replications with the following: control, agricultural limestone, agricultural gypsum, pulverized drywall, and pulverized drywall at twice the rate of calcium as agricultural lime. Corn grain yield was 25% higher on the plots receiving ground drywall than on control plots. The concentrations of arsenic, barium, cadmium, lead, mercury, selenium, and silver were below detection limits in the grain, and either below detection limits or not higher than other plots for corn ear leaves. Drywall added to the soil at rates that did not exceed the recommended amount for agricultural gypsum was beneficial. The gypsum waste was compared to agricultural gypsum and limestone with favorable results.

Crushed drywall waste was also found to be comparable in effectiveness to commercial gypsum fertilizer when applied to potato crops in Wisconsin (Wolkowski, 1998). The study was conducted because there are manufactured housing plants that produce a significant amount of drywall waste close to major regions of potato production. Since many potato farmers already used commercial gypsum to fertilize their potato crops, the use of crushed drywall waste in its place would provide a low cost alternative in addition to reducing the waste management costs of housing manufacturers and potentially develop business opportunities for recycling companies. The crushed drywall waste was compared to commercial gypsum fertilizer that was applied to three different soil types with potato crops. It did not negatively affect crop growth or yield. Also, soil calcium levels were increased at one site and soil sulfur levels were increased at two sites.

Mushrooms are another crop that can utilize gypsum. They are typically grown in an environment that includes gypsum in the form of compost. Some examples of mixtures used to grow mushrooms include adding 30 pounds of gypsum for every ton of horse manure; or 15 tons of corn cobs, 7 tons of meadow hay, 4 tons of clover or alfalfa hay, and ½ ton of gypsum. Mushrooms are grown in the United States except in the south, where the climate is too harsh, as they require cooler temperatures. Eastern Pennsylvania is the largest mushroom producing region in the U.S. (University of Washington, 1976).

GYPSUM FOR IMPROVING SOIL STRUCTURE

Gypsum can be used to improve soil structure by providing calcium, which is necessary to flocculate clay soils. Flocculation is the process in which many individual small clay particles bind together to form fewer, but larger, clay particles (Shainberg et al. 1989). Gypsum may be used to improve clayey soils because they typically have high magnesium levels and little organic matter. This condition tends to make the soil particles so tight that air and water cannot penetrate it. By adding gypsum to clayey soils, ion exchange results, which improves soil tilth and friability. Tilth and friability simply refer to the soils' structural properties. This means that it is in a more "workable" condition because it is loose and no longer compacted. This, in turn, allows water and air to penetrate the soil, which promotes root growth and plant strength.

Dispersive soils occur in arid, semiarid and humid climates. They have an unstable structure, which allows them to be eroded easily (Shainberg et al., 1989). This characteristic causes these types of soils to disperse and develop a compacted structure mostly at or near the soil surface, making them difficult to manage. Dispersive soils are also compacted by mechanical stresses such as raindrop impact and cultivation when moist. Some of the problems associated with dispersive soils as outlined by Shainberg et al. (1989) include surface crusting, high runoff and erosion, reduced water infiltration, and restricted plant establishment and growth.

Prior to the EPA statute restricting the use of phosphogypsum in agriculture (Federal Register, 1992), studies were conducted using phosphogypsum to improve soil structure, which showed favorable results. For example, spreading phosphogypsum on sandy loam soil with distilled rainwater prevented clay dispersion, tripled the permeability of the soil and decreased runoff depth and soil loss (Warrington et al., 1989). Also, spreading 5 megagrams per hectare of phosphogypsum on 6 different soil surfaces decreased soil loss greatly from dispersive soils, and moderately from non-dispersive soils (Ben-Hur et al., 1992).

RECLAMATION OF SODIC SOILS

Sodic, or alkali soils, are those soils that have high sodium levels and various soluble salts. Elevated sodium levels such as those in sodic soils can prevent plant or crop production. Reclamation of sodic soils involves removal of sodium (Na^+) and replacing it with calcium (Ca^{2+}) to provide a better environment for crops to establish themselves and increase root penetration. Gypsum dissolves in the soil to provide a level of permeability such that water can enter into the soil profile and allow for the exchange of sodium for calcium. Typically, sodic soils will disperse in water. This means that they will absorb water during a rain until they disperse into individual particles (Russell, 1973). As the individual particles disperse, they form a crust on the surface of the soil. This causes water percolation through the soil profile to be reduced or completely blocked.

According to a study by the USDA (1954), electrolytes in the soil provided by gypsum maintain permeability to allow water into the soil profile, and to exchange calcium for sodium. Gypsum can prevent swelling and dispersion, increase soil tilth and reduce surface crusting with respect to sodic soils (Shainberg et al., 1989). In a study by Ilyas et al. (1997), a gypsum application of 25 Mg/ha was found to increase soluble sodium in the top 20 cm of the soil when tested on a low permeability, saline-sodic soil with crop rotation. Gypsum also removes bicarbonate ions from soil solution, which can lower soil pH (Lindsay, 1979 and Rengal et al., 1999). Singh et al. (1997) found that removing bicarbonate ions from the soil with the addition of gypsum clearly benefited alkaline, sodic soils in India. In Australia, red–brown wheat soils (Alfisols) have been studied to evaluate gypsum use to increase crop yields. These soils have very poor physical properties which do not allow proper infiltration of water, therefore decreasing crop yields. Wheat yields with increases of 20% or more and as high as 50% have been reported (Howell, 1987). Increases in wheat yields are directly attributed to higher moisture content in the soil from the addition of gypsum.

CORRECTION OF SUBSOIL ACIDITY

Shainberg et al. (1989) has postulated that the greatest potential for economic use of gypsum may lie in crusting soils with acid subsoil horizons. The condition of subsoil acidity is described as soils having toxic levels of aluminum, and often deficient amounts of calcium, that partially or completely deter roots from entering the subsoil. This prevents the plant from gaining moisture below the surface and may hinder plant yield and root growth due to water stress. Lime has been used to treat this condition. It does not, however, work in all cases, as many acid subsoils have variable charges and do not allow for movement of lime down the soil profile (Sumner, 1990). This method is not effective due to the labor intensity of incorporating the lime to subsoil depths.

Yield responses on acid soils to gypsum have been shown in Brazil, South Africa, and the Unites States. Subsoil acidity is a severe problem in Brazil due to high annual rainfall, which causes the soil to erode and leach very quickly.

Sumner (1990) studied the effects of applying phosphogypsum versus mined gypsum to highly weathered soils in Georgia in order to ameliorate subsoil acidity. The crops studied included alfalfa, corn, soybeans, cotton and peaches. Phosphogypsum was found to be a suitable ameliorant in correcting subsoil acidity and was also found to be equivalent to gypsum in this respect. Given one to two years, gypsum was found to dissolve and move into the subsoil where it supplied calcium for root elongation. This, in turn, allowed the crop to reach water that was previously beyond reach and increased crop yields. A treatment of an initial 10 tons of gypsum per hectare lasted more than five years, making it economically feasible to use gypsum for amelioration. Also, net profit due to gypsum application ranged from $100 to $500 per hectare per year for alfalfa, peaches and cotton.

Although Florida does not experience all of the soil problems discussed here, they are present in other parts of the United States as well as foreign countries. The southeastern U.S. does experience problems with dispersion-induced crusting (FIPR A, 1989) and soils that are low in calcium and sulfur (FIPR B, 1989). Soils with low calcium and sulfur levels are located along or adjacent to the coastal plains of the eastern seaboard, or those from Florida that are located north of Ft. Myers and Belle Glade (FIPR B, 1989). Therefore, gypsum is needed for soils in Florida as well as other parts of the U.S. and abroad.

OTHER AGRICULTURAL BENEFITS

Scrap gypsum drywall has been used as a component in mixtures with wood shavings as an animal bedding material (Wyatt and Goodman, 1992). The study was based on the idea that scrap gypsum drywall would control moisture levels. The mortality, feed conversion, and incidence of leg abnormalities of broiler chicks was studied using scrap gypsum drywall as a bedding material. It was used alone or with fir wood shavings and compared to fir wood shavings alone. The composition of the scrap drywall was 71% to 89% gypsum, 2% to 19% limestone, 1% to 2% paper, and 1% to 2% crystalline silica. A lower body weight gain was observed after 21 days for chicks reared on scrap drywall alone when compared to the other two treatments. After 41 days (the end of the growth cycle), however, there was no difference in body weight gain between the three treatments. It was recommended by the authors that a layer of wood shavings should overlay the material, as it was quite dusty. The study did conclude that scrap gypsum might assist in controlling litter moisture levels.

Scrap gypsum drywall used as a bedding material for animals was also studied by the Clean Washington Center (1995). There were problems with anaerobic conditions occurring because a farmer was land applying the material, and a cease and desist order was made. However, it was concluded that if these conditions were prevented from occurring, it would be an acceptable practice. Some health officials felt ambivalent about this practice.

Gypsum may also prevent certain plant diseases. Aflatoxins are secondary metabolites produced by molds that grow on a variety of crops, including peanuts. They are a concern because they are carcinogenic, mutagenic and teratogenic compounds. Human exposure to aflatoxins can result directly from ingestion of contaminated foods or from eating meat that has been infected from feed prior to human consumption (Rustom, 1997). Peanuts grown in gypsum treated fields were found to have less aflatoxin produced on them when compared to peanuts grown without gypsum amendments (Reding and Harrison, 1994). Calcium content increased as the application rate of gypsum increased and fungal growth was inhibited in peanuts receiving the gypsum supplement.

Gypsum was found effective in reducing the amount of soluble phosphorous leached from manure-loaded soils from dairy use (Anderson et al., 1995). Phosphorous from dairy animal manure is a contaminant to surface waters near Lake Okeechobee in south Florida. It is a nutrient known to accelerate eutrophic conditions by leaching into surface waters in this area. The soils with high phosphorous concentrations are found under dairy and beef land use areas, such as those close to milking barns, holding pens and feeding lots for cattle. These soils are typically acid and low in calcium. Two studies were conducted using gypsum. The first was the gypsum amendment study, which was to verify the effectiveness of gypsum amendment under high manure-loading conditions. The second was the microbial activity study, which was to determine whether biological activities are influenced by an imposed soil amendment practice.

In the gypsum amendment study, four rates of gypsum (0, 4, 8, and 16 grams per kilogram) using four replications were added to 100 grams of soil containing high levels of total organic carbon from dairy animal land use. In the microbial activity study, treatments consisted of four rates of gypsum (0.1, 1.0, 10, and 100 grams per kilogram) and one control (0 grams per kilogram) applied to the soil. Gypsum was effective in reducing phosphorous at all pH ranges under anaerobic conditions used during the study, and had a positive impact on soil microorganisms. Bacterial suppression occurred, but it was unclear why. Dissolved organic carbon, soluble nitrogen and soluble phosphate used in leaching tests all decreased with increasing applications of gypsum. Gypsum, as a waste material from the construction industry, was concluded to have an impact on soil microorganisms by cycling and mobilization of nutrients.

USE IN PRODUCING COMPOST

Gypsum drywall waste can also be used as a bulking agent in compost and has been demonstrated to be successful in several instances. Bulking agents are typically coarse material that will break down slowly in the compost and improve the structure by allowing air circulation. Bulking agents are important when there is not a good mixture of materials or when raw materials tend to pack together. Gypsum waste can reduce nitrogen loss to the atmosphere, control odors and add calcium and sulfur. Case studies where gypsum waste was used as a bulking agent in compost are reviewed in this section.

Closeup of unscreened compost material amended with processed scrap gypsum drywall.

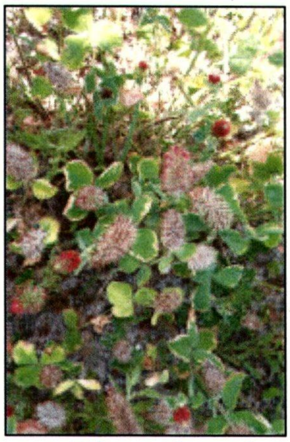
The Clean Washington Center found that scrap drywall could be incorporated into the composting process as a bulking agent without hindering product quality (CWC, 1999). Porosity, temperature, oxygen, moisture, odor, decomposition, and pH were monitored over an 8-week period. Calcium, boron and organic content were determined at the end of the study. The mix reached temperatures adequate to destroy pathogens by EPA regulations. It was also suggested that drywall be used to supplement other bulking agents when composting biosolids, to balance the carbon to nitrogen ratio (C:N), absorb excess water and provide necessary porosity. It was proposed that waste paper from drywall be composted to serve as a carbon source and moisture absorber.

Another case study took place at Wood Recycle in Wichita, Kansas. Drywall was composted after a large drywall distributor in the area started sending five to six tons per week to the facility (Block, 1999). Also, a homebuilders' association was approached about segregating drywall for recycling at nearby job sites. The process Wood Recycle uses is relatively simple. The drywall was ground up before composting in windrows that were 300-350 feet long, 12 to 14 feet wide and four to six feet high which were turned weekly. Moisture levels were kept between 40 and 50 percent and the optimum temperature was approximately 150°F. The compost was screened to ½-inch minus and sold for $15.00 per cubic yard.

The USDA opened a compost facility in Beltsville, Maryland at its Agricultural Research Center where drywall and other construction scraps and byproducts from the electric power industry are used as residue for composting (USDA, 1998). Researchers worked with the Gypsum Association of Washington, D.C. and the National Association of Home Builders' Research Center in Upper Marlboro, Maryland on this project. The project is helping to keep up with Maryland's voluntary nutrient management program, which keeps nitrogen and phosphorous out of the Chesapeake Bay.

ENVIRONMENTAL ISSUES WITH REUSE OF GYPSUM DRYWALL IN AGRICULTURE

Gypsum drywall components such as asphalt-based wax emulsions, starch-based glues, organics and boron are noted by Burger (1993) as ingredients other than gypsum in drywall. Starch-based glues should be biodegradable, and asphalt-based wax emulsions are used in moisture resistant drywall, which is not typically used in recycling for land application purposes. Boron is a concern due to the potential of phytotoxicity to some plants (light tips on clover leaves in picture below). According to Korcak (1996), phytotoxicity usually occurs when plants are seeded with or planted with materials containing high levels of boron, and can be avoided by applying scrap gypsum material some time prior to the establishment of the plant. This would mean applying the gypsum material in the fall if the planting or seeding were to take place in the spring. Burger (1993) further suggests that phytotoxicity should not be a problem if boron concentrations in the drywall are not excessive and the application rates are held within the recommended 5 to 10 tons per acre (equivalent basis) range. Phytotoxicity is not a problem specific to Florida, but can occur anywhere there is an excessive amount of boron present in soil or plant tissue.



The suitability of scrap drywall as a cropland amendment with an emphasis on boron content was evaluated by Dixon (1984). A waste drywall pile was evaluated to find boron concentrations in the range of 92 to 156 ppm, which is equivalent to 0.18 to 0.31 pounds of boron per ton of material. Common application rates of gypsum in California range from one to four tons per acre except for saline or alkali soils, which go up to 8 tons per acre. Dixon found that a four ton per acre application of scrap drywall using the highest boron concentration of 156 ppm only added 1.25 pounds of boron. This amount is within the recommended fertilization range for boron. Dixon also found that cadmium, lead, arsenic and selenium were not a serious concern if common crop production practices were followed for gypsum application. Scrap gypsum drywall was found to be suitable for agricultural use, but should be evaluated on a case-by-case basis where soil boron is high or where irrigation water contains elevated boron levels. Chemical monitoring of the material was recommended to fulfill guaranteed analysis, and further recommendations were to process the material to a particle size that would pass a 60 mesh Tyler screen.

Korcak (1996) found that the boron concentration was higher in agricultural gypsum than in pulverized drywall. Pulverized drywall was obtained from U.S. Gypsum Corporation's Stony Point facility in 55-gallon drums and agricultural gypsum was bagged Ben Franklin Landplaster by U.S. Gypsum. The pulverized drywall had a concentration of 20 ppm boron and the agricultural gypsum contained 97 ppm boron. An application rate of 5 tons per acre was used for both, which was equivalent to 0.20 pounds boron (from pulverized drywall) and 0.97 pounds of boron (from agricultural gypsum) per acre.

GYPSUM USE IN CONSTRUCTION MATERIALS

Another potential use for recovered gypsum drywall is in construction materials. Gypsum has been used in concrete, stucco, plaster and blocks. Gypsum may potentially be combined with other materials like fly ash and cork for recycling into bricks and other products. Most of the investigation of gypsum recycling in construction materials has primarily been for phosphogypsum, or the by-product gypsum produced from acid manufacturing industries or gypsum produced from the flue gas desulfurization process at coal-fired power plants. However, due to the similarity in composition between the two materials, it is likely that gypsum could be used for the same purposes.

GYPSUM AS AGGREGATE IN CONCRETE

The potential use of scrap gypsum drywall as an aggregate in concrete was reviewed by Hemmings and Venta (1994). Gypsum is an essential part of the Portland cement manufacturing process; however, all of the calcium sulfate is consumed in the manufacturing process. The use of drywall as aggregate in cement is possible, however, sulfate content is a concern. High sulfate content in concrete affects the soundness of the material and testing beyond standardized testing is required for concretes with higher than normal sulfate levels. Severe deterioration, shown by expansion and cracking may occur in concrete with high sulfate levels. The sulfate reacts with the calcium hydroxide and aluminates in the cement forming an expanding crystal that causes expansive stress and damage to the concrete (Hemmings and Venta, 1994).

ROAD CONSTRUCTION

Phosphogypsum and fluorogypsum have been used for road stabilization in several studies (Chang and Mantell, 1990 and Vipulanandan and Basheer, 1998). Phosphogypsum is produced from the wet acid manufacture of phosphoric acid, as explained in a previous section. Fluorogypsum is a byproduct of the production of hydrofluoric acid from fluorospar, a mineral composed of calcium fluoride and sulfuric acid. Again, due to similarities in the composition of by-product gypsum and gypsum drywall, it can be inferred that road stabilization would be a potential market for reuse.

Road base stabilization can include many activities that are meant to improve the strength and stability of road base materials. In general, stabilizing road base materials can result in improvement of strength of the road base, help the road last longer, reduce routine maintenance requirements, reduce required thickness of pavement overlays, and reduce aggregate material loss for unpaved roads. Recycled materials have also been used in embankment construction due to a lack of suitable borrow material. Typically, geotechnical properties such as moisture content, Atterburg limits, unconfined compressive strength, California Bearing Ratio (CBR), and compaction are measured to evaluate the effectiveness of the waste material as a replacement for quality soils in road construction.

Two case studies using phosphogypsum for road base material were reviewed by Chang and Mantell (1990) for the Phosphate Research Institute. The first case study was carried out in LaPorte, Texas with Mobil Mining and Mineral Company, Texas A&M University, and McBride-Ratcliff, Inc. (a local geotechnical firm). Each street constructed had seven sections, two of which were controls that had 8" bases of crushed limestone. The other five sections contained different phosphogypsum (PG) mixtures. These were: 90% PG and 10% Portland Cement (PC), 75% PG and 25% fly ash, 85% PG and 15% fly ash, 95% PG and 5% PC, and 82.5% PG and 7.5% PC. The sections were evaluated and found to be acceptable road base materials based on the fact that degradation did not occur at the time of the follow up report three years after construction. The PG and PC mixtures had the highest effective thickness at the time of follow up evaluation.

The other study took place in Polk County, Florida on an experimental road. The previous method of road stabilization used in this area was adding fine-grained soils (clay) to granular soils (sand), but proved to result in problems during the rainy season. Testing of the experimental road was a joint effort by the University of Miami, Florida Department of Transportation (FDOT) and Polk County. Nuclear density measurements, moisture determinations, and the California Bearing Ratio (CBR) test were performed to determine the subgrade bearing ratio of the soil. After adding phosphogypsum to the soil and compacting, the CBR was improved from 17 to 133. It was found that, under optimum moisture conditions, the CBR may be improved up to 100%. Groundwater was sampled for 31 months and was reported to have "no measurable influence on the water quality at the site." The construction crew for the project also gave an assessment of the experiment and found that phosphogypsum mixtures were easier to work with than clay mixtures, operating costs are less expensive, and that the stability of the mixtures is greater than that of clay mixtures. It was also found that these mixtures did not cause delays in construction because the compacted mixture did not absorb water as the clay mixtures do. Overall, phosphogypsum was considered to be a good binder for road base material (Chang and Mantell, 1990).

Fluorogypsum was found to be a suitable material for subgrade construction based on CBR test results by Vipulanandan and Basheer (1998). A water leaching test and TCLP (Toxicity Characteristic Leaching Procedure) were used to determine the effects of this material on the environment. Leachate was analyzed for metals and sulfates using ICP (Inductively Coupled Plasma) and IC (Ion Chromatography), respectively. Because fluorogypsum is largely calcium sulfate, the leachate from the water leaching test had a high concentration of sulfate. In the TCLP test, calcium concentrations were higher than in the water test due to agitation and acidic leachate solution. Sulfate concentrations were lower, indicating that sulfate is not readily leached from the solid matrix as metals are in an acidic environment. Overall, fluorogypsum was rated as a suitable material for subgrade construction.

GYPSUM AS AN ON-SITE SOIL AMENDMENT

Pulverized gypsum drywall was found to be a suitable substitute under conditions where agricultural gypsum would be recommended as a soil amendment around new home construction sites (Korcak, 1996). The pulverized gypsum drywall material was analyzed for content, applied to turf grass, tomato and broccoli plants, and used in a soil column leaching study. The study found no abnormally high elemental contents from an agricultural viewpoint. No differences were found between pulverized drywall and agricultural gypsum after running TCLP tests and a dioxin screen and neither material posed a leachate contamination problem from the soil column leaching study. It was concluded to be similar in content to agricultural gypsum.

The pulverized drywall and agricultural gypsum were also applied to turf grass to study biomass production (Korcak, 1996). Neither material had a significant effect on turf grass biomass production. The elemental content of grass samples showed the same compositional differences expected from the addition of gypsum to soils. In the leaching study, no indications of trace element leaching which could cause groundwater contamination problems were found. A trend toward enhanced mobility of aluminum through the soil column was also found, which could be beneficial on plant root growth. The tomato and broccoli growth on amended soils in pots was inconclusive because deer ate some of the broccoli heads. Tomato fruit yields and fruit composition were, for the most part, little affected by the application of either material. The author noted that the results are from plants grown in amended soils grown in confined pots and not in open soil.

Recommendations for applying pulverized gypsum drywall waste to new home construction sites include having an elemental analysis of the drywall used, develop a biological "quick" test, and prediction of a beneficial use based on soil surveys (Korcak, 1996). Manufacturers can supply product information or a database with analyses performed on drywall from different manufacturers may be kept. The biological "quick" test mentioned previously could determine within 4 to 7 days whether or not a specific soil will respond to scrap gypsum drywall application. Since virtually all counties have been mapped with respect to soil type and include information about the major soil types in the region, it would be a relatively simple task to identify which soils would be responsive to scrap gypsum after performing the "quick" test for soils in a given county. Builders could use this information at specific construction sites to determine whether they could recycle their scrap drywall waste on-site.

OTHER RECYCLING MARKETS

Gypsum has other uses in addition to its role in agriculture and construction, according to The California Integrated Waste Management Board (CIWMB) (1998). Recycled gypsum was used in bulking and drying sludge and to settle dirt and clay particles in turbid water. In turbid water, gypsum will cause the clay particles to flocculate and settle to the bottom, decreasing the turbidity. Both of these studies were funded by the State of New York. Recycled gypsum could also be used to make flea powder, since it comprises approximately 90 percent of the inert material in some flea powders. Due to its absorbent properties, gypsum waste could be used by mechanics to absorb spilled grease. Recycled gypsum waste could be used instead of lime to mark lines on athletic fields as well.

COLLECTION AND PROCESSING

COLLECTION AND TRANSPORTATION

Gypsum waste material must be collected in a manner that saves time and money in order to make the recycling process profitable. Job site source separation has been an effective method to collect specific wastes in a relatively clean fashion while keeping cost and contamination at a minimum.

C&D debris is typically collected in 20 cubic yard roll-off containers that are placed on the construction site. At other sites, material is collected in a pile or in a corral, which is then removed by a waste collection service. Most construction sites do not have a separate container for drywall, however, Doherty's Construction Management in Bellevue, Washington uses several small containers (13 to 16 cubic yards) placed strategically on construction sites to facilitate recycling. They place the containers close to the work areas and work with the builder to find the most convenient places to put multiple containers. This keeps labor cost down because the workers do not have to travel as far to deposit recyclable materials.

Transportation costs are an important factor in gypsum recycling. Since gypsum is a bulky, heavy material, it often has greater transportation costs than lighter C&D constituents. It has been estimated that, if transported greater than 50 miles, gypsum waste is not economical to recycle unless tipping fees in the area are very high. This is where competition in the market comes into play, because even if the tipping fees are high, other products on the market may be more economical than waste gypsum drywall.

PROCESSING OPTIONS AND ISSUES

Equipment and product specifications for several processing options are investigated in this report. Gypsum waste can be processed by equipment ranging from a small chipper to a large trommel screen and conveyor. This section is intended to present an overview of the equipment used to process gypsum drywall waste and the various types of end products made in the process.

The origin of the waste must be known prior to processing to make sure there are no contaminants in the waste. There are two types of gypsum drywall waste: construction and demolition. In general, gypsum drywall waste from demolition sites contains contaminants such as nails, tape, joint compound, and paint. This simply means that it takes more time to process because workers have to pull contaminants out of waste piles. The equipment, therefore, runs less smoothly and it cannot be used for agricultural purposes. Occasionally, contaminants are present in new construction waste, but not as frequently as in demolition waste.

Nails can cause equipment failure for some machines and should be removed prior to processing. They can cause the end product to be unusable. If the end product were to be reused as new drywall, nails may potentially hurt workers or residents if the wallboard is broken. Tape, which is used to smooth the joints of the drywall, needs to be screened out unless it is intended for use in compost where it will break down. It cannot be allowed in the end product if it is to be used as an ingredient in cement. Joint compound is comprised of limestone or gypsum, but can contain asbestos as a contaminant. This is a concern especially if the structure from which it came was built before the mid-1970's (CIWMB 1998). Paint is typically used to cover drywall in homes.

Paint used in structures built prior to 1978 may contain lead. Drywall that has lead-based paint on it should not be recycled. It should be disposed of properly since it is toxic (CIWMB, 1998). Most processors take only clean gypsum waste because it is more expensive to handle demolition materials that are potentially contaminated.

The Construction Materials Recycling Association (CMRA) (Turley, 1998) has outlined some of the methods used to process waste gypsum drywall. The first method, which claims to remove almost all paper and approximately 98% metals, is used by Kolberg-Pioneer. Their process is to use a trommel screen and some form of rolling stock, which could be a wheel loader. If the material is left outside to get wet, it breaks down the glue adhesive that holds the paper backing to the gypsum core, separating the gypsum into a powder and the paper in larger pieces. A front-end loader is then driven over the material to break it up even more prior to placing it on the trommel screen. The recommended setting for the screen mesh is 7/8" or smaller so that virtually all of the gypsum falls through the screen and the paper is taken out on the conveyor to a different pile. The screen may be set at a smaller mesh or removing nails or other metal contaminants magnetically if they are detrimental to the product.

A horizontal grinder is used by All Seasons Enterprises in Iowa to process out of spec and waste gypsum drywall. The gypsum enters the system through a feed hopper and is forced into an enclosed grinding chamber by a hydraulic ram. The gypsum is ground up via a horizontal rotor with cutter bits against stationary shearbars. The gap between the rotor and shearbars controls the product size, but a screen that is after the rotor controls the final sizing. The product is then sent to a conveyor.

Another processing system uses a grinder with a flexible impaction system to remove paper backing from the core before breaking it down to the final product size. The material is sent through a trommel screen with three output settings (1/8-inch, ½-inch and paper) after being passed through a magnet. All of the problems such as material contamination, dust containment, and weather protection are avoided because the system is in an enclosed container.

Another system to process gypsum drywall tumbles the material in a 25-foot long drum. Doors on opposite sides of the drum are operated by hydraulic pinion gears to load the material. The material is tumbled inside the drum, which has paddles welded inside to help crush the material and turn the load, for approximately 30 minutes at 7 rpm. Close to the end of the cycle, the doors are opened, allowing the material to fall out of the drum over several rotations.

A pilot program conducted by the National Association of Home Builders (NAHB), U.S. Environmental Protection Agency (USEPA) and Indiana Department of Environmental Management (IDEM) evaluated the feasibility of the on-site grinding of wood, drywall and cardboard components of new residential construction waste as an alternative to landfilling. The material was land applied based on research that demonstrated beneficial effects to the soil and plants. The state evaluated the processing systems available after sending out letters to manufacturers of machines that may be used for the project. They got a weak response from the industry, and found that most of the companies that responded had equipment that did not meet the specifications for the job. Some equipment that did meet the requirements was tested in demonstration projects to evaluate their performance prior to purchasing. The grinders were evaluated on criteria such as mobility, particle size, customer friendly operation, and cost. The machine needed to be small and easy to maneuver on building lots, a minus one inch particle size, not produce excess noise, dust or paper in the air, and cost less than $100,000. The selected grinder was a top-loading, low-speed, horizontal drive grinder manufactured by Concept Products Corporation of Paoli, Pennsylvania named the "Shred-All". It uses a 28-80 RPM, six-foot long auger-shaft with 35 replaceable teeth, powered by a 125 horsepower diesel engine. The trailer assembly was eight feet long and six feet wide, weighing about 8,000 pounds, and pulled by a one-ton pick up truck.

The grinder's throughput was an average of 10.5 to 11 cubic yards per hour, which was loaded manually by two workers. The processed material was reduced in volume by about 60 percent. The gypsum waste was essentially processed into dust and the paper backing was processed into fragments of three inches or less. There were a few problems with overheating and dust, but these problems were minor. A water misting system was installed to reduce dust during part of the project and only one complaint was received during the six-month project. It included three misting heads in the hopper/auger area, supply lines and an electric pump. The water was supplied through a residential water hose. This water supply may not be available at other sites at the right time.

The overall economic feasibility was found to be cost competitive with landfilling. The project is basing these conclusions on moderately high tipping fees, modest labor rates, and low transportation costs. Since some drywall contractors haul their own waste off site and include this in their total price for the house, it should be noted that grinding the drywall onsite eliminated this extra cost, which was found to be approximately $50 to $100 per house. The recommended source for processed scrap drywall to be land applied was regular, clean drywall, pulverized to a minus one inch size, and spread evenly around the site at rates up to eight tons per acre.

A hammer mill can be used to process gypsum drywall waste (CIWMB 1998). The hammer mill produces material that is 93 percent gypsum powder and seven percent shredded paper by weight. Paper waste from gypsum drywall recycling can be recycled into new drywall paper, paperboard, packaging or compost.

EXISTING RECYCLING PROGRAMS

Drywall programs are as diverse as the states that have developed them. Not every state or country has drywall recycling programs. In response to problems associated with landfilling waste gypsum drywall, the Washington State Department of Ecology (1990) published a progress report on gypsum waste with recommendations for best available technologies. The technologies were ranked after being evaluated against a set of environmental, economic, waste management, and technical criteria. Eliminating gypsum wastes from landfills using alternative waste management methods was one of the main approaches to the problem. These methods included recycling, incineration, ocean disposal, and use as an agricultural fertilizer. Recycling waste drywall back into new wallboard ranked first, use of gypsum drywall waste in agriculture ranked second, and best possible landfill control practices and ocean dumping tied for the third rank.

Recycling received the first rank because it is most important for the state, environmental and health impacts are positive, and the technology is proven, available, and cost-effective. Some issues that were associated with recycling were availability of recycling facilities to drywall waste producers, feasibility of separating the waste from other C&D debris, and transportation costs of delivering the waste to a recycling facility from the construction site. Use of drywall waste in agriculture ranked second because it would be an ideal situation for reusing the waste. No studies were cited in the report and the authors felt it was unclear whether or not this option was feasible at that time. Since then, many studies have been undertaken and gypsum has proven to be an adequate substitute for agricultural gypsum. Best possible management practices and ocean dumping ranked third because both technologies were considered basically environmentally safe and feasible. The best possible management practices technology appeared to be the best solution for drywall waste management at landfills that were located far from recycling facilities, but did not address reducing the amount of waste being disposed of at the landfill. Ocean dumping was found to be expensive and difficult to implement, since opposition was strong against dumping anything in Puget Sound. Obtaining permits and site location processes were found to complicate this technology. The following sections describe current major recycling programs in detail. Appendix A contains a table of brief summaries of other programs that have been or are in place.

NEW WEST GYPSUM INC.

New West Gypsum (NWG) (Harker, 2000) is the largest drywall recycling company in North America, and has recycled over one million tons of drywall since it started processing for Domtar, now owned by Georgia Pacific, in 1987. The business spawned from legislation in British Columbia to divert gypsum drywall waste from disposal in landfills in 1983. They have successfully established themselves as the leader in the drywall recycling industry by expanding operations and patenting their process. NWG has operations in New Westminster, B.C, Toronto, Seattle and Vancouver. NWG has established transfer stations for its clients, making it convenient for them to dispose of their waste. They take recycled product back to drywall manufacturers to be used in the manufacture of new board, which accounts for approximately 15-20 percent of the raw feedstock at these facilities. Most recyclers of gypsum drywall waste do not recycle the paper backing. NWG recycles the paper backing of drywall in addition to the gypsum core. A paper defibering system is under development at NWG which will clean the drywall paper so that it may be returned to paper companies and made into new paper products, like the backing for drywall. The company is planning to expand operations by franchising or licensing their technology to other areas in North America, Australia, Japan and Europe.

WASTE REDUCTION PRODUCTS CORPORATION

Gypsum drywall scrap is one of the biggest components of the C&D waste stream in North Carolina, which has the second largest manufactured home industry in the United States. Waste Reduction Products Corp. of Goldston, North Carolina has found a way to economically produce products from reclaimed waste drywall scrap (Ewadinger and Gray, 1998). They were established in 1993 with help from the Recycling Business Assistance Center to develop markets for C&D debris in North Carolina. They have created economic benefits for drywall scrap generators by cutting tipping fees by 50% formerly paid to landfills and reducing the number of pulls to empty collection containers. Offering a low cost alternative to disposal is the key to success. Essentially, state officials convert drywall into calcium sulfate powder and cellulose fiber, forming pellets or using both as base materials for other products. End user markets are home gardening, lawn care, golf course maintenance, spill absorbents, animal waste management and cat litter. Currently, there are plans to expand operations into three other states.

AGRICYCLE, LTD.

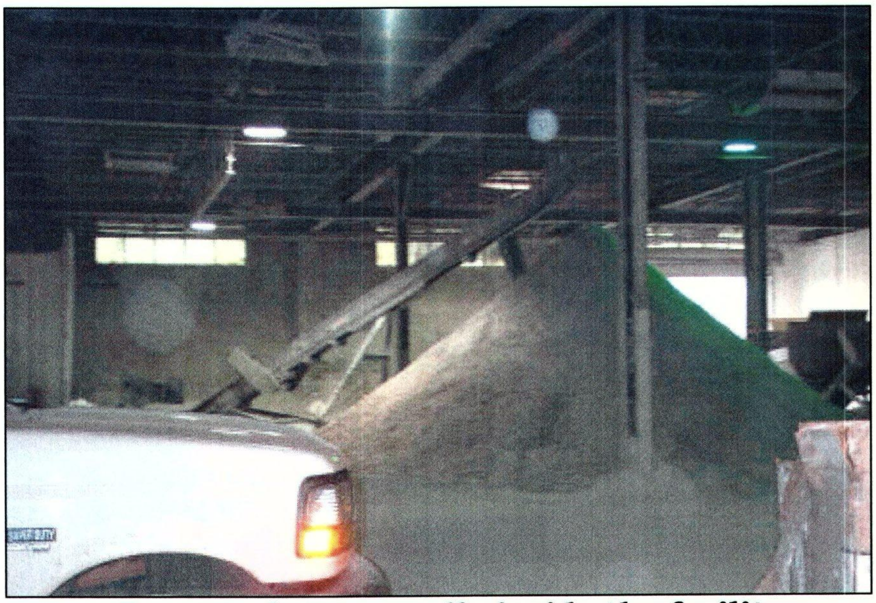
AgriCycle operates a gypsum drywall processing facility in Columbus, Ohio as well as mobile processing centers located at several large drywall manufacturing plants. The facility in Columbus, Ohio is located in a large warehouse in an industrial park and processes approximately 250 tons of scrap drywall per week from *residential construction projects* only. They also operate a 24-hour construction site waste pickup service (a scrapping service) for drywall. AgriCycle sells the processed gypsum for use in agriculture and cement manufacturing.

Drop-off area for incoming loads of scrap drywall.

Since drywall contractors in the Columbus area are responsible for the disposal of their own waste, they leave the scrap drywall at the point of generation and hire AgriCycle to clean up the site. This includes removing all scraps of drywall as well as sweeping up the drywall dust. AgriCycle subcontracts with a number of private haulers to perform the cleanup service at the site, and only scrap drywall is collected. The drywall contractor pays AgriCycle based on the number of linear feet of drywall in the construction project ($0.01 per foot). The drywall is collected and then transported to the processing facility.

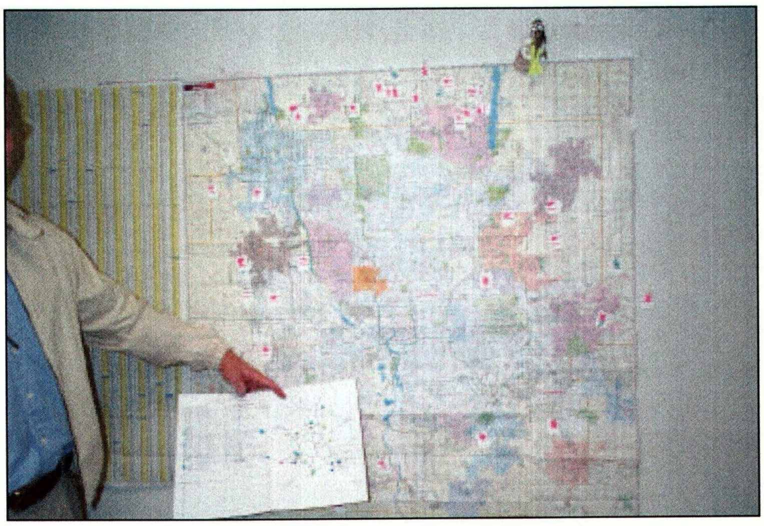
Pile of scrap drywall to be processed.

Loading scrap drywall onto trommel screen for processing.



Processed gypsum pile inside the facility.

The collection process has proven to be successful in the Columbus area. Scrap drywall is kept at the site at which it was generated until the project is completed, at which time the drywall contractor calls AgriCycle. AgriCycle noted that many other communities have construction contractors in Ohio that operate in the same type of manner. All of the dispatching and routing of cleanup trucks occurs from the main facility in Columbus. They maintain a map of local construction projects in their area.



Map showing local construction projects in the area.

GYP-PACK CONTAINER, INC.

Gyp-Pack Container, Inc. of Tonowanda, New York has fabricated machines capable of processing gypsum drywall since February 1993 (Steuteville, 1994). These machines strip the paper from the drywall by using knives as well series of grinding and screening operations, and bale the product into cubes that weigh approximately 1.5 tons. The main markets for the product are new drywall factories and the agricultural industry, which buy the material for an average of $25 per ton.

DOHERTY CONSTRUCTION WASTE MANAGEMENT

Doherty Construction Waste Management in Bellevue, Washington saved $44,000 in costs, compared to another site that did not recycle, by recycling wood, gypsum drywall and corrugated cardboard on site (Biocycle, 1996). State officials also found that recycling decreased the overall amount of waste generated at the site by 50%, indicating that it made the workers less wasteful. Doherty provides an incentive to separate materials by charging fees that are lower than disposal costs. Doherty used 13 to 16 cubic yard roll-off containers at various places on site to collect the materials. The roll-off containers and trucks were relatively small, facilitating collection because they were in close proximity to the work area. Labor costs are reduced because site workers do not have to walk as far to deposit the waste. State officials say that the key to cutting disposal fees is to recycle the biggest volume materials such as wood and gypsum drywall. Most of the company's projects are not as large as this one. In other projects, workers make separate piles of specified waste (typically drywall and wood), and load this onto trucks manually. Manual loading ensures a clean load for the recycling processor and can double the tonnage of material per truckload because it is packed more tightly this way. In projects where there is more material produced, a roll-off container is placed at the site.

DRYWALL COMPANY RECYCLING

Celotex and Lafarge Gypsum companies focus their recycling efforts internally on waste drywall at their manufacturing plant sites. They are able to recycle about 1-2% of the waste drywall at their facilities. Georgia-Pacific Gypsum takes unprocessed drywall at no payment or fee, but charges $4 per ton for crushed or ground drywall and doesn't remove the paper. James Hardie Gypsum accepts scrap from construction job sites and charges for the service. State officials remove the paper during the recycling process.

CHAPTER 4

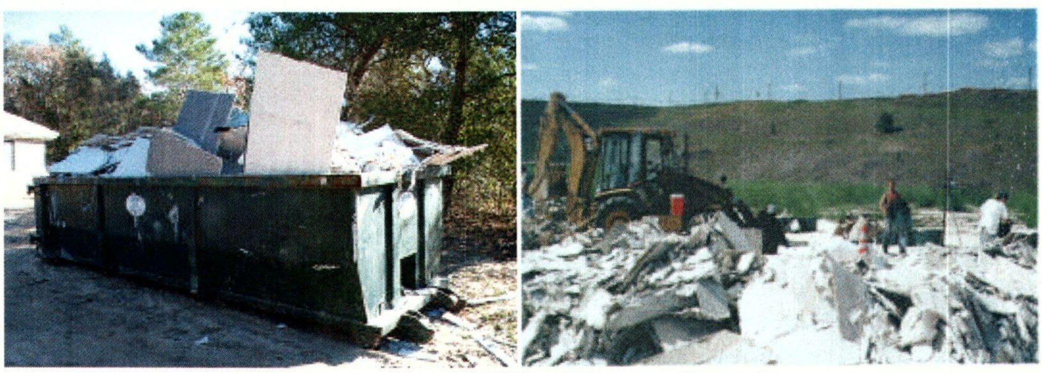
CITRUS AND PUTNAM COUNTY IRG

PROJECT OBJECTIVES

Citrus and Putnam Counties were jointly awarded an Innovative Recycling Grant (IRG) by the Florida Department of Environmental Protection (FDEP) to assess the feasibility of drywall recycling. The primary objective of the project was to demonstrate whether gypsum drywall could be successfully recovered from the construction waste stream and recycled. The two major reuse markets targeted were use of recovered gypsum in the manufacture of new drywall and Portland cement. Several drywall-manufacturing facilities and cement kilns and are located within 100 miles of Citrus County's border.

Putnam County played the role of lead county in the beginning, but after it was determined that Putnam County's potential for drywall recycling was small, Citrus County took the lead. In addition to relatively large amount of construction activity, a privately operated C&D landfill in Citrus County has also experienced odor problems believed to be attributable to the disposal of drywall.

The IRG participants performed several tasks as part of this investigation, as outlined in Table 4-1. Waste and market assessments were conducted, along with demonstrations of drywall separation and processing and a study of the economic feasibility. Citrus County officials sought the input of potentially involved and impacted parties throughout the project. This chapter summarizes the tasks conducted and the results of such efforts. The economic feasibility of collecting and recycling gypsum drywall in Citrus County and other counties involved in similar Innovative Recycling Grants is further expanded in Chapter 7.



Waste drywall in Citrus County

Table 4-1. Major Project Tasks in Citrus / Putnam County IRG

Task	Description
A. Putnam County waste stream assessment	A gate survey was conducted at the Putnam County Landfill. Waste composition studies were also performed on several loads.
B. Citrus County waste stream assessment	A series of gate surveys were conducted at several landfills in the county. Visual waste surveys were conducted at 11 residential houses. Site visits were made to several C&D transfer stations serving Citrus County.
C. Pilot separation: phase I	A subcontractor was hired to collect segregated loads of gypsum drywall from residential construction projects in Citrus County.
D. Processing and market analysis	In conjunction with the New River Solid Waste Association Innovative Recycling Grant, a processing demonstration was held at the Citrus County Landfill. The processed material was sent to the Florida Crushed Stone cement plant in Brooksville, Florida and used to produce cement
E. Pilot separation: phase II	Pilot job-site separation was performed at two residential construction projects and one commercial construction project.
F. Stakeholder meetings and program development	Several stakeholders meetings were held to discuss ways to implement drywall recycling in Citrus County beyond this innovative recycling grant. Economic assessments were also conducted.
G. Project extension	A full-scale test is to be performed to find out if a drywall-recycling program can work in Citrus County. This will include establishing a storage and processing facility and several drop-off locations for segregated drywall. Collection, processing, and reuse of the drywall will occur over a six-month time period.

CITRUS AND PUTNAM COUNTIES

CITRUS COUNTY

Citrus County is located on the west coast of Central Florida. Figure 4-1 presents a map displaying the major cities, roads, and landmarks in Citrus County. As of April 1998, 112,424 people resided in Citrus County. Major employment industries include service (37.5%), retail trade (29.2%), transportation (9.2%), and construction (8.6%) (BEBR, 1999). The number of all building permits issued in 1999 and those issued in January to September 2000 are in Table 4-2.

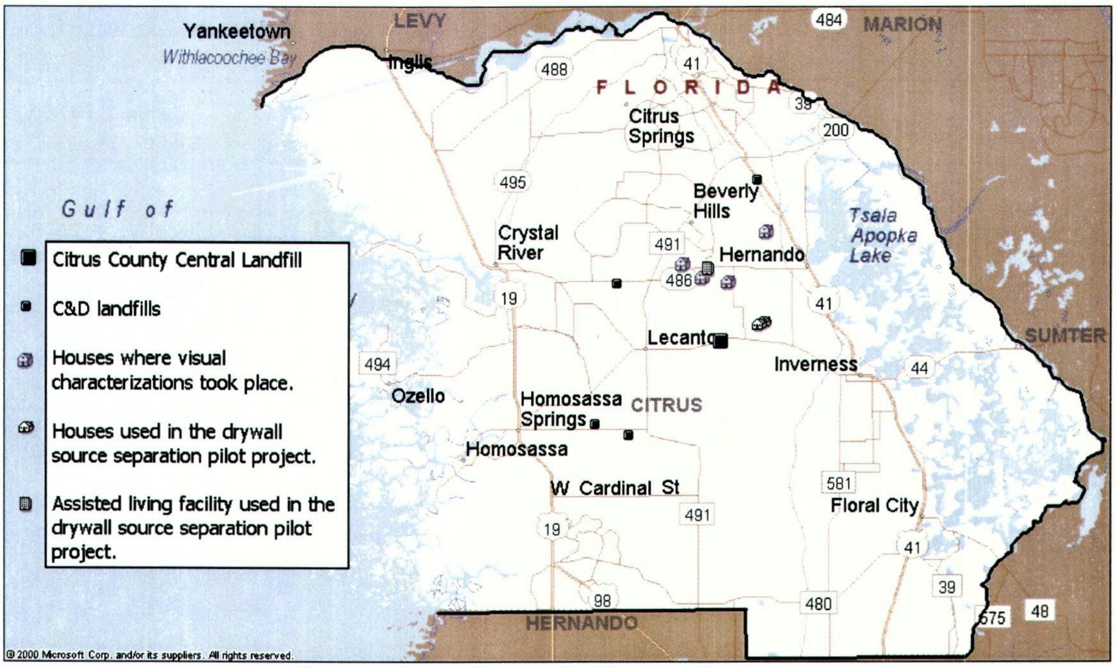


Figure 4-1. Map of Citrus County

Table 4-2. New privately owned residential building permits issued for Citrus County, Florida (U.S. Census Bureau, 1999)

Cumulative year-to-date (September 2000)				Annual 1999		
Item	Buildings	Units	Construction Cost ($)	Buildings	Units	Construction Cost ($)
Single Family	755	755	46,538,325	1,014	1,014	62,981,357

The county-operated landfill, the Citrus County Central Landfill (CCCL), is located in Lecanto, Florida. This facility accepts MSW for disposal in its lined class I cell. No landfill cells specifically for C&D debris are operated at this site. Four private C&D landfills are permitted to accept C&D debris in the county. These facilities include Citrus Sand & Debris, Citrus Sand & Debris II, Materials Exchange Corporation, and Sand/Land of Florida Enterprises. The locations of all of the facilities are presented in Figure 4-1. A listing of how much C&D waste material that each landfill handled, how much C&D waste material each facility recycled, and the origin of the waste in 1998 is listed in Table 4-3.

Table 4-3. Amount of C&D waste handled by each C&D landfill in Citrus County in 1998 (FDEP C, 2000)

C&D Landfill	County of Origin	Tons of C&D Waste Disposed	Tons of C&D Waste Recycled
Sand/Land	Citrus	12,500	90
Citrus Sand & Debris	Citrus	46,786	0
Citrus Sand & Debris II	Citrus	32,017	0
Materials Exchange	Citrus	14,505	96
	Hillsborough	130,552	48

The county and the state track the amount of C&D debris managed in the county to some extent. Figure 4-3 presents the composition of MSW (including C&D debris) reported by the county for 1997. During 1998, 80,000 tons of MSW were disposed in the CCCL (Metcalfe, personal communication, 2001). A total of 14,289 tons, or 0.7 pounds per capita per day (pcd), of building-related C&D debris were reported in 1997. While the 1997 data were only reported by the county to the FDEP (including data reported by the private C&D facilities to the county), recently released 1998 estimates are believed to be more accurate. The 1998 data includes waste amounts reported directly to the FDEP by the private facilities (as a result of a new rule requirement). In 1998, 236,360 tons of building-related C&D waste (11.5 pcd) were disposed in Citrus County, with 45% of this amount originating in Citrus County and the remainder (55%) of the waste originated in Hillsborough County. If this were true, this would mean that C&D material represents around 57% of all the waste that originated in Citrus County. It is generally believed, however, by district DEP employees and by the solid waste employees in the county that some of the waste that is reported to FDEP as waste originating in Citrus County actually represents waste that comes from not only Hillsborough County, but from Pinellas and Pasco Counties, as well. A total of 186 tons (0.07%) of the building-related C&D waste entering the waste stream were recycled (as reported in 1998), including ferrous materials, aluminum, and wood (FDEP C, 1999).

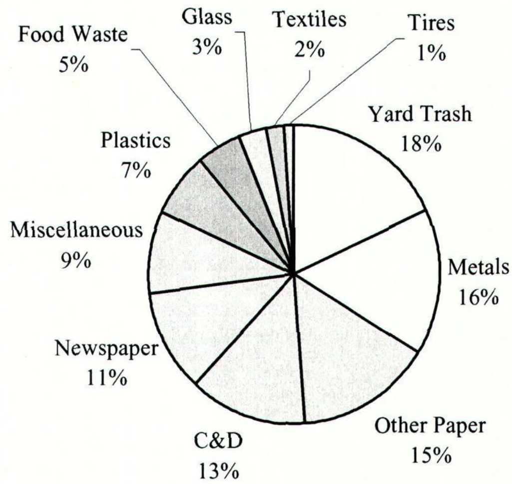


Figure 4-2. Composition of MSW in Citrus County (FDEP G, 1999)

PUTNAM COUNTY

Putnam County is located in north-central Florida. Figure 4-4 presents a map displaying the major cities, roads, and landmarks in Putnam County. In April 1998, there were 71,454 residents in the county. The major employment industries are services (26.8%), retail trade (26.1%), and manufacturing (23.8%). The number of all building permits issued in 1999 and those issued in January to September 2000 are in Table 4-4.

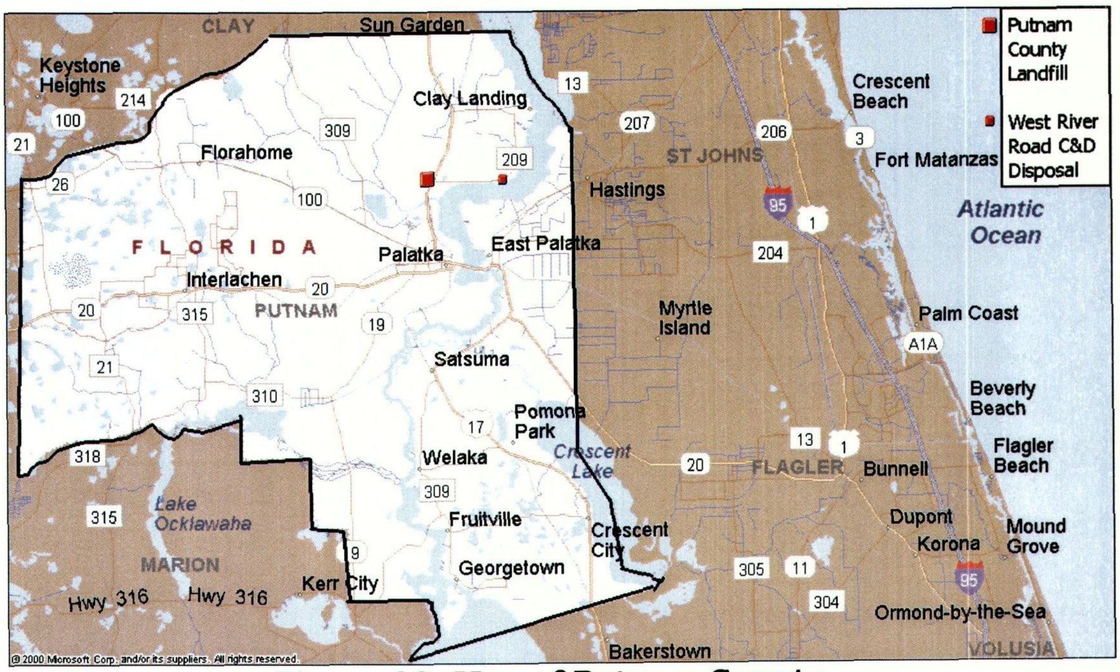


Figure 4-3. Map of Putnam County

Table 4-4. New privately owned residential building permits issued for Putnam County, Florida (U.S. Census Bureau, 1999)

Cumulative yearto-date (September 2000)				Annual 1999		
Item	Buildings	Units	Construction Cost ($)	Buildings	Units	Construction Cost ($)
Single Family	110	110	9,603,627	130	130	11,435,391

There is one county-operated landfill facility in Putnam County that operates both a Class I and a Cass III landfill (the Putnam County Landfill, see Figure 4-4). One private C&D landfill that maintains a permitted C&D debris disposal facility operates in the county (the West River Road C&D Disposal facility, see Figure 4-4). Figure 4-5 presents the composition of MSW (including C&D debris) reported by the county for 1997. The amount of C&D debris reported by the county in 1997 was 18,374 tons, or 1.43 pounds per capita per day (pcd). Again, due to the fact that the method of reporting has changed, recently released data for 1998 is believed to be more accurate. In 1998, 13,429 tons of building-related C&D waste (1.03 pcd) were disposed in Putnam County. All of that waste originated within the county. That same year, 2,099 tons (15.6%) of building-related C&D waste entering the waste stream were recycled, all of which consisted of concrete (FDEP E, 1999). Table 4-5 describes the amount of building-related C&D waste each landfill handled and recycled and the origin of the waste in 1998.

Table 4-5. Amount of C&D waste handled by each C&D landfill in Putnam County in 1998 (FDEP E, 2000)

C&D Landfill	County of Origin	Tons of C&D Waste Disposed	Tons of C&D Waste Recycled
Putnam County Class III Landfill	Putnam	412	0
West River Road C&D Disposal	Putnam	13,017	2,099

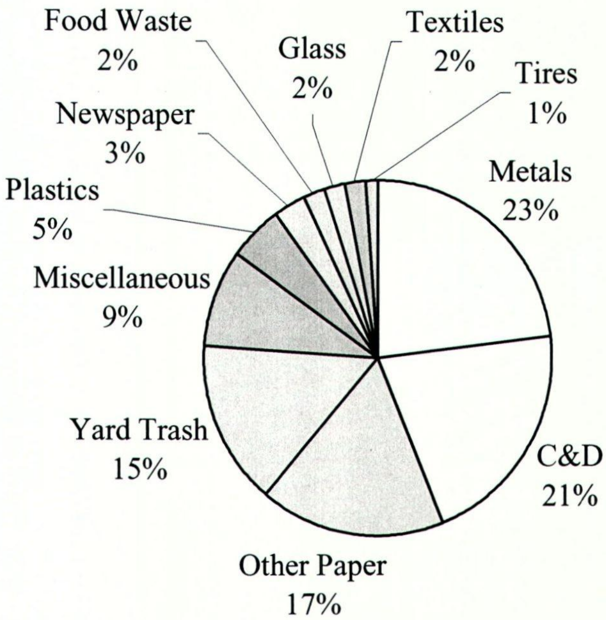


Figure 4-4. Composition of MSW in Putnam County (FDEP G, 1999)

PROJECT TIMELINE

Figure 4-5 presents a timeline of all the project tasks. The timeline extends five months past the publish date of this report. This time represents the extension of the project. The tasks completed during this time period are not reported in this paper, but will be presented in a supplemental report published at a future date.

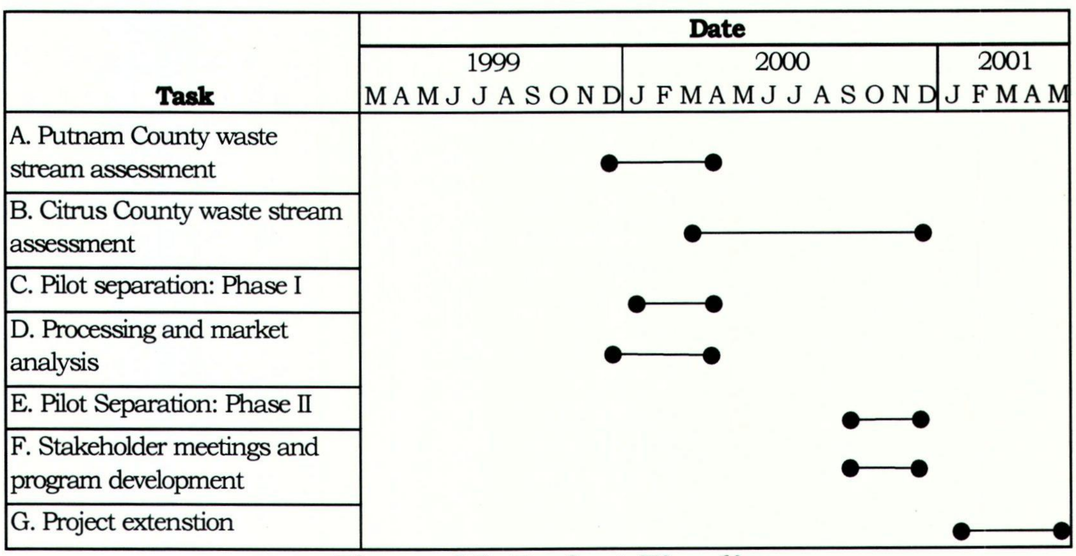


Figure 4-5. Project Timeline

PUTNAM COUNTY WASTE STREAM ASSESSMENT

As previously stated, Putnam County was the lead county in the Citrus/Putnam IRG application. One of the first project steps was to conduct a C&D debris waste stream assessment with a specific look at the amount of drywall present. A solid waste composition study was conducted at the Putnam County Landfill on December 9 and 10, 1999 (see full report in Appendix B). The objective of the study was to perform an initial survey of these waste streams in Putnam County. Two different solid waste streams were evaluated. The first was Class III debris collected at the Putnam County Class III landfill facility. The second was C&D debris from a private C&D landfill located near the County landfill and was also conducted at the Putnam County Landfill.

Weight-based composition study at the Putnam County Class III Landfill facilitv

Methodologies for performing waste composition studies on bulky debris such as Class III and C&D debris are not well established as with municipal solid waste (MSW). A single load of C&D may be very different from other loads of C&D debris because the load represents only a portion of a given project (house construction, building demolition, etc.). Therefore the traditional method of mixing and dividing loads of waste and measuring the composition of small fractions of the waste (to represent the whole) is not applicable. The approach taken during the two-day survey was to perform a visual sort on all loads of waste selected (on the entire load) and to perform a mass sort on selected loads for comparison.

A visual survey, a volume-based composition study, of incoming waste at the class III landfill at the Putnam County Landfill facility was performed for each day during one week in April 2000 to determine if a drywall-recycling project in the county would be feasible (see Figure 4-6). Two people performed visual characterizations of each load as it came in at the landfill. A total of 208 loads (2,073 cubic yards of waste) were surveyed. An estimation of volume for each component in the load was found by multiplying an estimation (by percent) of the composition of the load by the total volume of the waste. The results of the survey revealed that the waste coming into the landfill contained less than 1% drywall.

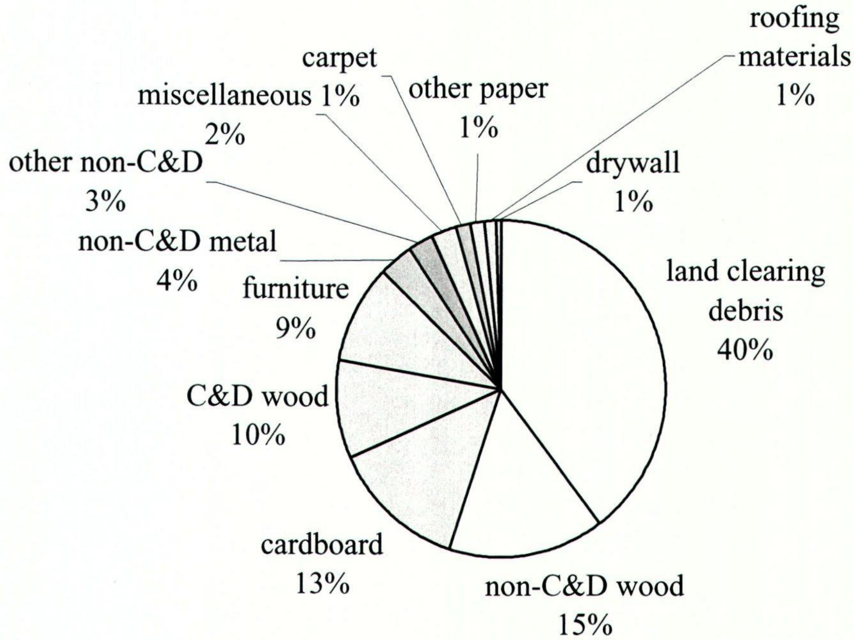


Figure 4-6. Composition by volume of the incoming waste at the Putnam County Class III Landfill

It was decided that, due to the lack of incoming drywall into the county landfill, lack of construction in the county in general, it would not be feasible to proceed with this project in the county.

CITRUS COUNTY WASTE STREAM ASSESSMENT

In a similar manner as Putnam County, a waste stream assessment was conducted to determine where C&D debris was being disposed in Citrus County, how much gypsum drywall was present in the waste, and where gypsum drywall might be separated for recycling purposes. Unlike Putnam County, it was known that Citrus County did have a number of C&D debris landfills and quite a bit of new residential construction under way. Four steps were used in the waste stream assessment:

- A gate survey of the Materials Exchange landfill
- A phone survey of C&D management practices
- A visual survey of residential construction waste generation
- A waste composition study to determine the percentage (by weight) of gypsum drywall in new residential construction

GATE SURVEY AT MATERIALS EXCHANGE LANDFILL

During one week in June, a gate survey was conducted of the waste coming into the Materials Exchange Corporation (MEC) landfill. The MEC landfill was selected for several reasons. It was believed to represent the largest C&D debris landfill in the county. It was also well known for odor problems believed to be caused by the disposal and subsequent decomposition of gypsum drywall. The survey was performed daily in a fashion similar to the visual characterizations performed in Putnam County. This type of composition study is strictly volume-based. One person stood by the open face of the landfill and performed visual characterizations of each load of waste that came in. In other words, he or she made percentage estimates of each component of the total volume. These composition estimates are multiplied by the volume capacity of the truck the waste came in, providing an approximate volume of each component in the load of waste.

The categories used for this survey are wood, metals, roofing material, drywall, land clearing debris, cardboard, glass, plastic, and concrete. A total of 3,080 cubic yards of waste were characterized from 56 loads of waste. The results of this volume composition estimate are presented in Figure 4-7. The largest components of the waste stream were wood, land clearing and yard debris, drywall, and roofing materials. The survey determined that 19% of the incoming waste consisted of drywall. While this percentage is high and seems promising relative to drywall recycling potential, most of the drywall that came in was in the form of very small pieces that could not be practically separated from the rest of the waste. Most waste disposed in the MEC landfill, about 90% in 1998, originates in Hillsborough County (FDEP C, 1999). Much of the C&D waste collected in Hillsborough County is sent to transfer stations in Hillsborough or Pinellas Counties. The manner in which the waste is handled, along with the number of times it is handled, results in a degree of breakage for some components, such as drywall.

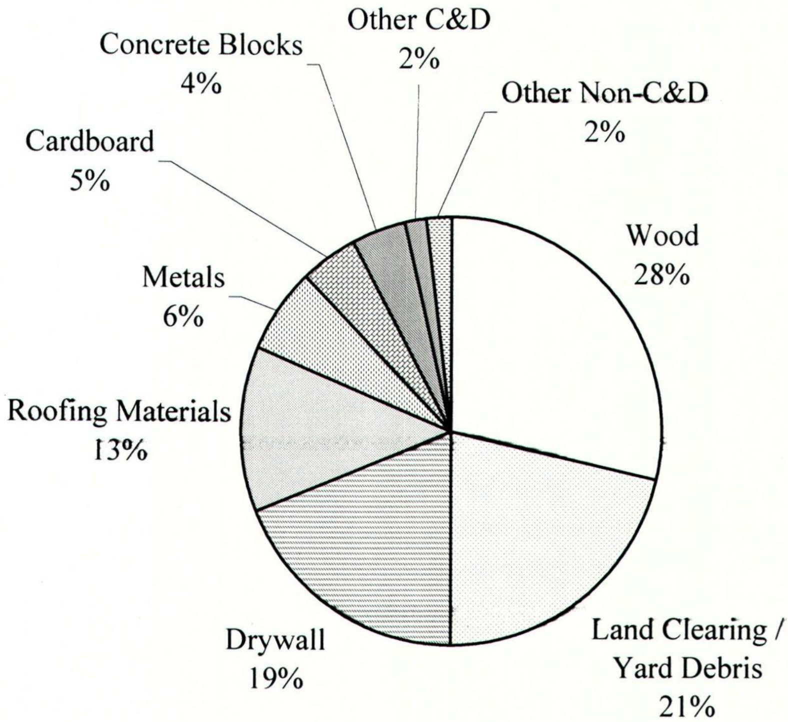


Figure 4-7. Composition of incoming waste at the Materials Exchange C&D Landfill.

SURVEY OF COUNTY C&D DEBRIS MANAGEMENT PRACTICES

The gate survey and discussions with the landfill operator indicated that most of the Materials Exchange Landfill waste stream consisted of out-of-county material. The project team next posed the question, "Where is C&D waste generated in the county being disposed?" They then conducted a phone survey to the major waste haulers that service the county to answer this question. A list of C&D landfills used by waste haulers in Citrus County is presented in Table 4-6. This phone survey determined that most of the waste haulers took their C&D waste to all of the landfills except the MEC landfill. Many were very reluctant to take any waste to the MEC landfill due to the controversy that surrounds it. Another question that was asked regarded the haulers' waste collection practices. Most replied that they place 20 cubic yard containers at the job site to be collected once they are full. The one exception was Spectrum Enterprises. They place corrals at the jobsite in which the waste is collected. Once the corral is full, the four panels of the corral are removed, then waste is removed and hauled away. A further discussion of the waste collection practices by Spectrum Enterprises exists in the section "Pilot Separation: Phase I" of this chapter.

Table 4-6. C&D landfills used by each hauler in Citrus County.

Hauler	C&D Landfill(s) Used
Boone	All except Materials Exchange
Citrus Recycling	Sand/Land
Majestic Disposal	Sand/Land
Seaside Sanitation	No comment
Spectrum Enterprises	Citrus Sand & Debris, Sand/Land
Superior Waste Services	Citrus Sand & Debris, Sand/Land
Waste Management	Citrus Sand & Debris, Sand/Land

VISUAL SURVEY OF WASTE GENERATION FROM RESIDENTIAL CONSTRUCTION

The results of the gate survey and hauler survey, along with exploration into methods used by others who are currently recycling gypsum drywall, led the project team to focus on source separation of scrap gypsum drywall, the preferred method for recovering drywall from the waste stream. Two important factors to be considered when planning a job-site separation program include how much drywall is generated (tons or cubic yards) and when the waste drywall is produced in the construction process. The amount of drywall produced is important in determining whether recycling is feasible. While several composition studies show drywall to be a major component of construction debris and provide estimates of the percentage that drywall comprises of the waste stream (see "Gypsum Drywall in Construction and Demolition Waste" in Chapter 2), these studies were mostly performed on wood-frame house construction. The houses under construction in Citrus County are largely concrete block homes. Thus, composition information (both mass and volume) from specific homes in Citrus County is important to assess waste amounts.

The importance of when drywall waste is produced becomes evident when one considers the timing of construction. Duration of construction varies from house to house, depending on the house size, weather, promptness of payment from the client, and other factors. In general, the first stage of waste consists primarily of concrete and wood. This waste results from the external framing stage of the house. In this stage, a concrete foundation has been laid, external concrete block framing has been built, and the roof has been put on. In the second stage of the house, roofing shingles are applied, internal framing is built into the house and wiring and insulation are installed. The waste from this stage consists primarily of roofing shingles, wood, and ferrous metal

metal (depending on what the builder uses for internal framing). The third stage of the house is the drywall installation stage. Here, the predominant waste component is gypsum drywall. In the final stage of the house, appliances, flooring materials, and cabinetry are installed. Consequently, the waste from this stage largely consists of cardboard and some flooring materials, such as carpet padding and tile. It is important to know when the waste drywall will be generated to efficiently target source separation.

Visual characterizations of waste from three houses in Citrus County began on July 11th, 2000, (see Figure 4-2) to determine the percentage of drywall in the waste that is generated in the construction houses. The three homes were constructed by Citrus Hills Construction and are about the average size of the homes that they build, around 2,500 square feet. Citrus Hills Construction is the largest homebuilder in Citrus County. Surveys were conducted each week until all of

(Clockwise from the top) House A, House B, House C, and one load of waste from House B.

the houses were completed. The results from these waste surveys are in Figures 4-8 to 4-10. House A, House B, and House C produced approximately 55, 60, and 80 cubic yards of waste, respectively.

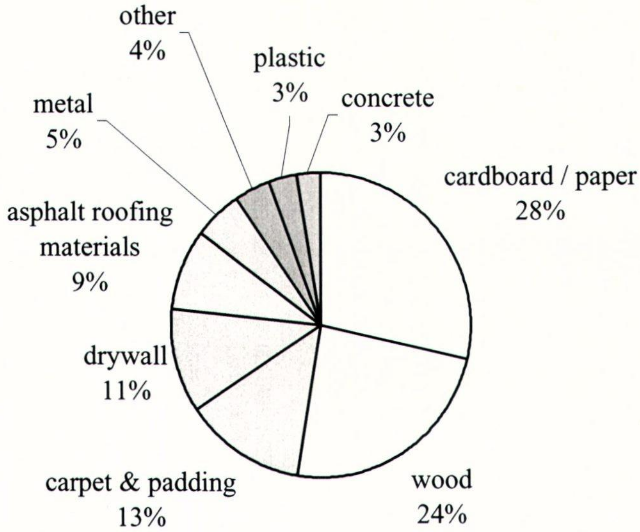


Figure 4-8. Composition of waste from House A (2,535 square feet)

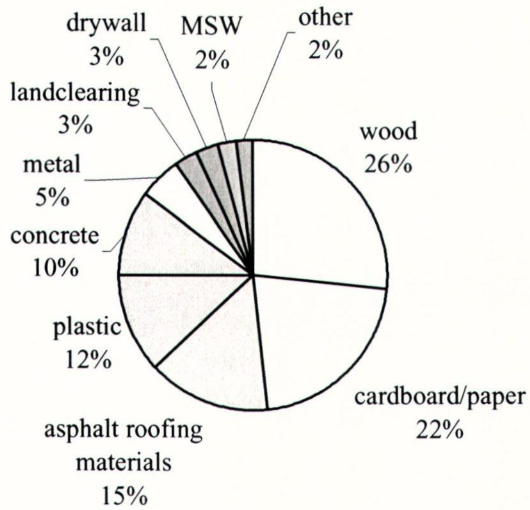


Figure 4-9. Composition of waste from House B (2,670 square feet)

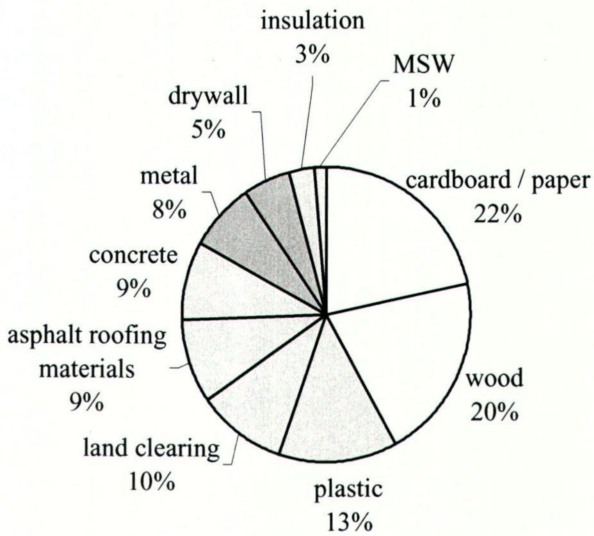


Figure 4-10. Composition of waste from House C (2,277 square feet)

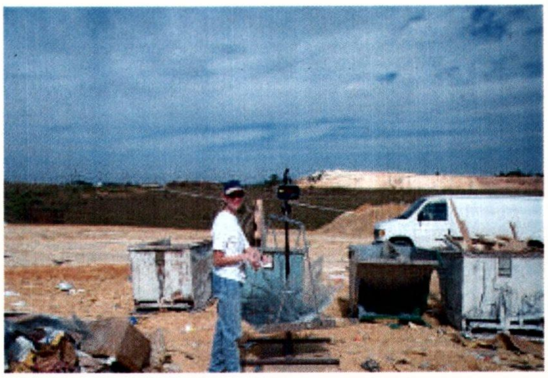
The surveys were all volume based. Wood and cardboard are the largest components of the waste from each house. In one of the graphs, drywall is shown to be one of the largest components. In the other two, however, it is one of the smaller components. This may be due to the fact that the surveys were only taken once each week. Between two times that the surveys were taken, work may have been conducted that produced a lot of waste. If the waste were removed before the next survey time, there would be no way to account for the lost waste. This loss could affect the above results.

WASTE COMPOSITION STUDIES

The information gathered by the visual surveys provided indications of how much drywall was present by volume, not by weight. The project team therefore decided to conduct several weight-based composition studies. The studies were conducted by separating each component from the waste and placing it into a bin. The bins were then weighed. The empty bin weight was subtracted from the total. These weights were then compared to the weight of the waste when it first came into the landfill. Four to six people sorted the waste, depending on the job. For the heavier loads, it took a half of a day

Workers sorting the waste by component

(four hours) to sort 20 cubic yards of waste. For lighter loads, it took only two hours to complete a sort of the same volume. Copies of the data sheets used to collect the data are included in Appendix C. A small, mobile scale was used to weigh the material. Larger, heavier components were placed in a bin and taken by a front-end loader to be weighed at the landfill scale house.



Weighing waste for a weight based composition study

A weight-based composition study was performed for one load of waste (22 cubic yards) on March 23rd, 2000. This load was one of three from a house being constructed by Sweetwater Homes Construction. On average, residential construction produces three to five loads of waste (60 to 100 cubic yards) per home. The drywall stage had just been completed for this house and, hence, the waste contained a lot of drywall, wood, and roofing materials. The results from the study (by mass) are presented in Figure 4-11. Dirt, soil, and fines are not included in this graph due to the fact that they became mixed in with the soil in the landfill and therefore were not weighed. The resulting mass, which amounted to almost 5,400 pounds, equaled nearly half the weight of the original amount that was brought in by the truck, totaling more than 10,800 pounds. The difference, approximately 5,400 pounds, is most likely due to the fact that the fines and dirt were not weighed. In future studies performed, the waste loads were placed on a tarp or a concrete slab to prevent this loss.

Weight-based composition study on wast from a house built bySweetwater Homes

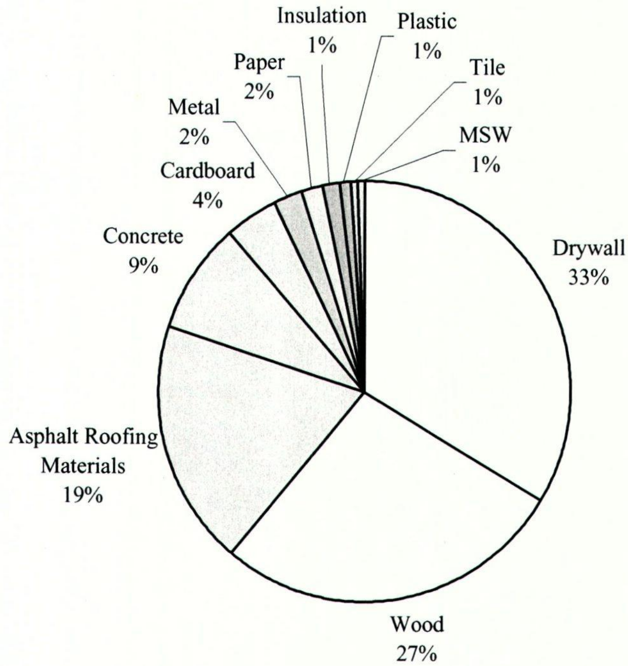
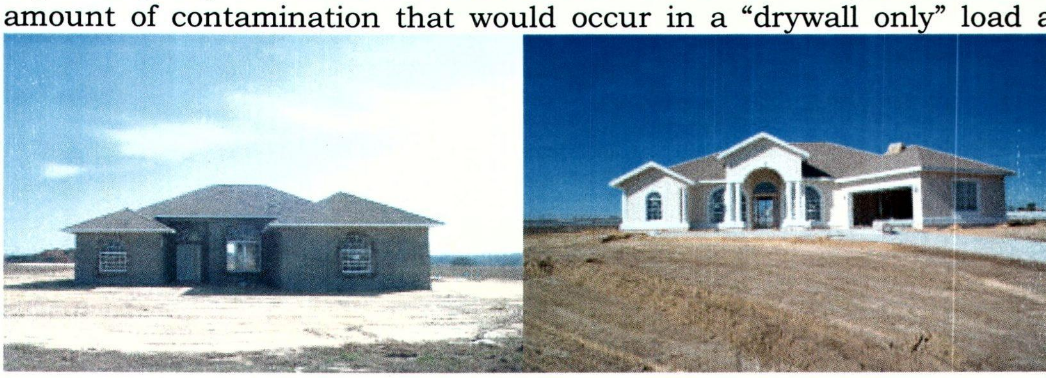


Figure 4-11. Composition of one load of waste from a Sweetwater home

Several weight-based composition studies of the waste from two houses constructed by Citrus Hills Construction were conducted from October through December 2000 (see Figure 4-2). The purpose was to determine the percentage of drywall in the waste that is generated in the construction of the average home. These houses are the ones used in the source separation pilot project, discussed further later in this chapter. The purpose of the project was to determine the feasibility of source-separating drywall from the rest of the waste and to determine the amount of contamination that would occur in a "drywall only" load at



Houses 1 and 2 used for the weight-based composition studies and for the pilot-recycling project

a residential construction site. For this project, extra bins were placed out at the job site to collect only drywall. All of the waste was hauled to the Citrus County Landfill to be sorted. Both of the houses have an area of about 3,000 square feet, which is about the average size of home that Citrus Hills Construction builds. The waste was dumped onto a tarp to ensure there would not be any loss (or gain) of material. Labor was contracted out to Labor Ready, a temporary labor agency in Ocala, Florida. The results from the mass sorts are shown in Figures 4-12 and 4-13.

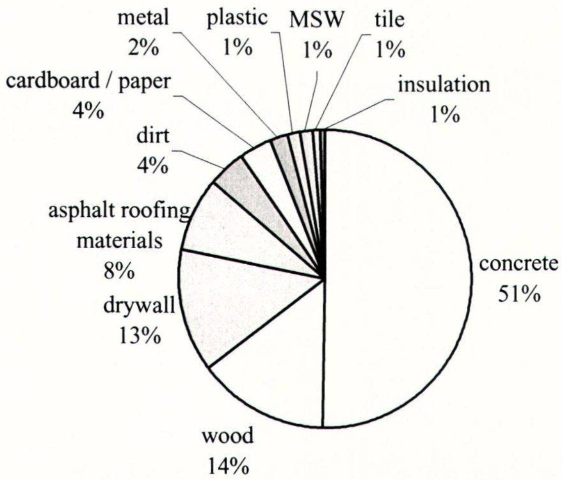


Figure 4-12. Composition of waste from theconstruction of House 1

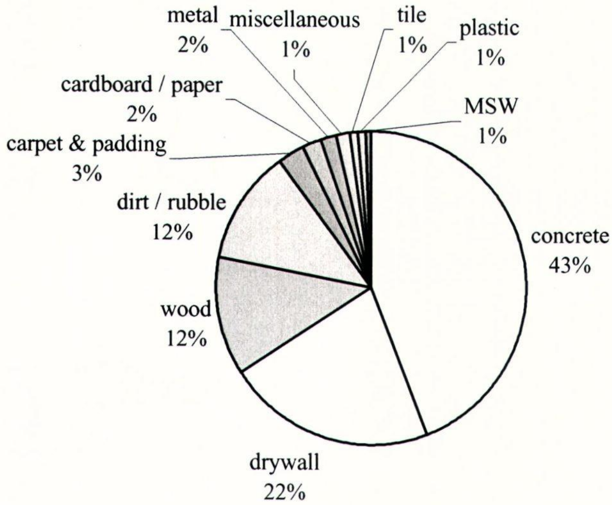


Figure 4-13. Composition of waste from the construction of House 2

These figures both show that drywall is one of the three largest components of residential construction. The total mass of waste resulting from the construction of the House 1 and House 2 was equivalent to 10.4 and 19.5 tons, respectively. The difference in these weights can most likely be explained by the fact there was a lot of dirt and rubble disposed from clearing the land at the end of construction of House 2. This was not the case for House 1. The two houses had two different project managers, which may also explain other differences in the composition of waste.

PILOT SEPARATION: PHASE I

At the beginning of the year 2000, a C&D waste hauler was contacted to see if it was possible to separate drywall from the waste loads at the job site. The hauler, Spectrum Enterprises, was contracted to collect drywall only from residential construction sites and bring it to the Citrus County Central Landfill to be processed and then sent to FCS for the cement trial run. Spectrum Enterprises operates a construction site waste service that differs from the traditional waste collection service in the county. Instead of renting out waste containers, Spectrum place a construction debris receptacle (CDR) at the job site. The CDR is a sort of corral, which consists of four wood and screen panels. The construction workers deposit the waste into the corrals on the site. Then Spectrum sends a dump truck, towing a skid steer, out to the site. Spectrum removes the panels of the CDR and then use the skid steer loader to scoop up the waste and put it into the truck. Spectrum contacted the builders from whom they collect and asked them to separate their drywall from the rest of their waste. The builders did this accordingly and Spectrum hauled the drywall to the county landfill, taking the other waste to a C&D landfill. Spectrum Enterprises collected 90 tons of drywall waste.

CDR

Spectrum's dump trucks and skid steers

Sorting drywall loads

A weight-based composition study was performed on some of the drywall-only loads collected by Spectrum Enterprises on February 29, 2000 to determine the level of contamination. The tonnage sorted totaled over 4.8 tons. AgriCycle has commented that in order for the processing to work well, there cannot be more than 20 percent contamination. The results of the sort show that the drywall loads contained approximately nine percent contamination. This contamination consisted mostly of concrete and wood (see Figure 4-14). The pile consisted of 91 percent drywall, four percent of which was greenboard. Greenboard is a type of drywall that is water-resistant (see section "Gypsum Drywall" in Chapter 2).

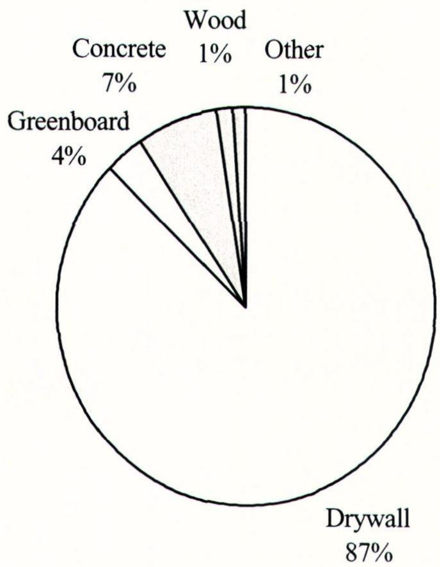


Figure 4-14. Mass sort on segregated drywall loads

PROCESSING

Processing is an important step in any drywall-recycling program. The processing evaluation conducted for this Citrus/Putnam IRG was conducted in coordination with the NRSWA IRG. The reader is referred to "Processing Demonstrations" in Chapter 5 for information on the first three processing demonstrations. The final processing demonstration was held in Citrus County at the Citrus County Central Landfill.

A firm with experience processing and recycling drywall was contacted to conduct a drywall processing demonstration. AgriCycle owns a drywall recycling business in Ohio. In December 1999, a visit was made to the processing facility in Ohio to observe their drywall-recycling procedure. AgriCycle is also processing scrap drywall at the U.S. Gypsum facility in Jacksonville. AgriCycle transported a trommel screen to the Citrus County Central Landfill on April 25, 2000.

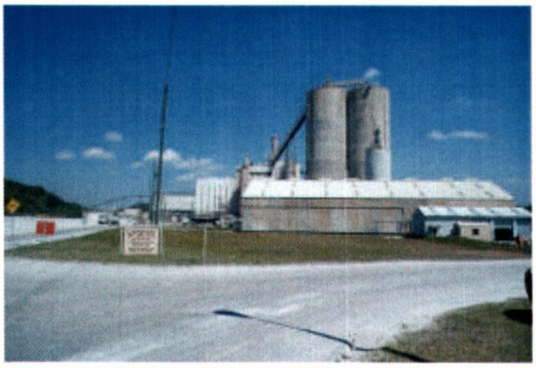
The entire machine is 27 feet long. The screen is 20 feet long, seven feet in diameter, and has a ¾ inch size mesh. The trommel screen is a large rotating cylindrical screen that is tilted at an angle. The drywall is loaded at the higher end. The trommel screen breaks up the drywall by using gravity and the weight of the wallboard. The cylindrical screen rotates, causing the drywall to break apart as it tumbles down. The gypsum falls through the screen at the bottom and the paper continues to move down to the other end of the machine. The gypsum is transported via conveyor belt into a dump truck or a pile. The paper is also transported by a conveyor and lands in another pile.

Even though dust is a big problem, there were no dust suppression mechanisms on the machine for this event, due to the fact that it was a demonstration and the project members were not aware of the large amount of dust that would be produced. In accordance with F.A.C. Rule 62-701.500 (11) e, dust at landfills should be controlled. It is recommended that processing not take place on significantly windy days and that dust suppression mechanisms, such as misting, should be used.

The drywall processed came from two sources: residential construction scrap material collected in Citrus County, and scrap from Homes of Merit, a manufactured homes plant in Lake City, Florida. The processing took about four hours to complete at a rate characterized by AgriCycle as "slow" for demonstration purposes. Of the 134.52 tons of drywall that were processed, 93.8 tons (69.7 percent of the total drywall weight) of gypsum was recovered. The recovered gypsum was then taken by several dump trucks to FCS to be mixed with their mined gypsum. The paper residuals were landfilled there at the Citrus County Central Landfill.

MARKET ANALYSIS

Initially, two end-use markets for recycled gypsum were pursued in this project: as an ingredient in the manufacture of portland cement and in the manufacture of new drywall. After talking with several drywall-manufacturing companies in Florida, it was decided that this was not a viable market for this project. The companies had little desire and incentive to pursue use of this material because they already have existing piles of scrap drywall available for recycling from their processes. The economics of using scrap gypsum as a raw material is also less favorable because the companies that own the gypsum wallboard plants also own gypsum-mining operations and supply gypsum around the world. An additional trend in drywall manufacturing is to use byproduct gypsum from electrical plants. In this way, they are already using recycled gypsum, so there would be no reason to start to use the gypsum from construction. As a result of these discoveries, the project team decided to focus on cement manufacturing as the most viable end-user market for the Citrus County region.



FCS facility in Brooksville, Fl

A visit was made to FCS in Brooksville, Florida (which is in Hernando County, just south of Citrus County) on February 17, 2000 to establish communications with FCS and to watch and better understand the cement-making process, particularly when and where they add the gypsum to the process (see "Gypsum Use in the Manufacture of Portland Cement" in Chapter 3).

Two days after the processing demonstration had taken place (on April 27th, 2000) the recycled gypsum was blended in with the mined gypsum at FCS for a test run of the material. The ratio of the recycled gypsum to the mined gypsum was 1:1 by weight. Since it was unknown whether the recycled gypsum would work, state officials did not want to do the test using 100% recycled gypsum. The recycled gypsum had a density of about 35 lbs per cubic foot, while the mined gypsum has a density of 85 pounds per cubic foot. Hence, the mix ratio by was about five parts recycled gypsum to two parts mined gypsum (by volume). A front-end loader was used to mix one pile of mined gypsum and one pile of recycled gypsum. It was added to the process just as the normal mined gypsum is added (see "Gypsum Use in the Manufacture of Portland Cement" in Chapter 3).

FCS employees conducted tests on the cement made with the recycled gypsum. The results showed that this was as good as the cement made with mined gypsum (Wheeler, personal communication, 2000). The only comment made by FCS regarded the amount of silicon dioxide in the cement. The cement made with recycled gypsum contained about 1.97

percent more silicon dioxide than cement made with mined gypsum. This is most likely due to the fact that a large amount of sand was also picked up and put into the machine when the drywall was scooped up and placed into the trommel screen at the landfill. An earlier run with a very small amount of recycled gypsum (about 20 pounds) that was given to FCS did not have this problem. The tests using this gypsum showed that the cement produced with recycled gypsum met all of the required specifications (Wheeler, personal communication, 2000).

The high amount of silicon dioxide caused an increase in the percentage of insoluble residues by 1.75 percent. The maximum percentage allowed by the Department of Transportation (DOT) and the American Association of State Highway and Transportation Officials (AASHTO) II is 0.75 percent. A cement company would not be able to sell this cement for road construction because it did not meet the required specifications (FCS, 2000). This amount of extra silicon dioxide can be prevented if the right precautions are taken so that a large amount of sand will not contaminate the end product. The results from the tests on the cement made with the recycled gypsum are in Table 4-7.

Table 4-7. Chemical and physical composition of cement

Chemical Composition	DOT / AASHTO II Minimum	DOT / AASHTO II Maximum	Sample of cement made with mined gypsum	Sample of cement made with recycled gypsum
% SiO_2	20.0	-	20.81	22.78
% Al_2O_3	-	6.0	5.15	5.23
% Fe_2O_3	-	6.0	3.75	3.59
% CaO	-	-	63.71	62.58
% MgO	-	6.0	0.97	1.05
% Ca_3Si	-	55	51	33
% Ca_3Al	-	8	7.3	7.8
% SO_3				
$Ca_3Al < 8\%$	-	3.4	3.64	2.78
$Ca_3Al > 8\%$	-	3.5		
% Insoluble Residue	-	0.75	0.33	1.75

PILOT SEPARATION: PHASE II

Drywall-only container at the assisted living fcility job site

From September through November 2000, a second pilot project was conducted to determine how well drywall separation could occur at the job site. Two residential homes (Houses 1 and 2 used in the weight-based composition study discussed earlier in this chapter) constructed by Citrus Hills Construction and one assisted living facility constructed by SGW Construction were selected for this project (see Figure 4-2). The characteristics of each job are listed in Table 4-8. Separate 20 cubic yards bins, marked with "Drywall only" signs, were set out on each site to collect the drywall. The loads were taken to the Citrus County Central Landfill where they were stored to be processed at a future date.

Assisted-living facility used in the pilot project

Visual characterizations of the drywall loads were conducted to determine the amount of contamination in each load. All of drywall loads that came into the landfill from the assisted living facility and the two homes contained no visible contamination. The contractors doing the separation found that there were no complications in separating the drywall. As long as the drywall container was removed in a prompt fashion and the container was clearly marked, there were no contamination problems. The total weight of drywall collected from House 1, House 2, and the Assisted Living Facility is equal to 1.29 tons, 4.24 tons, and 18.73 tons, respectively.

Table 4-8. Characteristics of the buildings used in the jobsite source separation pilot project.

Job	Area (ft²)	Contractor	Type of Construction	External Framing	Location
House 1	2,859	Citrus Hills Construction	Residential	Concrete block	Inverness, FL
House 2	3,015	Citrus Hills Construction	Residential	Concrete block	Inverness, FL
Assisted Living Facility	52,000	SGW Construction	Residential	Concrete block	Homosassa, FL

STAKEHOLDER MEETINGS AND PROGRAM IMPLEMENTATION

On September 28 and October 19, drywall stakeholders meetings were held at the Citrus County Administration Building. These meetings involved building contractors, drywall contractors, C&D waste haulers, landfill operators, county administrators, FDEP regulatory staff members, consultants, researchers, and members of the Citrus County Home Builders Association. The purpose of these meetings was to have a round-table discussion about how drywall waste is currently handled and how that could be changed so that a drywall-recycling program might take place.

At the first meeting, a facilitator was used to direct the meeting. A stock-flow diagram was created of the entire drywall process by all that attended, including where drywall is handled and where problems arise. The facilitator also included where costs and payoffs are in the system. He then posed the question, "What factors will be key to the attractiveness of a drywall recycling program in Citrus County over the next year?" Everyone was told to give three to five answers. These answers were then put into groups. The group categories that resulted were:

- Contractors' support
- Collection logistics
- Demonstrated community benefit
- Economic feasibility
- Political/regulatory permission or enforcement
- Sufficient end-market need
- Technology transfer

The project team decided that if a drywall-recycling program is to work, the problems in each of these categories need to be addressed. Collection logistics were focused on and a number of source separation options were discussed. After discussing whether source separation would be possible at this first meeting, team members determined that more information, specifically economical information, on the options for source separation was needed. These options, presented in detail in Appendix D, were provided to all that were involved in the meeting. The four options were:

- Utilize a two container system, one for mixed C&D and one specifically used to collect separated drywall
- Utilize the current system, processing the "drywall" load of the waste from the house and assuming all contamination will be screened out
- Utilize a scrapper service; a service that would clean up all waste after the drywall installers have finished
- Utilize a contractor service that picks up drywall-only loads

At the second meeting, these options were discussed and it was determined that the most feasible solution was to have an individual drywall waste hauler or contractor pick up the separated drywall.

The owner of the Sand/Land landfill stated at the second meeting that he was planning to be the processor of drywall at his landfill facility. After this was discussed, it was determined that several tasks still needed to be accomplished. These tasks include:

- Gain FDEP approval of using Sand/Land as a processing site
- Construct storage area at the processing site (Sand/Land)
- Create several drywall drop-off places at multiple landfills
- Restart collection of drywall-only loads from Sweetwater Homes
- Meet with the largest builders in Citrus County to discuss the drywall-recycling program
- Promotion of the project
- Determine the value of the end-product

A representative from Sand/Land and members of the project team and met with FDEP staff in Tampa, Florida on November 9, 2000. At this meeting, the regulatory staff from the FDEP gave verbal approval of this scenario provided that several tasks completed and turned in to the DEP. Several general rules that they must follow to be allowed to recycle drywall are:

- The collection and processing operation must be located within the solid waste management system at the site.

- MSW must be segregated, as is required for all C&D waste management
- If there is a load that is less than 95% drywall, it must be separated in the cell and drywall can then be taken to the storage and processing area. Processing does not have to occur in the cell.
- All "overs" (includes paper backing, concrete, wood, roofing, and metal) must go directly into a truck or a container for disposal in the landfill.

The project team supplied to the FDEP, as requested:

- Processing machine specifications
- An operating plan, which is to include:
    - List of materials not allowed to go through the trommel screen
    - Litter prevention and dust suppression plans
    - A design for the concrete pad on which the drywall will be stored

Subsequently, Sand/Land was permitted to collect and process drywall at their site.

EXTENSION OF THE PROJECT

The Citrus and Putnam County IRG deadline has been extended until June 1, 2001 from its original deadline of January 31, 2001. A full-scale test of the drywall recycling process and system will be conducted during this period. This will include establishing a storage and processing facility, establishing drop-off locations for segregated drywall, and promoting the project to local contractors. A supplement to this report will be released at that time detailing all further work that is completed for this project.

CONCLUSION

For the Citrus and Putnam IRG, the project team conducted waste assessments to determine the amount of drywall in the waste stream for each county. Waste compositions were assessed to determine the amount of waste drywall generated from residential construction on a per house basis. Processing demonstrations and a cement manufacture test run were conducted to determine the easiest way to recycle the drywall and to demonstrate that these steps can be accomplished. Source-separation trials were conducted at the job site to see if this was a feasible option or if separation at the landfill was a more viable option. Finally, meetings were held to educate as well as to get input from all parties involved in the system from the time the drywall waste is generated to the time it is disposed or recycled.

Drywall is a substantial component of C&D waste. The most viable type of activity from which it can be recycled is new construction. It cannot be recycled if it is sent through a transfer station that crushes and mixes material. Processing drywall is relatively simple. There is a definite market available that can use as much gypsum as this industry produces. The biggest hurdle that must be overcome is the collection economics, as further discussed in Chapter 7. As discussed before, recycling at the job site can be more costly than disposal in a landfill, depending on how each contractor decides to work the waste. Even if recycling at the job site is not more costly, there still is not a large cost-savings in participating.

CHAPTER 5
NRSWA IRG

PROJECT OBJECTIVES

The New River Solid Waste Association (NRSWA) targeted two reuse options for gypsum drywall in their IRG: an agricultural soil amendment and a material for road construction. Land application as an agricultural soil amendment was selected because of the current uses of gypsum in many locations in the United States, and the proximity of the New River Regional Landfill to many agricultural operations. The possible use of gypsum in road construction was explored partly because phosphogypsum has been reported to be an effective material for road construction (Chang et al., 1989). The NRSWA accepts discarded drywall from all three of the association counties for disposal in their Class III landfill. As part of this project, New River Regional Landfill (NRRL) employees separated gypsum drywall from the incoming waste stream on a case-by-case basis. The major source of scrap drywall in this project, however, was Homes of Merit (HOM), a manufactured housing company with a plant in Columbia County. HOM previously disposed of drywall waste with other construction waste at the Columbia County Landfill.

Several tasks were conducted as part of this IRG project, including processing demonstrations, agricultural trials, and trial road construction. The specific tasks completed for the IRG are outlined in Table 5-1. This chapter summarizes the activities conducted, results gathered, and is organized by major project tasks.

Row of crops after planting in January, 2000 at the Suwannee Valley Research and Education Center with markers to show project identification.

Table 5-1. Major Project Tasks for the NRSWA IRG

Task	Description
A. Scrap Drywall Collection Program	Drywall collection in the NRSWA was evaluated. A collection program with a nearby manufactured housing plant was established.
B. Processing Demonstrations	In conjunction with the Citrus County IRG, several processing trials were conducted to evaluate available equipment.
C. Agricultural Trials	
Trial I	Processed gypsum drywall was tested on four different cool weather crops at the Suwanee Valley Research and Education Center (SVREC). This task was accomplished by working with the Baker County IFAS (Institute of Food and Agricultural Sciences) Extension Office.
Trial II	Processed gypsum drywall was tested at the Baker County IFAS Extension office in an observational trial of five crops. This task was also accomplished by working with the Baker County IFAS Extension Office.
D. Road Construction	A road was constructed using processed gypsum drywall in a mixture with sandy soil. The road design was based on laboratory data collected for different mixes of processed drywall with sand.

DESCRIPTION OF NEW RIVER SOLID WASTE ASSOCIATION

LOCATION AND POPULATION

The NRSWA members include Baker, Bradford and Union counties, which had a collective population of 59,945 in 1998 (BEBR 1999). Figure 5-1 presents a map of the three counties and the location of several facilities, both within and outside the counties, that played a role in this project. The major cities in the NRSWA include Macclenny (Baker County), Starke (Bradford County), and Lake Butler (Union County). The New River Regional Landfill (NRRL) is located in Raiford, Florida, in Union County. According to the North Central Florida Regional Planning Council (1999), the employment in this region is largely through the government and services sectors. Government jobs are primarily state and local positions. The school board, Department of Corrections, and DuPont are the largest employers in Bradford and Union counties. The state hospital is the largest employer in Baker County.

Figure 5-1. Map of the New River Solid Waste Association

Residential building permit data were collected from each county. This data was used to estimate the 171 tons of drywall waste that were generated by the NRSWA in 1999 (Eqn. 7-1). Cumulative year-to-date and annual 1999 new residential construction statistics for Baker, Bradford, and Union counties are presented in Table 5-2. A total of 170 residential building permits were issued in the NRSWA area in 1999. By September 2000, 109 residential building permits have been issued for counties in the NRSWA. These counties were ranked 57th both collectively and as an average in 1998 for residential construction activity when compared to other counties in Florida (BEBR, 1999). The Bureau of Economic and Business Research (BEBR) ranks counties in Florida against each other based on criteria such as construction activity from U.S. Census Bureau data. As of September 2000, Baker County exceeded 1999 construction costs, and leads the NRSWA in construction activity, for 1999 as well as in year-to-date records. Within the NRSWA, Bradford County ranks second in construction activity and Union County ranks third.

Table 5-2. New privately owned residential building permits issued for Baker, Bradford, and Union Counties, Florida (U.S. Census Bureau, 1999)

	Cumulative yearto-date (September 2000)				Annual 1999		
	Item	Buildings	Units	Construction Cost ($)	Buildings	Units	Construction Cost ($)
Baker	Single Family	47	47	6,024,048	66	66	4,656,660
Baker	Two Family	1	2	94,432	1	2	46,556
Baker	Total	48	49	6,118,480	67	68	4,703,216
Bradford	Single Family	40	40	2,738,580	62	62	3,974,250
Bradford	Total	40	40	2,738,580	62	62	3,974,250
Union	Single Family	21	21	1,540,770	41	41	3,360,130
Union	Total	21	21	1,540,770	41	41	3,360,130

SOLID WASTE MANAGEMENT

The NRSWA was the first regional solid waste association in Florida. It operates the NRRL, which began operations in July 1992. The NRRL currently accepts waste from the Association Counties (Baker, Bradford and Union counties), as well as out of Association Counties (Alachua, Levy and Gilchrist counties). Currently, most of the NRRL's waste stream arrives from Alachua County. The NRSWA waste stream has increased from about 180 tons per day in 1992 to the current rate of approximately 700 tons per day (Class I and Class III combined).

The NRSWA operates a Class III landfill for disposal of C&D waste and other non-putrescible items such as furniture. The total amount of Class III waste disposed at the NRRL in 1999 was approximately 9,600 tons. The nearest C&D landfills to the NRRL are Trail Ridge C&D Landfill in Duval County, which is 14 miles away, WWW Carter in Putnam County which is 24 miles away, and WG Buck Johnston in Alachua County which is 26 miles from the NRRL. Approximated distances from these facilities to the NRRL range from 15 to 30 miles.

C&D waste generation rates and disposal rates are recorded to some extent by Counties and the State. Figure 5-2 presents the average composition of MSW (including C&D waste) for the NRSWA (FDEP-G, 1999). The amount of C&D waste reported for Baker County in 1997 was 549 tons, or 0.14 pounds per capita per day (pcd). Bradford County collected 908 tons of C&D debris, or 0.20 pcd. Union County reported 947 tons of C&D waste, or 0.40 pcd. The total amount of C&D waste collected in 1997 from the three NRSWA counties was 2,404 tons or 0.22 pcd. The total amount of C&D waste recycled in the NRSWA counties during 1997 was 236 tons. Data from 1997 was only reported by the county (including data reported by the private C&D facilities to the county). 1998 data are believed to be more accurate due to the fact that waste amounts were reported directly to the FDEP by private facilities as a result of a new rule requirement. The data that were collected in 1998 (Table 5-3) shows that Baker County disposed of 815 tons of C&D waste (0.21 pcd), Bradford County disposed of 1,297 tons (0.28 pcd), and Union County disposed of 760 tons (0.31 pcd) (FDEP-A, B, F, 1999). A total of 2,872 tons of C&D waste were disposed in 1998, with 28% originating in Baker County, 45% from Bradford County, and 27% from Union County. No C&D waste was reported as recycled in any of the NRSWA counties for 1998.

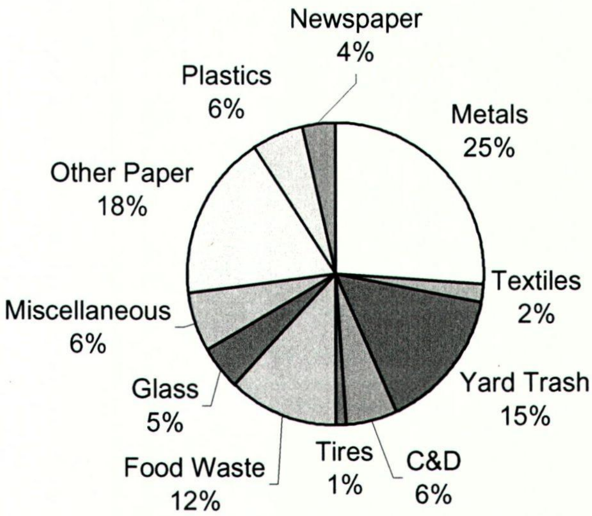


Figure 5-2 . Weighted average of MSW composition or Baker Bradford, and Union counties (1999 FDEP Solid Waste Management in Florida Annual Report).

Table 5-3. Amount of C&D waste handled by each C&D landfill in the NRSWA during 1998 (FDEP).

C&D Landfill	County of Origin	C&D Disposed (tons)	C&D Recycled (tons)
Baker	Baker	815	0
Bradford	Bradford	1,297	0
Union	Union	760	0
Total		2,872	0

PROJECT TIMELINE

Figure 5-3 presents a timeline of all major activities and milestones completed for the NRSWA IRG.

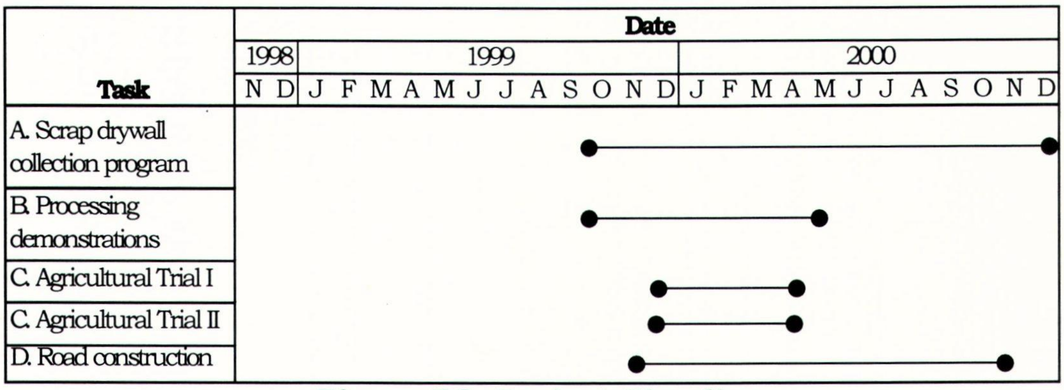


Figure 5-3. Project Timeline

SCRAP DRYWALL COLLECTION PROGRAM

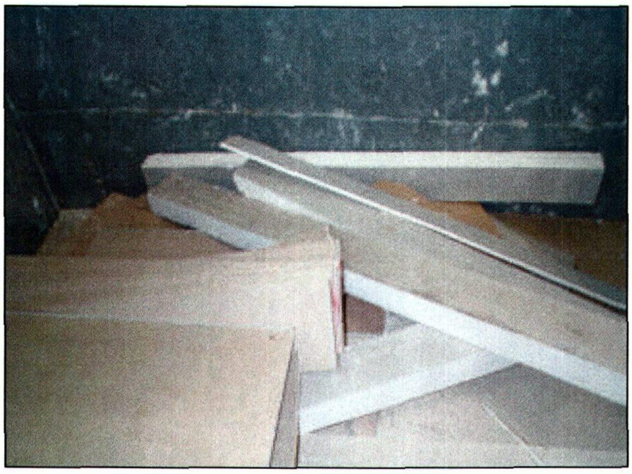
Two sources of discarded gypsum drywall supplied material for the processing demonstration and reuse projects. Drywall was separated from the incoming waste stream at the working face of the NRRL Class III cell. Since only a small amount of drywall was produced by new construction in the NRSWA counties, the majority of drywall was collected from Homes of Merit (HOM), a manufactured housing facility located in Lake City.

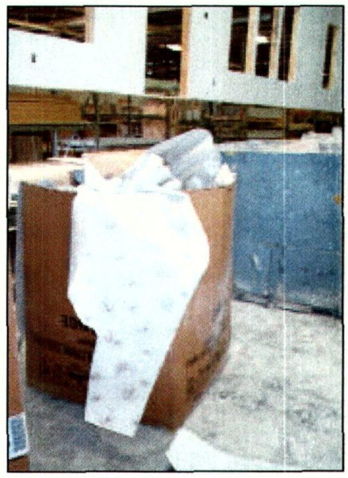
SEPARATION FROM NRRL CLASS III UNIT

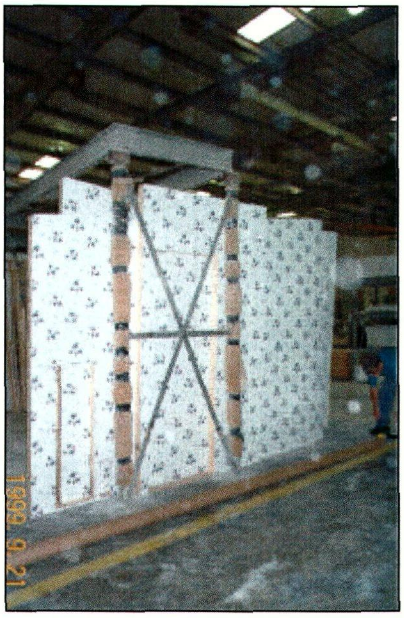
Approximately 19.7 tons of waste drywall was diverted from the NRRL Class III waste stream from over a period of ten months. Each load of incoming Class III waste was assessed on a case-by-case basis to determine if drywall recovery was feasible. Recovered drywall was placed in a 20 cubic yard roll-off container, weighed, and stored on site at the landfill.

COLLECTION FROM MANUFACTURED HOUSING FACILITY

HOM was chosen as the source of scrap drywall because it was known to be a major source of construction debris, including drywall. A review of existing drywall programs in the U.S. revealed that a concentrated source of drywall was preferred for recycling. HOM produces a relatively continuous stream of drywall waste daily, approximately 750 pounds or 0.375 tons per day (Billy Martin, personal communication, 2000). HOM recycles many of the construction materials used on site, including plastic, cardboard, lap siding (vinyl siding), and carpet padding. Prior to participating in the drywall recycling project, HOM deposited approximately two tons per week of scrap drywall in waste to the Class III landfill in Columbia County, where tipping fees were $28.00 per ton.







Clockwise from top left:

1) **Scrap drywall with paper backing removed**

2) **Vinyl backing that was removed by hand and stored in a receptacle at the manufactured housing plant**

3) **Drywall panel with vinyl backing attached**

A portion of drywall used at HOM for installation is manufactured with vinyl backing. Because the vinyl material is not acceptable for agricultural use, it is removed by hand prior to placing the drywall scrap into the 40 cubic yard roll-off container for collection. The HOM facility is located relatively close (approximately 31 miles) to the NRRL. Therefore, transportation of the material was less of a problem than if it had been located farther away. Collection started in December 1999 and continued until the end of the grant. A total of approximately 52 tons of drywall were collected from HOM during the ten-month period beginning in January 2000. This number does not represent all drywall collected from HOM over the ten month period because some loads were not taken to the NRRL, but disposed at the Columbia County landfill instead. The drywall loads disposed at the Columbia County landfill were done so because there is only a limited amount of trucks available from the NRRL for transport, and precedence was given to the routine pick-ups instead of the drywall. The 52 tons of drywall represents waste generated from the construction of approximately 157 manufactured homes. Collectively, HOM typically constructs around six homes per week at three plants in Lake City. Therefore, approximately 2 tons of scrap drywall are generated per week or 100 tons per year.

Dumping internal collection container from the plant into the 40yd roll-off container outside the plant (left) and view inside the roll (right).

PROCESSING DEMONSTRATIONS

Since all three IRG recipients required processing of gypsum drywall, some coordination of processing trials was considered prudent. The NRSWA and Citrus/Putnam counties collaborated on several of these trials. To avoid overlap in grant work, FDEP agreed that the NRSWA and Citrus and Putnam counties could work cooperatively since they are close in proximity to one another. Demonstrations were conducted in order to evaluate which system was optimal for processing waste drywall. The results of these demonstrations are summarized in Table 5-4.

Table 5-4. Processing Demonstrations

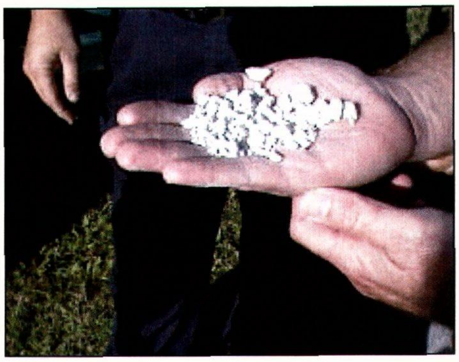
Demo name	Total unprocessed drywall (tons)[2]	Total processed drywall (tons)	Total waste (tons)[2]	% Losses[1,2]	% Gypsum Recovery[2]
New River chipper	2	0.5	2	2	2
Morbark	17.05	11.57	3.49	12%	68%
Ellington Construction	15.5	7.74	7.65	1%	50%

[1] **Losses due to wind and spillage; Loss = [total unprocessed drywall] - [(total processed drywall) + (waste)]** [2] **Data not available**

DRYWALL PROCESSING USING STANDARD WOOD CHIPPER

The first demonstration took place at the NRRL on October 29, 1999. Waste gypsum drywall that had been collected from various construction sites around Citrus County was transported to the NRRL by Citrus County because a source of drywall had not yet been selected by the NRSWA. A Bandit wood chipper, owned by the NRSWA, was used for processing. The wood chipper was able to reduce the size of the drywall. However, it was not capable of removing the paper backing which caused the chipped to become clogged. Paper was included in the end product, which is undesirable for most reuse purposes.

The Bandit wood chipper and collection container.



Drywall collected from residential construction sites for processing (left) and end product (right).

DRYWALL PROCESSING USING AGGREGATE SCREEN

The second demonstration took place on November 17, 1999 at Ellington Construction in Lake Butler, Florida. Scrap drywall that was collected from HOM was transported to Harlis R. Ellington Construction, Inc. for processing (Ellington). The machine used to process the drywall, an Extec Turbo, manufactured by Extec USA, Inc., is typically used by Ellington to sort various types of aggregate. The Extec Turbo was tested for processing drywall because it is designed to screen materials such as aggregates, soil, coal, and industrial and demolition waste. This equipment produced a small, pebble sized material with a recovery rate of 50%. A total of 7.74 tons of drywall was processed at this event. Some pieces of waste drywall were sent through the machine again because some gypsum was still attached to the paper backing. The entire processing event took approximately four hours. This included the time for reprocessing about 60 to 75% of the waste drywall to recover additional gypsum.

Waste drywall for processing (left) and the Extec Turbo aggregate screen (right).

DRYWALL PROCESSING USING A TROMMEL SCREEN

Upon learning that a trommel screen was processing drywall successfully at a plant located in Ohio, efforts were made to locate a trommel screen locally. Wood Resources Recovery (WRR) agreed to hold a "one-time" processing demonstration at their facility, located in Gainesville, Florida, on December 7, 1999.

The waste drywall for this demonstration was also collected from HOM. The vinyl backing was removed at HOM prior to placement in the collection container. The waste drywall was transported from the NRRL to Gainesville. The processing machine was a model PT 727 Trommel Screen manufactured by Morbark. The trommel screen was used because it is designed for high volume screening and sorting of various materials, including soils, yard waste, construction and demolition waste, and compost. The Morbark trommel screen produced a small, pebble-sized material and had a recovery rate of 68%. A total of 11.57 tons of drywall was processed at this event. The trommel screen processed material at a relatively rapid rate and appeared to efficiently separate gypsum from the paper backing.

The Morbark PT727 trommel screen used to process drywall at Wood Resources Recovery in Gainesville, Florida.

(Clockwise from top left). Drywall waste is loaded into the Morbark trommel screen; gypsum recovery material deposited into truck; and view of the two conveyors that separate paper and gypsum. Paper is on the conveyor is toward the back of the picture.

A fourth, and final, demonstration was held at the Citrus County Central Landfill in Lecanto, Florida on April 25, 2000. This demonstration was held in collaboration with Citrus County as part of the agreement to work cooperatively and avoid overlap between the two grants projects. Please refer to the processing section of Chapter 4 for a detailed explanation of the final processing demonstration.

SUMMARY OF PROCESSING EVENTS

The demonstrations provided insight about how to successfully process drywall. One lesson learned was that drywall does not necessarily need to be ground before screening. Drywall can be processed using only a trommel screen with a conveyor belt to separate the paper waste from processed drywall. The rotating action of the trommel screen is sufficient to pulverize the drywall, causing the core to separate from the backing. The fines fall through the mesh and the paper is carried to a separate pile via conveyor. This method was the most effective for the processing demonstrations held as part of the grant, and can been viewed as effective by the continued success of AgriCycle, Ltd.

As expected, a considerable amount of dust was produced at each of the processing demonstrations, but it was found that wetting the material prior to processing cut down on the dust considerably. Other options are to spray the material with water as it is being processed. It should be noted that permanent processing centers may be subjected to regulatory requirements to control dust, and that regular cleaning of processing equipment to remove fines is imperative to satisfactory operation.

Dust produced by the Morbark P-T27 trommel screen at the third processing event in Gainesville, Florida.

Dust produced by the Extec turbo aggregate screen at the processing event in Lake Butler, Florida.

AGRICULTURAL TRIALS

As mentioned previously, one of the reuse options for the scrap gypsum drywall was through land application as a soil amendment. Benefits of gypsum as a soil amendment can include an increase of sulfur and calcium concentrations in the soil, flocculate clay soils, and ameliorate sodic soils. This reuse option included choosing crops that would potentially benefit from the amendment, planning for the cultivation of crops, incorporation of the gypsum into the soil, and analysis and evaluation of the results of the study.

Reusing drywall as a soil amendment was a collaborative effort between the Baker County Cooperative Extension Service (a division of the University of Florida Institute of Food and Agricultural Sciences (IFAS) in Macclenny, Florida), the NRSWA, and the University of Florida. Two separate sites were chosen for the land application of gypsum drywall as a soils amendment. Agricultural Trial I took place at the Suwannee Valley Research and Education Center and Agricultural Trial II took place at the Baker County Extension Office. The evaluation performed by IFAS included yield data and quality assessment at the time of harvest. The NRSWA supplied the processed gypsum drywall that was separated from their class III incoming waste to be used for the soil amendment and the University of Florida assisted in expediting the harvests.

Agricultural Trial I

Agricultural Trial I took place near Live Oak, Florida at the Suwanee Valley Research and Education Center (SVREC), which is maintained by IFAS. Four crops were evaluated at the SVREC: Top Bunch collards, Bravo cabbage, Buttercrunch lettuce and China Blue Chinese cabbage. These crops were chosen because they are winter crops, have a short growing season, and are easy to harvest.

The field was prepared in Lakeland fine sand and the gypsum was applied by a drop spreader or by hand. Gypsum was applied at six treatment rates: 0, 1000, 2000, 5000, 10,000 and 20,000 pounds per acre (Table 5-5). Treatment rates up to 5,000 pounds per acre were applied by hand and treatment rates of 10,000 and 20,000 pounds per acre were applied using a poultry manure drop spreader.

Treatment rates applied by hand (left) and by poultry manure drop spreader (right).

Table 5-5. Application rates of Agricultural Trial I with respect to plot number.

Gypsum application rate (lbs/acre)	Amount of gypsum applied per plot (lbs)	Plot #'s (For all 4 crops)			
0	0	1	8	14	22
1,000	2.3	2	10	13	19
2,000	4.6	3	7	18	20
5,000	11.5	4	11	16	21
10,000	23.0	5	9	17	23
20,000	46.0	6	12	15	24

Plots were 20 feet in length and treatments were replicated four times for each crop, yielding a total of 96 plots. All crops were planted on December 28, 1999. Appropriate irrigation, insect, disease, and frost control measures were taken to ensure proper growth of the crops.

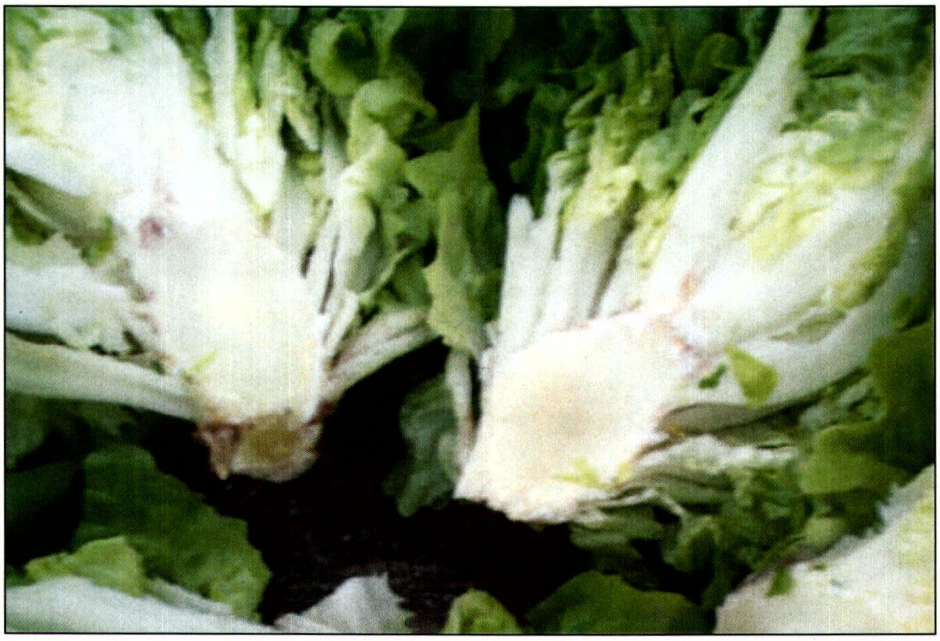
Planting crops. The rows were prepared prior to planting. Irrigation stips were laid under the plastic seen here, as well as pesticide.

Frost protection measures were taken by constructing a wire frame around the row, and placing a protective tarp (white material in left of picture) over the crops during frost conditions.

Plots were harvested on March 3, March 16, April 4, and April 11, 2000 for Bibb lettuce, Chinese cabbage, Bravo cabbage, and Top Bunch collards, respectively. Ten plants from the center of each plot were evaluated and weighed. Three plants from each plot were cut and observed for internal quality problems. Representative leaf samples from collard plants were taken for lab tissue analysis. The results of this analysis are presented in Appendix E.

Center of crop rows missing after harvest.

Normal Bibb lettuce heads (above) and some internal quality problems (below). Note the brown spots in the stalk, or white part, of the lettuce.



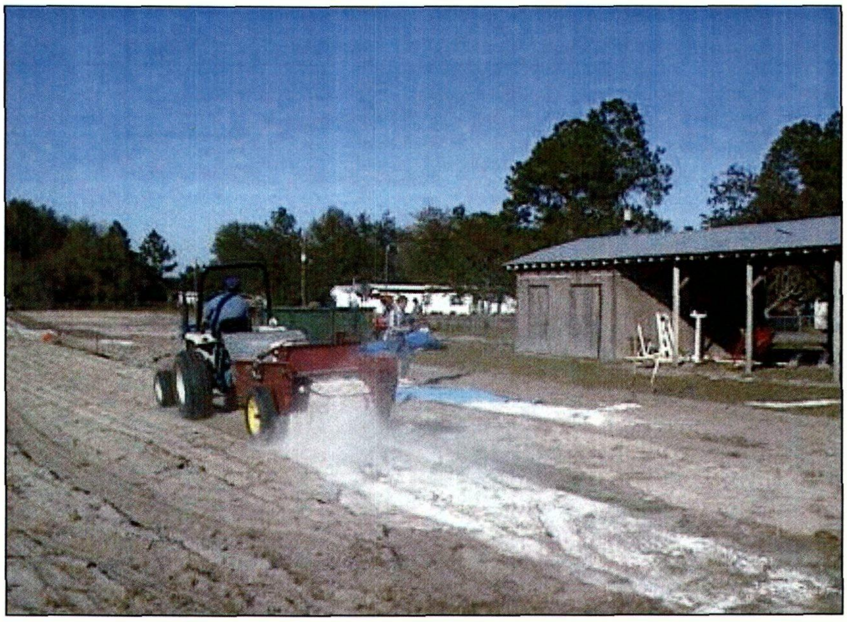
Results show that using scrap drywall as a soil amendment had little or no effect on crop yield and minimal effects on soil pH. In general, soil calcium was elevated for all application rates when compared the control.

Boron levels in tissue analysis of collard plants were elevated with respect to increasing gypsum rate application, but all boron levels were within plant sufficiency range. Evaluations of internal quality indicated some discoloration in ten heads of lettuce, but the discoloration was minimal and also found in heads that were grown in plots without gypsum. The detailed results of this study, which include yield data and a quality assessment at the time of harvest, are presented by the IFAS Baker County Cooperative Extension office and are included as Appendix E.

AGRICULTURAL TRIAL II

Agricultural Trial II took place at the IFAS Baker County Cooperative Extension office located in Macclenny, Florida. Several variations of five crops were evaluated at the Macclenny office: clover, ryegrass, wheat, rye and oats. These crops were also chosen because they are winter crops and have a short growing season. Unlike the quantitative research conducted at Live Oak, experiments conducted at the Macclenny site were for observational, or qualitative, purposes only.

The field was prepared in Albany fine sand and the gypsum was applied by a drop spreader or by hand. Gypsum was applied at rates of 0, 2000, 4000, 6000, 8000, 10,000 and 30,000 pounds per acre then disked to a depth of six inches (Table 5-6). The drop spreader was used for all application rates except 2,000 pounds per acre, which was broadcast by hand. Forage variety plots were established that measured 20 feet wide and 240 feet long on December 5, 1999. It should be noted that rainfall was below normal for the season and the plots flourished despite the limited rainfall, with some irrigation. Observational evaluations were held approximately every week during April 2000.



Spreading gypsum on field at IFAS Macclenny site.

Full view of the field at the Macclenny site.

Table 5-6. Crop types used in Agricultural Trial II.

Harrison Oats	AFC 20-20 Rye	Redland 3 Red Clover	Cherokee Red Clover
Chapman Oats	Wrens 96 Rye	Big Daddy Ryegrass	Rudolph Red Clover
Horizon Oats	GA89-482 Wheat	JumboRyegrass	Osceola White Clover
Wrens Abruzzi Rye	Fleming Wheat	Passerel Plus Ryegrass	Dixie Crimson Clover

It was concluded that the application of scrap drywall had little effect on crop production. Although some color and size differences were noticed during the growing season, none were noted at maturity. Phytotoxicity was noticed on Dixie Crimson Clover and Osceola White Clover with application of 30,000 pounds per acre of gypsum. The same varieties of clover with application rates of 10,000 pounds per acre of gypsum displayed no phytotoxicity problems. The results of this study, which include yield data and a quality assessment at the time of harvest, are presented by the IFAS Baker County Cooperative Extension office and are included as Appendix F.

Wheat at the IFAS Macclenny site in April 2000.

Dixie crimson clover cropri April 2000 at the IFAS Macclenny site.

Phytotoxicity observed on clover leaves with gypsum application of 30,000 pounds per acre.

RESULTS OF AGRICULTURAL TRIALS I AND II

It was found that processed gypsum drywall had little or no effect on crop yield for any of the crops evaluated in this study. Some internal quality problems were noted in ten lettuce heads; however, these symptoms were also noticed in heads grown in control plots with no gypsum. Boron levels in a portion of the collard plants increased with increasing rate of gypsum application. However, the increased Boron levels were within the acceptable range for the plants. Phytotoxicity was observed in two varieties of clover at the 30,000 pound per acre application rate. This was not noticed in varieties with application rates of 10,000 pounds per acre and below.

ROAD CONSTRUCTION

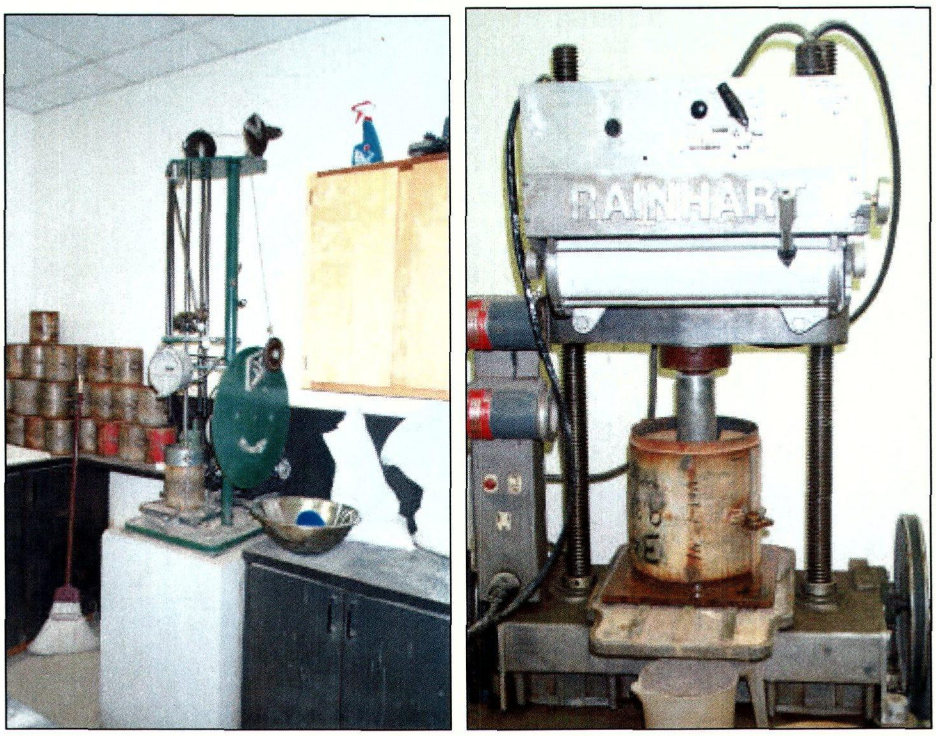
Drywall recycling was also facilitated through a road stabilization project at the New River Regional Landfill in Raiford, Florida. Stabilizing road base materials can result in improvement of strength of the road base, longevity of the road material, reduce routine maintenance requirements, reduce required thickness of pavement overlays, and reduce aggregate material loss for unpaved roads. The NRSWA road stabilization project was conducted on a service road constructed solely with on-site soils. The objectives of the road stabilization work included improving durability and reducing maintenance.

The NRSWA subcontracted Cal-Tech Testing (Cal-Tech), Inc. in Lake City, Florida to perform geotechnical tests on various mixtures of soil and drywall. Testing conducted by Cal-Tech included evaluation of the Plasticity Index of Soils (ASTM D-4318), Moisture Density Relationship (ASTM D1557), and Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures (LBR) (ASTM D 3668). Table 5-10 presents a description of the test methods used to evaluate processed gypsum drywall as a road stabilizer.

Table 5-10. Geotechnical tests performed on materials [illegible] in NRSWA road stabilization project.

ASTM Method	Description
D-4318 - Plasticity Index of Soils (Atterburg Limits)	The Atterburg Limits test determines the liquid limit (LL), plastic limit (PL) and the plasticity index (PI) of soils. LL - the water content (%) of soil at the arbitrarily defined boundary between the liquid and plastic states. PL - the water content (%) of the soil at a boundary between the plastic and brittle states. PI - the range of water content over which a soil behaves plastically. This is the numerical difference between the LL and PL. This method is used to characterize the fine-grained fraction of soils and to specify the fine-grained fraction of construction materials.
D 1557 – Moisture Density Relationship	This method was used to determine the compaction characteristics of soil using modified effort in the laboratory. This test method is used to determine the relationship between water content and dry unit weight of soils, essentially, a compaction curve, compacted in a 4- or 6-inch diameter mold with a 10-lbf rammer dropped from a height of 18 inches producing a compactive effort of 56,000 ft-lbf/ft^3.
D 3668 – Bearing Ratio of Compacted Soil-Lime mixtures in the Laboratory	This test method is used to determine the bearing ratio of soil-lime mixtures when compacted and tested in the laboratory by comparing the penetration load of the soil-lime mixture to that of a standard material.

Molds with soil and drywall mixtures in the LBR tank at Cedch in Lake City, Florida.



Compacting (left) and penetrating (right) samples with soil and drywall to determine the bearing ratio of the mixtures.

According to the Florida Department of Transportation (FDOT), material for use in the construction of a stabilized subgrade requires a minimum LBR value of 40 (FDOT 2000). Scrap gypsum drywall, when mixed at 20% with a poorly graded sand, exceeded the standard for purposes of creating a stabilized subgrade. Even though it exceeded the standards, scrap gypsum drywall was applied to a "light-traffic" access road at the NRRL, which is not required to meet FDOT standards for primary roads. Table 5-11 summarizes the results of the geotechnical tests performed on the soil and soil/gypsum mixtures.

Table 5-11. Results ofpreliminary geotechnical tests for road stabilization project

Material Description	LBR Value	Max. Dry Density (lbs/ft^3)	Optimum Moisture (%)	Liquid Limits	Plastic Limits	Plastic Index
Sample #1 Virgin soil	49	119.1	14.4	39	16	23
Sample #2 Virgin soil	41	121.1	13.3	36	16	20
Sample #3 Virgin soil	50	122.6	11.5	32	13	19
Sample #1 10% gypsum	59	115.5	12.5	33	16	17
Sample #2 20% gypsum	50	112.1	12.1	37	19	18
Sample #3 30% gypsum	26	95.3	13.2	42	22	20

It should be noted that blends of soil and gypsum for LBR testing were blended using nominal maximum size ¾-inch square cut pieces with paper included. Blends of soil and gypsum for Plasticity Index tests were blended using gypsum without paper, using only material passing a no. 40 sieve. Plasticity index tests were a composite blend of clayey soil from two locations and gypsum. The mixing ratio of soil and drywall was found to be optimal at 20% drywall (dry weight). Using a mixing depth of six inches, approximately 10.7 tons of gypsum drywall was needed for a 139-foot section of road, 18 feet wide.

An existing road at the NRRL, previously constructed solely with on-site soils, was used to evaluate waste gypsum drywall for road stabilization. The road was moistened, disked and tilled on October 21, 2000 to prepare for drywall application. Two truckloads of drywall were weighed and placed on the road on October 24, 2000. A D-6 Bulldozer was used to spread the piles of drywall over the entire area, approximately 2500 square feet. There were six sections to the road and each section was 139 feet long by 18 feet wide. Weather conditions during drywall application included light rain and low wind. There was a minimal amount of dust created during this event. Waste drywall will continue to be added to the road periodically. In-place test results including density, pH and LBR are provided in Table 5-12.

Table 5-12. Results of geotechnical tests on road at NRRL following application of drywall

Material Description	LBR Value	Maximum Dry Density (lbs/ft^3)	Optimum Moisture (%)
Sample #1 20% gypsum	43	110.4	14.5
Sample #2 20% gypsum	58	116.4	15.2

Table 5-13. Results of pH tests on road sections at NRRL following application of drywall

Road Section	Average pH
1	5.3
2	5.5
3	6.4
4	5.6
5	5.8
6	6.1
Overall average:	5.8

Spreading drywall onto road at the New River Regional Landfill (NRRL) in Raiford, Florida.

Tilling drywall into the road at the NRRL.

Road with drywall at the NRRL (January 26, 2001).

SUMMARY AND CONCLUSIONS OF NEW RIVER SOLID WASTE ASSOCIATION IRG

Processed scrap gypsum drywall was evaluated as an agricultural soil amendment and as a material for road stabilization as part of an IRG awarded by the FDEP to study gypsum drywall recycling. Recycling efforts took place in several forms, including:

- Collecting drywall waste from a local manufactured housing plant
- Holding several demonstrations to evaluate the best technology available for processing drywall
- Using drywall as a soil amendment for crops
- Using drywall as a material for road stabilization

The efforts described above are considered successful because they were found to be effective uses of processed gypsum drywall waste and diverted the waste from disposal at the landfill. Collection of waste drywall from the manufactured housing plant resulted in disposal fee savings while providing benefits to those receiving the product. The agricultural studies showed that processed gypsum drywall waste was a had little to no effect on crop yield for Bibb Lettuce, Chinese cabbage, Bravo cabbage, and Top Bunch collards, and minimal effects on soil pH. It is needed in Florida to compensate for soils that may be lacking essential macronutrients such as calcium and sulfur, or those that have been weathered and disperse easily. The processing demonstrations displayed a new, effective technology, because there were no prior efforts to recycle drywall in the state.

Gypsum drywall was found to be a suitable material for stabilizing road base. It provided a firm, unyielding subgrade and exceeded the FDOT required bearing value. Since scrap gypsum drywall was only tested on a road with limited traffic, it is not possible to determine whether this material could be used for stabilizing primary roads. Further investigation is required in order to establish uses of scrap gypsum drywall for roads other than those tested in this project.

Drywall recycling is technically feasible for the NRSWA; however, several factors should be further investigated in order to better evaluate its feasibility. There is not enough drywall waste generated in these counties from new construction, aside from the manufactured housing plant, to maintain a constant supply of waste for processing. The manufactured housing plant would need to serve as the sole supplier of the waste if a drywall recycling plant were to open in the area. Therefore, further exploration of the manufactured housing plant industry needs to be carried out to evaluate this possibility. There is an abundant amount of farmland in North Central Florida where crops that can benefit from gypsum are grown. Therefore, an end market for the processed gypsum drywall exists in this area. A farmer in Lake Park, Georgia sold agricultural gypsum to growers of peanuts, peppers, tomatoes, green beans, cucumbers, and carrots in North and North Central Florida last year. These crops could serve as a potential market for processed gypsum drywall as well.

Neighboring counties such as Suwanee, Levy, Alachua, and Columbia are all among the top ten peanut-producing counties in the state. All peanut farmers must apply some form of gypsum to ensure proper pod development. Collectively, these counties harvested over 16,000 acres of peanuts in 1998, with an estimated value of $9,780,000. If processed gypsum drywall were applied at 0.5 ton per acre, approximately 8,000 tons per year of processed drywall could be used for peanut crops in Suwanee, Alachua and Columbia Counties. Since the manufactured housing plant produces about 100 tons of drywall waste per year, all of the processed drywall could be applied to the crops in the area.

Particle size is another important issue in processing drywall. The processed material may take many forms, depending on the type of equipment used. Drywall waste essentially turned into a powder with paper commingled in it when the material was ground up during processing. It took a pellet-like form when it was processed with a trommel screen. Either material is suitable as an end product, but should be marketed accordingly. For example, agricultural gypsum is sold either as a powdery material that is somewhat wet for large applications and as a pellet for smaller applications. Using the right mesh size when processing is the solution to particle size. A mesh size of

¾-inch should be used for small, pellet-like material, but there will be some powdery material associated with it as well.

Initially, it was thought that drywall needed to be ground up and then screened to remove the paper. However, it was discovered that pre-processing was not needed. Drywall can be effectively processed using only a trommel screen to pulverize the drywall and separate the end products. A conveyor belt within the trommel is used to carry the paper waste to a separate pile than the fines. A private company, using similar equipment with modifications to better suit their end users, has proven this method to be effective. Processing methods may require adjustments to suit individual end use requirements. This can be accomplished by purchasing equipment or finding a processor to do the job.

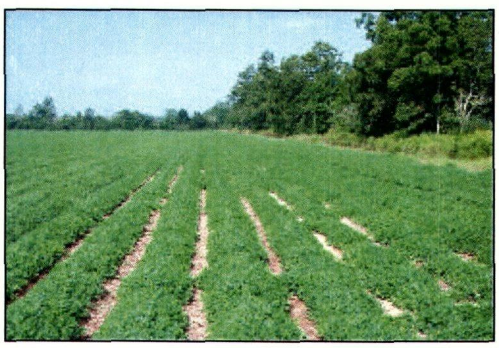
Drywall recycling is considered feasible in the NRSWA due to the successful demonstration of processing technology and the availability of end use markets. However, currently there is not a significant source of drywall waste generated in these counties due to low construction activity. This impacts the feasibility of drywall recycling because there would not be enough material to sustain continuous processing.

CHAPTER 6
OKALOOSA IRG

PROJECT OBJECTIVES

The Okaloosa County IRG involved the implementation of an innovative composting process that included drywall as an ingredient. Okaloosa County selected composting for several reasons. First, Eglin Air Force Base (EAFB), a major landowner in the county, had previously purchased an in-vessel composting system that was equipped to handle both food waste and yard waste generated on the base. EAFB had participated with the County on waste issues in the past and was aggressive in its approach to waste reduction and recycling. Second, Okaloosa County is home to many acres of peanut farms. Since farmers commonly apply gypsum to peanut crops, using gypsum as a compost ingredient provided a means to produce compost with a ready market in the County. The fact that EAFB employed an in-vessel composting system helped alleviate concerns of possible odors.

Okaloosa County involved EAFB and the Okaloosa County Extension Office of the Institute of Food and Agricultural Sciences (IFAS) in their efforts (Table 6-1). This program evaluated both in-vessel and traditional windrow composting methods for drywall, wood waste, and yard waste collected in Okaloosa County. Yard waste, food waste, and nitrogen were mixed with processed drywall for the in-vessel experiment. No food waste was added to the compost mix during the windrow process. The in-vessel method utilized an AgBag system, and involved composting in a contained, controlled environment as opposed to the traditional windrow method. The compost mix was provided for free to peanut farmers in Okaloosa County. Prior to this study, no major efforts involving composting drywall had been performed in Florida. Table 6-1 outlines the major tasks for this project.



Peanut farm in Okaloosa County (left), peanut crop grown with gypsum amended compost (right).

Table 6-1. Major Project Tasks in Okaloosa IRG

Task	Description
A. Scrap drywall collection program	Scrap drywall was collected with a focus on commercial sites. A collection program was established by contacting contractors and waste haulers in the area to solicit support for the project.
B. Processing	Processing of the drywall and compost took place in a tub grinder at the Wright Composting Facility.
E. AgBag composting	AgBag was contracted to demonstrate a new composting technology and assist with the harvesting. The AgBag windrow was harvested and screened approximately 8 weeks after being placed in AgBag. Gas samples were taken to document any possible odor production resulting from the incorporation of gypsum drywall.
C. Windrow Composting	The drywall was mixed with food/wood waste compost. The county worked with the Okaloosa County IFAS Extension office on this effort as well as the Wright Composting Facility.
D. Compost donated to peanut farm	The compost mixture was given to a local peanut farmer and applied to the crop to replace the use of agricultural gypsum.

DESCRIPTION OF OKALOOSA COUNTY

LOCATION AND POPULATION

Okaloosa County is located in Northwest Florida (Figure 6-1). The population as of April 1998 was 175,568 (BEBR, 1999). The largest cities in Okaloosa County are Crestview, Niceville, and Ft. Walton Beach. The largest employer in Okaloosa County is EAFB. Since the military is such a dominant employer in the county, a great deal of technology-based firms located here including Lockheed-Martin, Boeing, and Raytheon. The tourism industry also serves as a major employer, since Okaloosa County is part of the "Emerald Coast" of northwest Florida.

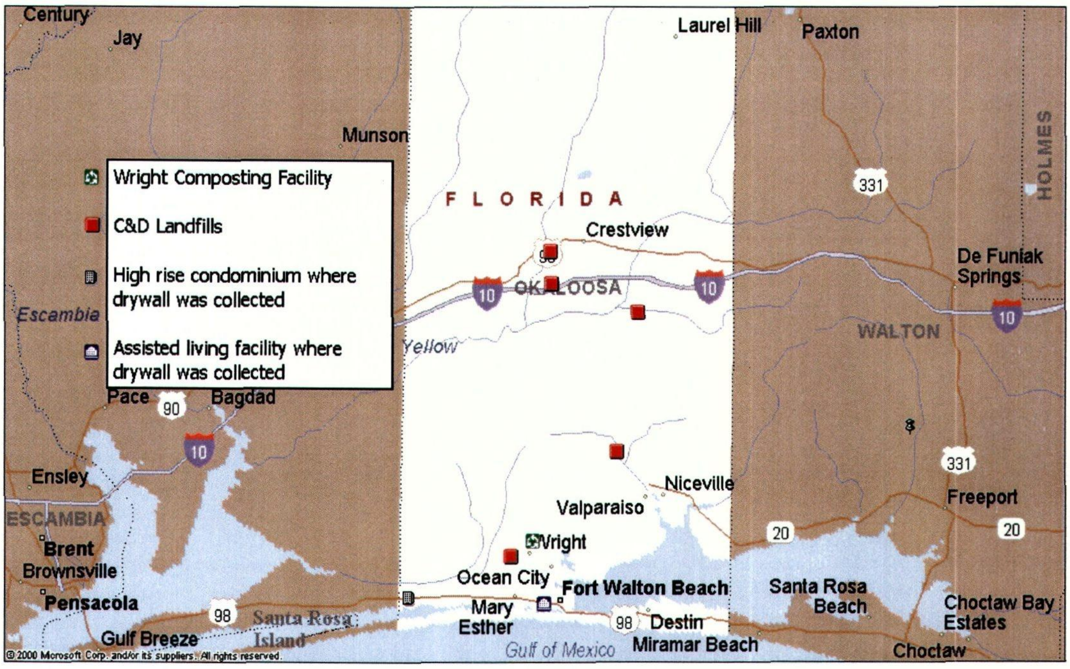


Figure 6-1. Map of Okaloosa County, Florida

New residential construction data were collected to evaluate how much drywall waste was generated in the county. Okaloosa County is very active with respect to residential construction, ranking 20th in the state in 1998 (BEBR, 1999). Okaloosa County also had more large residential construction projects than the other counties that received grants to study drywall recycling. There were a total of 1095 residential building permits issued in Okaloosa County in 1999. As of September 2000 (most recent data available), 424 residential building permits had been issued for the county. It was estimated that 970 tons, or 1,940,000 pounds, of drywall were produced from new residential construction in Okaloosa County in 1999. This estimate was made using methods outlined in Chapter 7 (Figure 7-1).Cumulative year-to-date and annual 1999 new residential construction statistics are presented in Table 6-2.

Table 6-2. New privately owned residenti building permits issued for Okaloosa County, FL (U.S. Census Bureau, 1999).

	Cumulative yearto-date			Annual 1999		
Item	**Buildings**	**Units**	**Construction Cost ($)**	**Buildings**	**Units**	**Construction Cost ($)**
Single Family	419	419	47,314,823	914	914	75,467,729
Two Family	1	2	67,140	2	4	185,920
Three and Four Family	3	11	661,590	4	13	440,000
Five or More Family	1	41	1,482,270	8	164	10,562,490
Total	424	473	49,525,823	928	1,095	86,656,139

SOLID WASTE MANAGEMENT

At the time of this work, Okaloosa County had no active MSW landfills. The 165,000 tons per year of MSW generated in Okaloosa County is transported to Jackson County's Spring Hill Landfill for disposal. Figure 6-2 presents the composition of MSW (including C&D waste) for Okaloosa County in 1997 (FDEP-G 1999). The amount of C&D waste reported in Okaloosa County in 1997 was 41,215tons, or 1.32 pounds per capita per day (pcd). While data from 1997 was only reported by the county (including data reported by the private C&D facilities to the county), recently released 1998 estimates are believed to be more accurate. The 1998 data includes waste amounts reported directly to the FDEP by private facilities as a result of a new rule requirement. The data that was collected in 1998 (Table 6-3) shows that Okaloosa County disposed of 55,025 tons of C&D waste (1.72 pcd) (FDEP-D 1999). Of this waste, 8% originated in Escambia County, and the remaining 92% originated in Okaloosa County. C&D waste reported as recycled in Okaloosa County for 1998 totaled 23,564 tons. There are five permitted C&D landfills in Okaloosa County. They are Eglin Air Force Base, Waste Recyclers of North Florida, Charles Lingenfelter C&D, Kevin Jernigan C&D Landfill, and Point Center. Tipping fees at these facilities average around $2.16/yd^3$, or $65.00 per 30 cubic yard roll-off container.

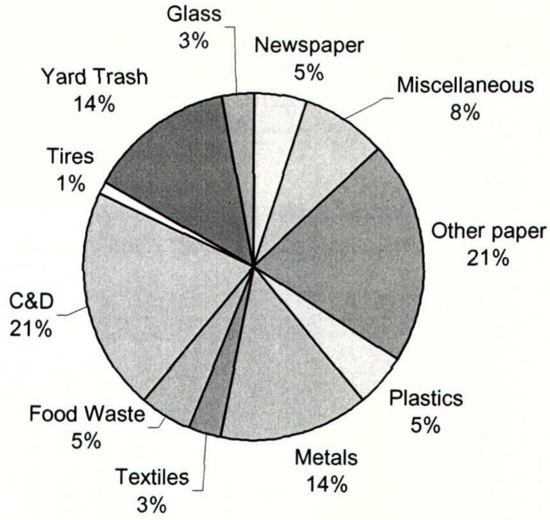


Figure 6-2. Okaloosa County MSW Composition in 1998 (FDEP 1999)

Table 6-3. Amount of C&D waste handled by each C&D landfill in Okaloosa County in 1998 (FDEP 1999)

C&D Landfill	County of Origin	Amount of C&D Disposed	Amount of C&D Recycled
Charles Lingenfelter C&D/ Arena Rd.	Escambia	470	0
Charles Lingenfelter C&D/ Arena Rd.	Okaloosa	3,183	0
Eglin AFB, Florida	Okaloosa	408	0
Kevin Jernigan C & D Landfill, Inc./K&K Const.	Okaloosa	22,811	0
County	Okaloosa	0	21,918
Point Center	Okaloosa	17,821	0
Waste Recyclers of North America (Crestview)	Okaloosa	10,332	1,646

PROCESSING

Since all three IRG recipients required processing of gypsum drywall, some coordination of processing trials was necessary. The NRSWA and Citrus/Putnam counties collaborated on several of these trials. The reader is referred to the processing section of Chapter 5 for an explanation of the first three processing demonstrations and to the processing section of Chapter 4 for a description of the final processing demonstration. Okaloosa County is located in the northwest part of the state, and was not focused on the same objectives as the other two grant recipients; therefore, they were not involved with work done by the other counties.

Two primary options were discussed for processing the scrap drywall that was collected as part of the Okaloosa County IRG:

- Utilization of Okaloosa County's Morbark 1300 tub grinder located at the Wright Landfill, and

- Contracting a third party processor to transport their mobile processing equipment to the Wright Landfill

Morbark tub grinder used to process scrap drywall at the Wright Composting Facility in Okaloosa County, Florida.

The third party processor, AgriCycle, Ltd., was identified during their drywall recycling work with Citrus County. AgriCycle performed the final processing demonstration that was discussed in the processing section of Chapter 4.

Because the quality (e.g. particle size, paper content, etc.) of recycled wallboard for composting applications is not as important as for that of industrial end uses such as cement manufacturing, the decision was made to utilize the County's tub grinder versus hiring an outside contractor. The quality is not as important for agricultural applications because paper content will not affect machinery or quality of the end product. In additon, the paper will degrade to some extent in the composting process and additional size reduction of the gypsums will occur during compost processing. However, the drywall should be size reduced so that the material is easy to apply to crops and so that it can disperse well in the soil. For example, a pebble has a higher surface to volume ratio than a large mass of material and would dissolve more quickly and evenly.

Drywall processing occurred at the Wright Landfill on two separate occasions. During the first processing event, recycled drywall was processed, and then co-composted with ground yard waste, food waste, and nitrogen utilizing the Ag Bag in-vessel composting system. Approximately ten tons of scrap drywall was processed during this event. The grapple included on the County's tub grinder was used to load the scrap drywall that had been stored on a compacted clay pad at the Wright Landfill. Materials were processed at a rate of 10 tons per hour using a ¼-inch mesh screen. The second processing event also took place at the Wright Landfill. The same procedures were followed, but no food waste was added and a traditional windrow system was employed instead of the AgBag.

AGBAG COMPOSTING

Yard waste, nitrogen fertilizer, food waste, and drywall were used in the compost mix. Approximately 50,000 pounds of wood waste was used in the process. The wood waste was primarily chipped wood waste consisting of tree trimmings and brush from roadside clearing operations that was supplied by Asplund Tree Services. The yard waste was spread over an area to a uniform depth of eight to twelve inches and water was then applied to attain a moisture content of approximately 50 percent. This also allowed for a more uniform mixing of the other materials with the wood waste by maximizing the surface area.

Nitrogen fertilizer ("Ammo-Nite") with nutrient value of 34-0-0, N-P-K, was then hand broadcast over the yard waste to provide a nitrogen source to generate a more favorable carbon to nitrogen ratio for the decomposition process. "Ammo-Nite" is an ammonium nitrate fertilizer that consists of 17 percent ammoniacal nitrogen and 17 percent nitrate nitrogen, with a total value of 34 percent. Thirty 50-pound bags of inorganic nitrogen were added due to the high carbon content of the woody waste, providing approximately 510 pounds of inorganic nitrogen to the mix. The nitrogen addition provided the mix with a 98 to 1 ratio of carbon to nitrogen on a weighted basis.

Approximately 2,000 pounds of food waste was spread over a portion of the woody waste and nitrogen mix with a front-end loader. Eglin Air Force Base's commissary supplied the food waste, which consisted mainly of fruit and vegetable cores. These cores were rejected produce items such as broccoli, pineapples, apples, lettuce, and tomatoes. The food waste was run over with a front-end loader to rupture and reduce the size of the food material. Only unused portions of the fruits and vegetables were used, meaning no "table waste" was included. Food waste was added to the wood waste to add nutrients and speed up the composting process. Only about one-third of the entire mix had food waste added given the limited amount of food waste available for demonstration.

Food waste that was added to the AgBag system

The processed drywall (19,000 pounds) was placed on the ground and mixed with the 50,000 pounds of yard waste, 2,000 pounds of food waste, 6,500 gallons of water, and 2,000 pounds of nitrogen fertilizer using a front-end loader. At this point, the mixture was ready to be loaded into the Ag Bag system. The mixture was not a planned "recipe"; however, it is recommended that if the process were repeated over a longer period of time, a recipe should be created to ensure consistency in the mixture. The composition, or "recipe", of the AgBag mixture is presented in Table 6-4. Table 6-5 presents the results of the gypsum analysis on the AgBag at the time of harvest.

Table 6-4. Composition of AgBag and windrow compost mixtures.

Compost type	Yard waste (lbs)	Drywall (lbs)	Food waste (lbs)	Nitrogen (lbs)	Water (gal)
AgBag (Event #1)	50,000	19,000	2,000	2,000	6,500
Windrow (Event #2)	50,000	19,000	0	4,000	6,500

Table 6-5. Average results of gypsum analysis for AgBag compost at time of harvest.

Sulfate Concentration (mg/L)	Moisture Content (%)	Lb gypsum/ lb wet compost	Lb gypsum/lb dry compost
1665	29.6	0.030	0.042

The mixture was then fed into the AgBag Environmental CT-5 compost system in the following manner: A specially manufactured polyethylene bag (AgBag) was fitted onto a mobile in-feed hopper unit. Tubing to blow air into the bag is also attached to the mobile unit (and remains in the bag throughout the length of the pod). Front-end loaders belonging to Okaloosa County dropped loads of the compost mixture into the in-feed hopper. From the hopper, the compost mixture was fed into the AgBag. As the bag fills, the mobile AgBag unit slowly moves away from the bag. The final length of the AgBag was approximately 135 feet. The AgBag has a diameter of five feet, meaning an estimated 125 cubic yards of mixed material was placed into the AgBag. The density of the material in the pod was estimated to be approximately 400 pounds per cubic yard.

Feeding compost mixture into the AgBag (left) and AgBag virtually full (right).

The Ag Bag compost was harvested on May 26, 2000 approximately ten weeks after it was mixed and placed into the AgBag. The compost had not completely decomposed at this point, and large pieces of wood remained in the product. Figure 6-4 presents temperature data for both the AgBag and windrow compost systems over a period of 81 days. Temperatures for the AgBag ranged from 94°C to 132°C, and 83°C to 126°C for the windrow.

Approximately half of the compost product was screened using a mobile screening unit with a ¼-inch screen. An AgBag brochure entitled "Composting Made Simple" is attached as Appendix G for more information on this process.

WINDROW COMPOSTING

During the second processing event on April 20, 2000, a traditional compost windrow was formed. Windrow composting typically involves mixing dewatered sludge with a bulking agent and stacking the mixture in rows that are referred to as windrows (Bitton, 1994). The drywall grinding and mixing occurred in much the same manner as it occurred during the first processing event. However, nearly twice as much nitrogen fertilizer (approximately 4,000 pounds) was added to the compost mixture to speed decomposition and no food waste was added. Food waste was not added to the windrow because it was not available at that time. The windrow that was constructed was approximately 60 feet in length, ten feet high, and eight feet wide.

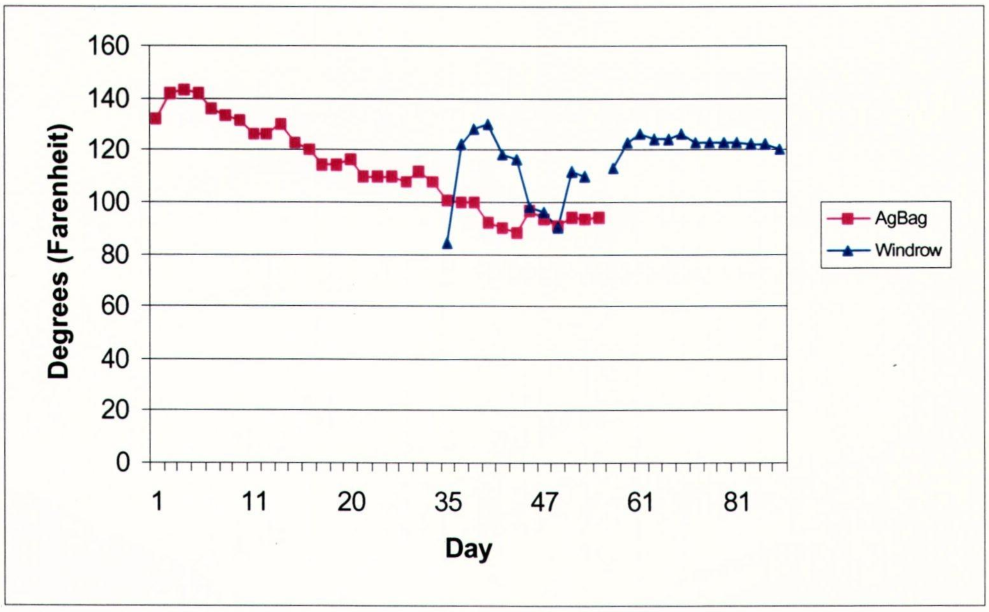


Figure 6-4. Temperature data for AgBag and windrow compost systems.

Unscreened compost (left) and closeup of pile (right) at the Wright Composting Facility in Okaloosa County, Florida. Pieces of gypsum (white flecks) can be seen in the compost.

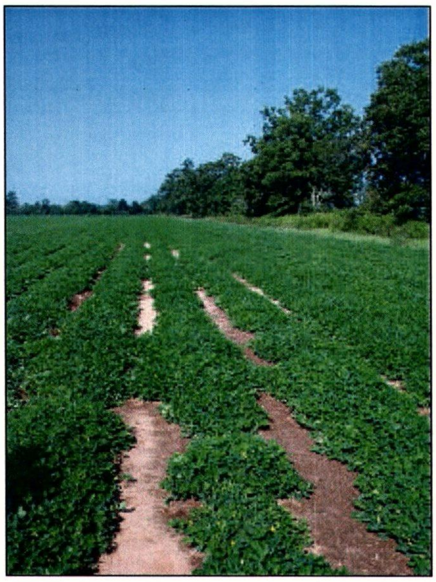
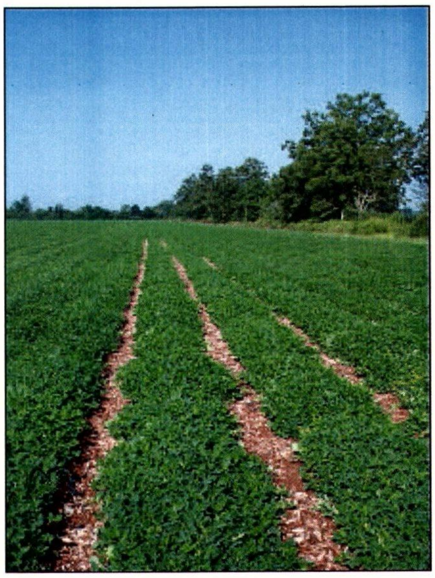
COMPOST DONATED TO PEANUT FARM

Screened and unscreened compost material was delivered to Greg Evers. Mr. Evers is a Baker, Florida farmer who grows peanuts, cotton, and hay. He was approached by Gerald Edmondson, an Okaloosa County extension agent, to participate in the project, and received the gypsum for free in return. He farms as well as owns and operates a local farm supply store that serves the Baker, Florida area. The agricultural gypsum that Mr. Evers typically buys and sells is produced by PCS Phosphate and is called "Land Plaster". He typically applies 600-1000 pounds per acre to peanut crops, which is broadcast with a fertilizer spreader approximately 50 days after planting.

The agricultural gypsum is sold and delivered in bulk for about $48 per ton to local peanut farmers. Prices range from $7 to $25 per ton from the distributor, depending on transportation costs, which are high if the material is hauled over long distances. Land Plaster is the main product sold to customers in the area who are predominantly peanut farmers. Peanut farmers use a fertilizer spreader to apply it. The pelletized form of agricultural gypsum is also utilized, but it is used mostly by homeowners and not as a commercial product for farmers.

Mr. Evers worked with staff from the University of Florida's Institute of Food and Agricultural Sciences (IFAS) Okaloosa Extension Office when the time came to apply the compost material prior to planting the peanuts. The compost was tilled into the soil prior to planting. Three different test plots of Southern runner peanuts were planted on June 23, 2000. The test plots were planted as follows:

- A control plot with no compost or gypsum;
- A test plot using the screened compost material; and
- A test plot using the unscreened compost material

Peanut crop with screened (left) and unscreened (right) compost. Note the large pieces of wood remaining in the unscreened compost.

Each of these plots took approximately 150 days to mature, and were harvested on November 28, 2000. IFAS was responsible for measuring the peanut yield from each of these three plots to determine the benefit of the using the gypsum compost product. Table 6-6 presents yield data taken from the peanut crops with gypsum-amended compost. The screened and unscreened gypsum-amended compost did not increase the yield above that of the control plot. However, since the trials were not replicated, it is inappropriate to say whether the plots amended with compost did not benefit from this addition. Soil samples were also taken from the test plots and these results are presented in Table 6-7. The addition of gypsum-amended compost increased soil calcium considerably, lowered pH, and increased soil phosphorous and potassium levels at a 6-inch mix depth.

Table 6-6. Results of yield samples taken from peanut plots.

Compost type	Weight (lbs per acre)
Control	3207
Screened	2886
Unscreened	3176

Table 6-7. Results of soil samples taken from peanut plots.

Sample	pH	P (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)
Control	6.6	42	45	147	724
3" depth	6.3	37	42	58	4264
6" depth	6.3	50	57	96	4272

SUMMARY AND CONCLUSIONS OF OKALOOSA COUNTY IRG

Processed scrap gypsum drywall was evaluated as an ingredient in compost as part of an IRG awarded by the FDEP to study gypsum drywall recycling. Recycling efforts took place in several forms, including:

- Collecting drywall waste from two large residential construction sites;
- Processing drywall and compost using a tub grinder; and
- Using drywall as an ingredient in both in-vessel and windrow composting

These efforts were successful due to the fact that they demonstrated a new technology for recycling drywall waste, and diverted the waste from landfill disposal. Collection of waste drywall from the construction sites alleviated disposal fees and utilized the material for agricultural purposes. The composting trials showed that processed gypsum drywall waste was a suitable material to add to compost. No odors were detected due to the addition of drywall. Processing gypsum with food and wood waste for compost displayed a new, effective technology, because there were no prior efforts to recycle drywall in the state.

Drywall recycling is feasible for Okaloosa County; however, there are several factors that should be addressed in order to maintain it. There is enough drywall waste generated in this county from new construction to maintain a constant supply of waste for processing (See drywall waste generation estimates in Chapter 7). However, cooperation from participants throughout the construction, waste management, and agricultural industries is needed to sustain the practice. The main participants whose support is required in this endeavor include:

- drywall and general contractors contractors;
- waste haulers;
- landfill operators;
- county agricultural extension agents; and
- farmers.

Drywall and general contractors must be willing to participate in the separation of drywall at the construction site. Options for drywall separation were evaluated on an economic basis as part of the Citrus and Putnam County IRG. The reader is referred to Appendix H for a detailed description of all separation options. The "best-case" scenario was found to be separation of drywall in a pile at some location on the construction site, facilitated by the drywall contractor. A third party hauler would pick up the drywall waste and deliver it to the recycling facility. This step in the process is critical, since the distance from the construction site to the processing site cannot be too great, as this will offset revenues for the hauler. The recycling facility could be located at the landfill, where processing and/or composting would take place. Agricultural extension agents are then needed to educate farmers about the benefits of using the compost or processed gypsum drywall waste on their crops. Farmers serve as facilitators of the entire process by providing a market that uses the product as a soil amendment and source of calcium and sulfur for crops.

Processing drywall waste in conjunction with composting was found to be ineffective from an economic standpoint and therefore, not a feasible practice for Okaloosa County to continue. However, processing drywall only instead of the compost/drywall mixture seems to be a better alternative. Since it appears that land applying processed gypsum drywall is advantageous to crops that need calcium, it should be applied directly to the crops or with screened compost instead of applied with unscreened compost. This is due to difficulty in harvesting the peanuts with unscreened compost applied. It is hard to say whether or not the gypsum-amended compost increased or decreased the yield because the trials were not replicated. However, the plots did maintain a noticeably darker green color than the control plots throughout the growing season. This color difference was also noted in the observational study done on forage crops by IFAS's Baker County Extension Office. This experiment is discussed in detail in Appendix F.

Overall, gypsum-amended compost was found to be a suitable peanut crop amendment if screened to a fine texture. Compost that was not screened was found to be difficult to work with at the time of harvest because of large chunks of wood. The common opinion of those who participated in this project is that processed gypsum drywall is beneficial to crops and certainly has a market in Okaloosa County. However, it should be marketed alone and not mixed with compost unless screened to a very fine material.

CHAPTER 7
ASSESSMENT OF GYPSUM DRYWALL RECYCLING FEASIBILITY IN FLORIDA

INTRODUCTION

Previous chapters examined background information regarding the recycling of gypsum drywall and discussed three specific efforts conducted to explore the feasibility of instituting drywall recycling in Florida. This chapter builds on the information gathered, assesses the potential for sustainable drywall recycling in the state, and discusses obstacles that must be overcome. The following issues are explored in greater detail.

- The amount of gypsum drywall from new construction potentially available.
- The markets available in the state.
- Issues regarding the processing and collection of drywall.
- Actions for encouraging or requiring drywall recycling.

QUANTIFYING THE AMOUNT OF DRYWALL WASTE IN FLORIDA

One major question that must be answered as part of assessing gypsum drywall recycling in Florida is, "How much scrap gypsum from new construction is potentially available?" This information is important to determine the following:

- Does gypsum drywall represent a significantly large fraction of the waste stream to target?
- Is scrap drywall produced in large enough quantities to sustain markets?
- Are the existing markets capable of accepting the amount of drywall scrap produced?

The amount of gypsum drywall in Florida's waste stream has not been previously defined. While such an effort is currently underway by the authors (scheduled for completion in August 2000), a preliminary waste estimate is provided here for discussion and planning purposes. A simple estimate of the amount of gypsum drywall produced in Florida can be determined using construction data for the state. The equation used here is as follows:

$$\sum_{n=1}^{5+}[(House_n)(\frac{ft^2}{House_n})(\frac{lbs\ drywall}{ft^2})(\frac{ton}{lb})] \text{ where, (Eqn. 7-1)}$$

$House_1$ = number of 1-unit homes,

$House_2$ = number of 2-unit homes,

$House_{3,4}$ = number of 3 and 4-unit homes, and

$House_{5+}$ = number of structures with 5 units or more.

The estimated amount of drywall waste produced in Florida for 1999 based on new residential building permits is 385,246 tons (U.S. Census Bureau 1999). A calculation of the amount of drywall produced in Citrus and Putnam Counties is presented in Figure 7-1.

Figure 7-1. Drywall Waste Generation Estimates

Base Assumptions

Area of one single-family home = 2,000 square feet
Area of one two-family home = 4,000 square feet
Area of one three and four-family home = 6,000 square feet
Area of one five or more-family home = 10,000 square feet
Generation rate of waste drywall = 1 pound per square foot
One ton = 2,000 pounds

*Number of single-family homes built** = 106,659 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{106,659 \times 2000 \times 1}{2000} = 106,659 \text{ tons}$$

*Number of two-family homes built** = 1,644 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{1,644 \times 4000 \times 1}{2000} = 3,288 \text{ tons}$$

*Number of three and four-family homes built** = 3,578 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{3,578 \times 6000 \times 1}{2000} = 10,734 \text{ tons}$$

*Number of five or more-family homes built** = 52,931 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{52,931 \times 10000 \times 1}{2000} = 264,655 \text{ tons}$$

Total Amount of Drywall Waste Generated in Florida = 385,246 tons

Figure 7-1 (cont.). Drywall Generation

Citrus County (1999)

*Number of single-family homes built** = 1,014 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{1{,}014 \times 2000 \times 1}{2000} = 1{,}014 \text{ tons}$$

Putnam County (1999)

*Number of single-family homes built** = 130 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{130 \times 2000 \times 1}{2000} = 130 \text{ tons}$$

Total Amount of Drywall Waste Generated in Citrus and Putnam Counties = 1,144 tons

Baker County (1999)

*Number of single-family homes built** = 67 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{67 \times 2000 \times 1}{2000} = 67 \text{ tons}$$

Bradford County (1999)

*Number of single-family homes built** = 62 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{62 \times 2000 \times 1}{2000} = 62 \text{ tons}$$

Union County (1999)

*Number of single-family homes built** = 41 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{41 \times 2000 \times 1}{2000} = 41 \text{ tons}$$

Total Amount of Drywall Waste Generated in the New River Solid Waste Association = 170 tons

**There were no multi-family homes built in Citrus, Putnam, Baker, Bradford or Union Counties in 1999*

Figure 7-1 (cont.). Drywall Generation

Okaloosa County (1999)

*Number of single-family homes built** = 914 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{914 \times 2000 \times 1}{2000} = 914 \text{ tons}$$

*Number of two-family homes built** = 2 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{2 \times 4000 \times 1}{2000} = 4 \text{ tons}$$

*Number of three and four-family homes built** = 4 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{4 \times 6000 \times 1}{2000} = 12 \text{ tons}$$

*Number of five or more-family homes built** = 8 (U.S. Census, 2000)

$$\text{amount of drywall generated} = \frac{8 \times 10000 \times 1}{2000} = 40 \text{ tons}$$

Total Amount of Drywall Generated in the Okaloosa County = 9 tons

PROCESSING I

Several options are available to process drywall to a form which meets the needs of a given end-user market. Table 7-1 summarizes the different quality requirements as needed for the end-user markets explored in Florida. In general, markets where the gypsum is used as a raw ingredient in the manufacture of a product, the majority of the paper must be removed and gypsum must be size reduced to a reasonable extent. Screening is a necessary step. The requirement of screening becomes less important for the other markets. Because the paper will biodegrade over time, its presence in compost feed stock should not matter (if compost is adequately stabilized). Paper should also degrade to some extent when added as an agricultural amendment. While paper should still be removed, the degree of acceptable contamination should be higher than with manufacturing markets. State and local regulations should be consulted prior to land application of any waste material. Paper was not removed the type of road used in this project. The long term impact of including paper was not evaluated.

Table 7-1. Processingconditions for each waste drywall enduser market

Market	Conditions
Cement manufacturing	<2% contamination. Other materials, such as the paper backing, must be screened out from the gypsum.
New drywall manufacturing	Very little allowable contamination. Other materials, such as the paper backing, must be screened out from the gypsum.
Agricultural amendment	Paper may not have to be screened out. Wallboard must be reduced to a fine powder to be laid onto the soil.
Road base additive	Very little size reduction or screening needed. It is possible to lay the scrap drywall on the ground and crush it with a front-end loader in order to obtain acceptable.
Composting	Paper does not have to be screened out. Scrap drywall may be processed by any of the methods listed in this chapter and mixed with a variety of composting materials.

PROCESSING II

Equipment for processing drywall range from those systems designed primarily for drywall processing to those commonly found at many landfills and waste processing facilities. Traditional grinders such as tub grinders and horizontal mills can be used to process drywall. They require a screening method, however, as needed by the market. Screens such as trammels and vibratory screens can be used. One important lesson learned in this study was that a trommel screen could serve the purpose of both screening and size reduction. The rotation of the trommel screen breaks up the drywall and screens out the paper, allowing the gypsum to fall through and accumulate in one pile.

For many drywall-processing machines, dust can be a problem. Gypsum is a "chalk-like material that breaks apart easily." Dust is a problem for aesthetic reasons and, for a given processing location, there may be local restrictions or air quality standards that enforce a certain emissions limit. To ensure that dust is kept at a minimum, dust suppression mechanisms, such as water sprinklers where the dust is generated, must be implemented. Table 7-2 lists different machines and their specifications that can be used for drywall recycling purposes.

Table 7-2. A comparison of processing equipment for waste drywall

Name	Pros	Cons	Manufacturer	Approx. Cost	Approx. Processing Rate
Trommel screen	- Screens out contamination - Has a high processing rate.	-Creates a lot of dust.	Morbark	\$200,000 - \$250,000	50-60 tons per hour
Tub grinder	-Has a high processing rate.	-No screening mechanism. It might be necessary to screen out contamination, depending on the specifications of the end product.	Morbark	\$400,000	40-100 tons per hour
Andela Pulverizer	-½" screen can produce gypsum with less than 5% paper. -¼" screen can produce gypsum with less than 1% paper.	-The smaller the screen size, the slower the processing rate.	Andela Tool & Machine, Inc.	\$265,000	10 tons per hour
Packer 750	- Mobile - Grinds up drywall to be land applied at the job site. - No waste disposal costs	-No screening mechanism. It might be necessary to screen out contamination, depending on local regulations.	Packer Industries, Inc.	\$85,000	5 tons per hour (using ½" screen)
Shred-All	-Inexpensive and ideal for small amounts of drywall. -Mobile	-Not ideal for large amounts of drywall.	Concept Products Corporation	\$48,000	4 to 5 tons per hour

MARKETS

During the innovative recycling grant work, markets for processed scrap drywall in Florida were explored and most were found to be viable from a technical standpoint. Several issues regarding each use need to be addressed to successfully market the end product. These issues will be addressed and discussed in this section. Drywall from new construction is the only type that has been examined for use in these markets because of the possibility of contamination from using demolition and renovation material. Contamination of the drywall may consist of nails, screws, paint, heavy metals, and asbestos.

In an effort to compare the amount of waste drywall from new residential construction with the potential market demand, simple estimates of market demand were made for agricultural use (peanuts only), new drywall, and cement production. Again, more detailed estimates of these markets are currently being conducted by the authors.

AGRICULTURAL USES

Gypsum is used extensively in agriculture as a soil amendment and source of calcium and sulfur for crops. Processed gypsum drywall has been proven as a suitable alternative to agricultural gypsum. Therefore, it is a viable market for processed gypsum drywall waste.

One issue that requires attention regarding the use of processed drywall is marketing the material to farmers. Farm owners, farm supply stores and agricultural extension agents all need to be educated on the benefits of utilizing this material. Education could be in the form of extension agents making visits to local farms or farm supply stores promoting the use of this recycled material. The processed scrap drywall must be cost competitive with the other forms of gypsum already used in agriculture.

This may present a challenge because other options for agricultural gypsum already exist. These include mined (raw) gypsum and by-product gypsum. Both products are inexpensive, and by-product gypsum is virtually pure (approximately 90%), but by-product gypsum can contain some impurities that cause concern about land application. There is no current methodology for prescribing application rates of processed scrap drywall. Ranges of application have been found to fall between eight and 22 tons per acre. More experiments need to be performed in order to establish set guidelines for farmers to follow when using this product.

The amount of peanuts grown in Florida must be known in order to estimate how much scrap drywall may be used for this purpose. Information for peanuts can be found in Florida Agricultural Facts, which is published annually by the Florida Department of Agriculture and Consumer Services (Tables 7-3 and 7-4). Since the acreage of these crops is known, an estimate can be made for how much drywall may be used in growing these crops based on application rates used here.

Table 7-3. Leading PeanutProducing Counties in Florida in 1998 (Florida Agricultural Facts, 1999).

County	Harvested acres	Production Pounds	Estimated Value ($)
Jackson	30,100	78,712,000	19,678,000
Santa Rosa	13,500	39,893,000	9,973,000
Suwanee	5,300	14,443,000	3,611,000
Levy	4,600	13,386,000	3,347,000
Calhoun	3,900	11,486,000	2,871,000
Marion	4,600	9,821,000	2,455,000
Holmes	4,500	9,000,000	2,250,000
Walton	3,800	8,265,000	2,066,000
Alachua	2,600	6,565,000	1,647,000
Columbia	3,900	4,700,000	1,175,000
Washington	1,600	4,616,000	1,154,000
Okaloosa	1,600	3,976,000	994,000
Jefferson	800	2,420,000	605,000
Madison	700	2,384,000	600,000
Gilchrist	900	1,962,000	491,000
Gadsden	700	1,200,000	300,000

A total of 995,300 acres of field crops were harvested in Florida in 1998, which includes peanuts. Peanuts comprised 90,000 acres, or 233 million pounds, with a value of $57,343,000. Florida ranked fifth in the nation in peanut production. Table 7-4 contains the production of peanuts in Florida by County. If gypsum were applied at a rate of 0.5 tons per acre (a conservative estimate), 45,000 tons or 90 million pounds, of waste gypsum drywall could be used instead of raw gypsum or phosphogypsum. At a rate of two tons per acre (a more realistic estimate), the amount of waste drywall that could potentially be used increases to 180,000 tons, or 360 million pounds (Figure 7-1). The leading peanut-producing counties in Florida are outlined in Table 7-4. If a drywall recycling plant were located in close proximity to these counties, it would make the transition to using this material easier for the farmers because they would not have to sustain the high costs associated with transporting the material. An evaluation of the economic feasibility of using processed scrap drywall for peanut production is presented in the next section.

Table 7-4. Peanut Production and Value in Florida (Flroida Agricultural Facts, 1999).

Year	Harvested acres	Production (lbs)	Crop Value ($)
1998	90,000	233,100,000	57,343,000
1997	84,000	228,060,000	63,857,000
1996	82,000	236,160,000	66,361,000
1995	81,000	193,590,000	52,463,000
1994	84,000	207,480,000	58,302,000

CEMENT PRODUCTION

Portland cement is the most widely used type of cement. It is made from limestone, sand, clay, shale, water, and gypsum, and is used in non-residential buildings, highways, streets, and bridges, as well as non-construction purposes. Mined or by-product gypsum is used in the manufacture of Portland cement to control setting time, and comprises approximately 6% of the cement by weight.

There are some issues associated with using scrap drywall as a gypsum source in the manufacture of cement. Virtually all paper backing must be removed from the scrap drywall. This would require monitoring to ensure the paper is being removed properly or use of equipment that is efficient at this process. Size reduction is not a major factor in cement manufacturing, but the scrap drywall should be processed in a manner that results in a product similar to that of mined gypsum. Some modifications in handling and conveying equipment may be necessary to accommodate for the differences in drywall and mined gypsum. These differences are limited to minor physical characteristics and should not present a major problem if the source of the scrap drywall material is consistent.

A constant supply of drywall is needed to make this market successful, because of the high content of gypsum required to manufacture one load of cement. This content is approximately 120 pounds of gypsum per ton of cement, which is typically 6% of a load, but can vary from 5 to 10%. Maintaining a constant supply is difficult because construction is seasonal, and there may be times when a shortage exists. Conversely, there may also be times when the material is produced at a surplus. Then it could be stored for times of shortage in use for manufacturing cement. Mined gypsum is presently stored on site at cement plants.

There are five cement plants in Florida that produced 3,417,000 tons of portland cement in 1998 (Figure 3-5). If scrap drywall were used at 6% (120 pounds per ton) instead of mined gypsum in the manufacture of cement, 410,040,000 pounds or 205,020 tons, could be used in this manner (Figure 7-1). This is a significant amount of scrap drywall and it has not been determined yet whether this type of supply could be maintained constantly for cement plants.

NEW DRYWALL

Scrap drywall can be reused as stock material for manufacturing new drywall. This concept began in Canada and has been adapted in the northwest region of the United States. An issue related to using scrap drywall for new drywall is that many drywall-manufacturing plants have their own waste stock to rely on for new material. Quality assurance is also ensured when manufacturers use their own waste as opposed to foreign material. The risk of contamination increases when these companies accept scrap material from other sources. Fire ratings may also be affected if the scrap material is not properly screened to remove paper. Scrap material must contain less than 2% paper and cannot have any metal contamination. Typically, 10 to 20% of new drywall consists of recycled material.

Another issue with using scrap drywall for new drywall production is that many drywall companies own the gypsum mines that serve as their source of raw gypsum. This fact makes gaining the support of drywall manufacturers to use recycled material virtually impossible since they do not have to make decisions about suppliers of raw materials.

Florida produced 1,230,000 tons of calcined gypsum in 1998, most of which was used to make drywall. If the minimum of 10% recycled content was to be achieved, assuming all calcined gypsum was used to manufacture drywall, approximately 123,000 tons or 246,000,000 pounds, of scrap drywall could be used for manufacturing new drywall (Figure 7-2).

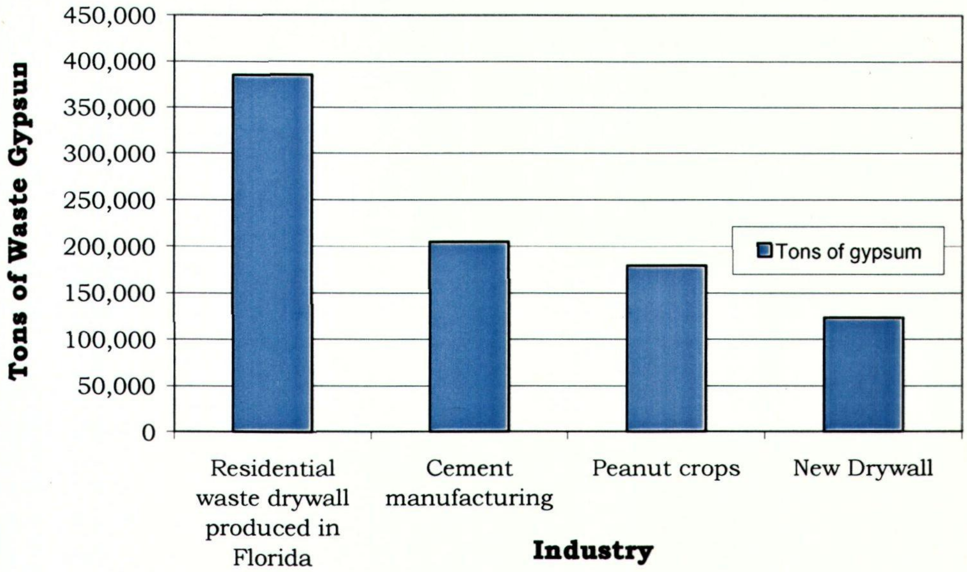


Figure 7-2. Predicted consumption of waste gypsum drywall by industry.

Figure 7-2 presents the predicted consumption of waste gypsum drywall in Florida by the cement manufacturing, peanut farming, and drywall manufacturing industries. Residential waste drywall produced in Florida amounts to 385,246 tons per year. The calculations for this estimate are presented in Figure 7-1. Cement manufacturing has the greatest potential as an end-market for using scrap drywall as an ingredient in Portland cement. Consumption estimates were calculated by the equations in Figure 7-3.

Figure 7-3. Predicted Gypsum Demand in Florida.

CEMENT MANUFACTURING

Assuming:

3,417,000 tons of Portland cement were manufactured in Florida in one year (USGS, 1999)

Gypsum comprises 6% of a one ton Portland cement mix

(3,417,000 tons portland cement)(120 lbs gypsum/ton)(1 ton/2000 lbs) = 205,020 tons

PEANUT FARMS

Assuming:

90,000 acres of peanuts were grown in Florida in one year (Florida Agricultural Facts, 1999)

Gypsum is applied at 2 tons per acre

(90,000 acres peanut crops)×(2 tons drywall/acre) = 180,000 tons

DRYWALL MANUFACTURING

Assuming:

1,230,000 tons of calcined gypsum were manufactured in Florida in one year (USGS, 1999)

10% of raw materials used to manufacture new drywall is recycled content from scrap drywall

(1,230,000 tons calcined gypsum)(0.10 recycled gypsum) = 123,000 tons

ECONOMICS

Factors that affect the economics of recycling drywall include the construction activity (amount of drywall produced), ease of separation, collection and processing methods, transportation requirements, and established markets for recycled products. The following sections examine several possible scenarios, one for each IRG area, and explore the economics. These analyses are not intended to be absolute or representative of all communities, but provide a look at whether recycling can be feasible, what factors are important, and a model which could be used to evaluate other regions.

ECONOMIC ANALYSIS: NRSWA

Since new residential construction is not particularly active in the NRSWA region, the economic analysis focuses on the collection, processing and reuse of the drywall waste produced by the manufactured housing plant in the area (HOM). The recycling of gypsum from manufactured housing waste has been proven successful in other areas of the country. Homes of Merit generates approximately 0.33 tons of drywall waste per day. The economic analysis compares two scenarios:

1. All of the drywall waste from HOM is disposed of at the NRRL
2. Drywall is source separated, hauled to a processing site, processed, and sold as agricultural gypsum.

HOM demonstrated a willingness to separate drywall during the IRG when it resulted in free disposal. This analysis will help determine what reduction in tipping fees could be available to provide incentive to continue this separation.

In this case, only the drywall fraction of the waste stream is considered. It is assumed that all other materials are handled by HOM as normal. The current system for disposing waste drywall and the current system of obtaining phosphogypsum for use in agriculture are represented in Figures 7-4 and 7-5.

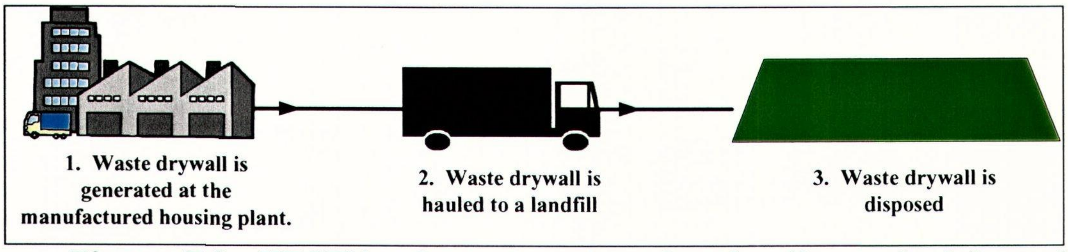


Figure 7-4. NRSWA: Current system for the disposal of drywall waste from a manufacturing housing plant

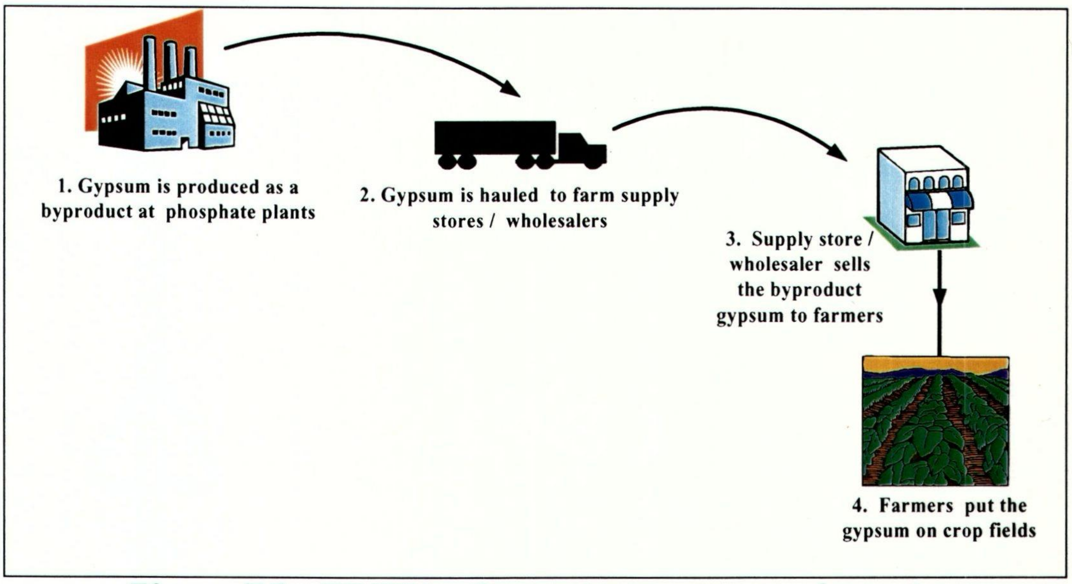


Figure 7-5. NRSWA: Current gypsum supply system

Currently, farm supply stores or wholesalers purchase phosphogypsum from phosphate plants, such as PCS Phosphate, for $7 to $25 per ton. They then sell it to farmers for approximately $45 per ton. Manufactured housing plants currently dispose of all drywall waste in a landfill with the rest of the construction waste. The cost for a manufactured housing plant to dispose of waste drywall includes hauling and disposal costs. On average, it costs $360 per load (40 cubic yards) to haul and dispose of the waste. A worksheet detaining how the costs in this section were determined is located in Figure 7-7.

Cost dictates the feasibility of recycling. If manufactured housing plants have to pay more to recycle their waste rather than disposing it, they likely will choose not to recycle. An optimal recycling system is presented in Figure 7-6. In this system, the manufactured-housing plant has drywall waste hauled to a processing facility instead of a landfill. Gypsum is recovered from waste drywall using a trommel screen. The recycled gypsum is then hauled to farm-supply stores or gypsum distributors. The costs associated with this system include:

- Hauling costs from the manufactured housing plant to the processing facility
- Processing costs
- Hauling costs from the processing facility to the farm supply stores or wholesalers

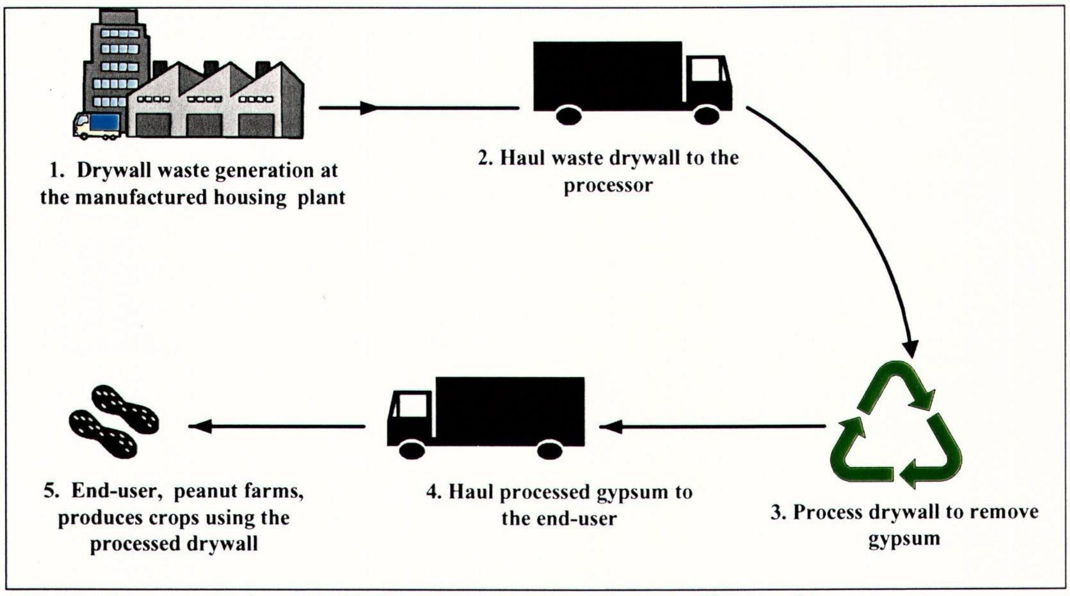


Figure 7-6. NRSWA: Projected drywall recycling system

The costs for processing include the initial purchasing cost of the machine along with operational and maintenance costs. As found in the processing demonstration for this study and reported in earlier sections of this report, the best type of machine to use to process drywall to recover gypsum for cement manufacturing is a trommel screen. The processor would be responsible for the cost of transporting the drywall waste from the processing facility to the wholesaler. The final cost for processing was determined to be equal to $1.47 per ton. Figure 7-7 presents a worksheet detailing how these costs were determined. If more conservative values were used, this processing cost would increase. If a slower processing rate were used, such as the rate used in the processing demonstrations (30 tons per hour), and the operation and maintenance cost were doubled (using $120 per hour instead of $58.65 per hour), the total processing cost would equal about $5.30 per ton.

Comparisons of each of the projected recycling costs to the current costs are presented in Table 7-5. The two key stakeholders that would benefit from this recycling process are the manufactured housing plant and the wholesalers or farm supply stores.

Figure 7-7. Economic Analysis: NRSWA

CURRENT SYSTEM – GYPSUM SOLD BY PHOSPHATE PLANTS TO FARMERS

1) Determine the cost farmers pay for one ton of gypsum from phosphate plants
   - *Hauling costs for phosphate plant* = $12.00 per ton
   - *Total cost to farmers for gypsum* = $40.00 to $50.00 per ton

CURRENT SYSTEM – HOM DISPOSES OF WASTE DRYWALL AT LANDFILL

1) Determine the total disposal cost for one load of C&D waste from HOM.
   - *Volume of one load* = 40 cubic yards
   - *Hauling cost for one load of waste* = $145.00
   - *Disposal cost for one load of waste* = $215.00

$$\text{Disposal cost for one load} = \frac{\$145 + \$215}{40\ \text{yd}^3} = \$9.00 \text{ per cubic yard}$$

2) Determine the disposal cost per ton.
   - *Average density of C&D waste* = 0.24 tons per cubic yard (Townsend, 2000)

$$\text{Disposal cost per ton} = \frac{\$9.00 \text{ per yd}^3}{0.24\ \text{tons}/\text{yd}^3} = \$37.50 \text{ per ton}$$

3) Drywall is approximately ¼ of HOM's waste stream.

$$\text{Cost of disposing drywall only} = \frac{\$37.50}{4} = \$9.38 \text{ per ton}$$

PROPOSED DRYWALL-RECYCLING SYSTEM

1) Determine the hauling cost without disposal fees.

$$\text{Hauling cost} = \frac{\$145}{40\ \text{yd}^3} = \$3.63 \text{ per cubic yard}$$

2) Determine the hauling cost per ton of uncompacted drywall.
   - *Density of uncompacted drywall* = 729 lbs/yd^3

$$\text{Hauling cost per ton of drywall} = \frac{\$3.63 \text{ per cubic yard}}{(729\ \text{lbs/yd}^3)/(2000\ \text{lbs/ton})} = \$9.96 \text{ per ton}$$

3) Determine the processing cost for one ton of drywall
   - *Average cost of trommel screen* = $200,000
   - *Operational and maintenance costs* = $58.65 per processing hour
   - *Average lifetime of a trommel screen** = 9,000 hours
   - *Processing rate* = 55 tons per hour

$$\text{Processing cost} = \frac{\left(\$200{,}000/9{,}000\ \text{hrs}\right) + \$58.65 \text{ per hour}}{55 \text{ tons per hour}} = \$1.47 \text{ per ton}$$

4) Determine the cost of transporting processed gypsum to wholesaler
   - *Average hauling cost* = $1.20 per mile
   - *Density of processed recycled gypsum* = 0.5 tons per cubic yard
   - *Volume of processed recycled gypsum rock in one truck* = 40 cubic yards
   - *Roundtrip distance to the farmer*** = 100 miles

$$\text{hauling cost per ton} = \frac{\$1.20 \text{ per mile} \times 100 \text{ miles}}{40\ \text{yd}^3 \times 0.5 \text{ tons per yd}^3} = \$6.00 \text{ per ton}$$

Total cost for manufactured housing plant = $9.96 per ton
Total cost for wholesaler or farm supply store = $1.47 + $6.00 = $7.47 per ton

Figure 7-7. Economic Analysis: NRSWA (cont.)

* *This price does not include any factor of interest due to the simplicity of this analysis.*

** *Assuming 50 miles from processor to wholesaler or farm supply store; this distance is assumed to be the maximum that would be traveled.*

† *This cost could incur a markup of up to 300% by the time the product reaches the farmer. In that case, the price would be $23.22, which is still under $45.00, the average price.*

Table 7-5. NRSWA IRG: Comparison of costs to each stakeholder

Stakeholder	Cost without recycling drywall	Cost after recycling drywall
Manufactured-housing plant	$37.50 per ton	$9.96
Wholesaler or farm supply store	$45.00 per ton (average)	$23.22

The economics do exist for this market to make a recycling system work. Demand is the potential problem in this system. It is not likely that there would be enough of a demand in this area for the recycled gypsum to make recycling feasible.

ECONOMIC ANALYSIS: CITRUS COUNTY

New residential construction is very active in Citrus County. Since the production of drywall waste is currently consistent from the construction, the economic analysis was found to be dependent on the separation, collection and transportation methods. The current system for disposing waste drywall and the current system of mining gypsum for use in cement production are represented in Figures 7-8 and 7-9.

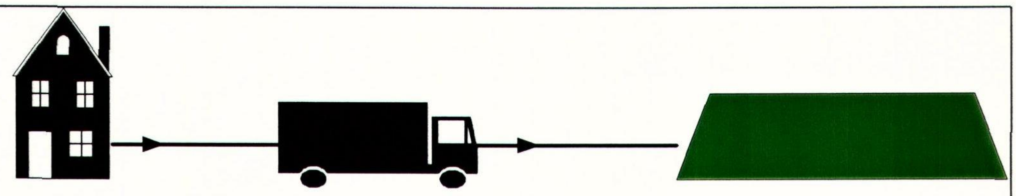


Figure 7-8. Citrus Couty: Current system of drywall waste disposal

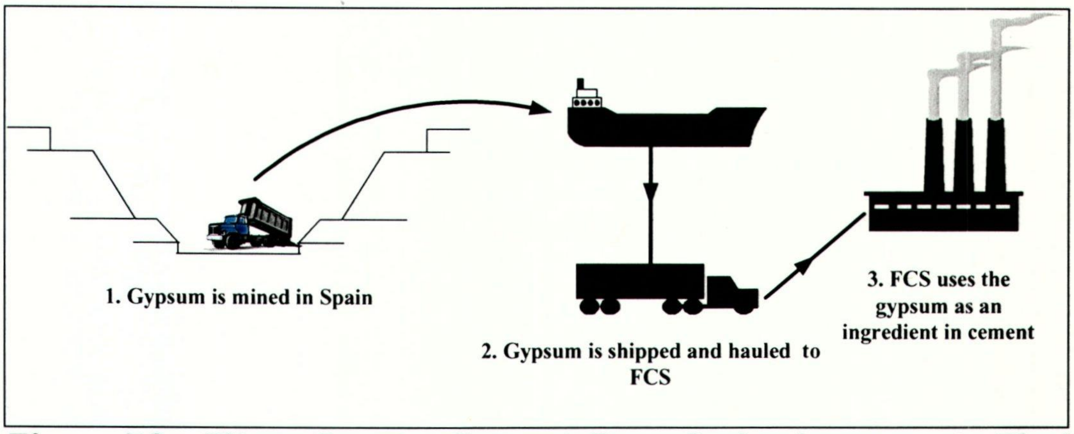


Figure 7-9. Citrus County: Current flow of mined gypsum to Florida Crushed Stone (FCS)

Currently, Florida Crushed Stone (FCS) purchases imported gypsum from Spain at the Port of Tampa for between $15.00 and $20.00 per ton. Trucks transport limestone to Tampa and pick up gypsum at the port, so minimal extra hauling costs are incurred supplying gypsum to the plant.

The current cost for a general residential contractor to dispose of waste drywall can vary depending on how the waste is collected. For an average 3,000 square foot house, it costs about $47.22 per ton to haul and dispose about 14.4 tons of waste. Figure 7-11 details how these numbers were calculated.

Cost dictates the method of collection. If general contractors have to pay more to recycle their waste rather than disposing it, they will not be likely to recycle. A cost analysis of all collection options was conducted to determine which would be the lowest cost option (see Appendix H). This analysis was performed in response to questions posed at the first Stakeholders Meeting in Citrus County. In order for the stakeholders in the county to know if they would be able to participate in the project, they needed to know the costs that were involved. The following options were examined as part of this report:

- Two containers
- Processed drywall load from existing system
- Utilize scrapping service
- Separate hauler for segregated drywall

It was noted that if contractors used a container with a volume of 30 cubic yards, rather than 20 cubic yards, disposal costs would decrease significantly. Sixty cubic yards of waste is the typical amount that is estimated from the construction of each house. Hauling costs would be considerably lower if the waste were taken to the landfill only twice, instead of three times, in larger containers. Another container could be placed at the site during the drywall installation process to collect segregated drywall. In this manner, the cost to recycle the drywall would be equivalent to the cost of disposal.

As a result of the cost analysis, it was also determined that a drywall collection service would be the least costly of all of the options. Spectrum Enterprises was used in the model for cost analysis. Though they currently do not offer a drywall collection service, their normal construction waste operations are similar to a drywall collection service. This service could collect drywall in a similar manner to a garbage truck that collects MSW. The waste drywall could be left in a pile outside of the house. The waste drywall could be picked up by a skid steer or the arm of a clamshell truck and placed into a dump truck for transportation by the drywall collection service. The drywall collection service could collect from several houses before returning to the processing center.

An optimal recycling system would start by source separating the waste drywall into a pile on the construction site (see Figure 7-10). A waste hauler providing a drywall waste collection service would pick up the waste. The drywall would be taken to a processing facility. The recycled gypsum waste would then be hauled to Florida Crushed Stone. The costs associated with this system include:

- Hauling costs from the construction site to the processor
- Processing costs
- Hauling costs from the processor to the cement plant

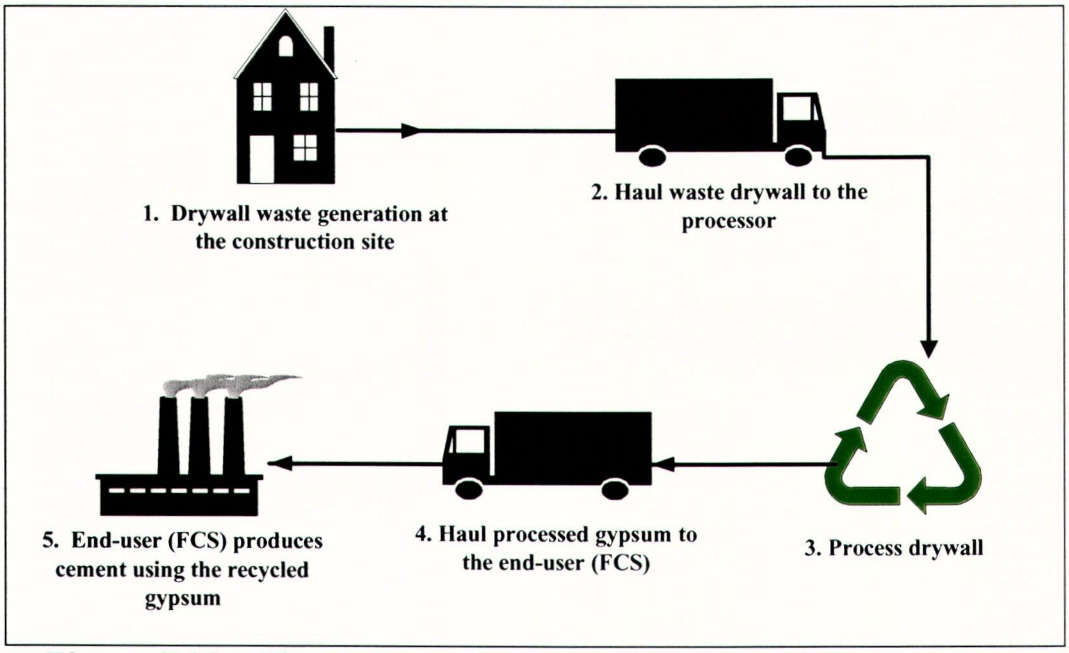


Figure 7-10. Citrus County: Projected drywall recycling system

The costs for processing include the initial purchasing cost of the machine along with operational and maintenance costs. As found in the processing demonstration for this study, the best type of machine to use to process drywall to recover gypsum for cement manufacturing is a trommel screen. It was determined in economic analysis for NRSWA that processing costs for a trommel screen would amount to $1.47 per ton.

The processor would also be responsible for hauling the processed gypsum end-product to the final end-user, a cement plant. The costs involved are simply the cost to operate and maintain the hauling trucks for the round-trip from the processor to the cement kiln. Sand/Land has already decided to serve in the processor role for Citrus County. They own a truck with a 100 cubic yard hauling capacity. It can only carry around 20 tons of material. The total distance from Sand/Land to Brooksville, FL (the location of both cement kilns) is about 64 miles.

A worksheet detailing how all of these costs were determined is presented in Figure 7-11. The total cost for the processor includes the processing and hauling costs. Comparisons of each of the projected recycling costs to the current costs are presented in Table 7-6. The two key stakeholders that would benefit from this recycling process are the general contractors and the cement manufacturing plant.

Even if more conservative values were to be used for the processing cost parameters, recycled gypsum would be more cost effective for FCS than buying mined gypsum from Spain. If a value of 30 tons per hour (the same rate used in the demonstration at Citrus County) was used for the processing rate and the operation and maintenance cost was doubled, the processing cost would still only be around $5.30 per ton. Adding that to the hauling cost of $3.84 per ton, the total price of $9.14 per ton would still be less than $15 per ton, the lowest price that FCS is currently paying.

Figure 7-11. Economic Analysis: Citrus County

CURRENT SYSTEM – MINED GYPSUM FROM SPAIN IS SHIPPED TO FCS

1) Determine the cost FCS pays for one ton of raw gypsum
   - *Total cost to FCS for gypsum* = \$15.00 to \$20.00 per ton

CURRENT SYSTEM – RESIDENTIAL CONTRACTORS DISPOSE SCRAP DRYWALL

1) Determine the total disposal cost for one house (assume 3,000 sq ft house)
   - *Loads of waste from one house* = 3
   - *Volume of one load* = 20 cubic yards
   - *Delivery charge* = \$50.00
   - *Pull charge* = \$140.00 per load
   - *Disposal fee* = \$3.50 per cubic yard

   $$\text{disposal cost} = \$50.00 + (\$140.00 \times 3) + (\$3.50 \times 20 \times 3) = \$680.00 \text{ per house}$$

2) Determine the total disposal cost for one ton of C&D waste
   - *Average density of C&D waste* = 0.24 tons per cubic yard (Townsend, 2000)

   $$\text{disposal cost per ton} = \frac{\$680.00}{3 \times 20 \times 0.24} = \$47.22 \text{ per ton}$$

PROPOSED DRYWALL-RECYCLING SYSTEM

1) Determine the total cost to the general contractor to recycle the scrap drywall
   - *Drywall recycling service (1 pick-up)* = \$170.00
   - *Volume of scrap drywall from the construction of one house* = 10 cubic yards
   - *Density of uncompacted drywall* = 729 pounds per cubic yard

   $$\text{disposal cost per ton} = \frac{\$170.00}{\frac{729}{2000} \times 10} = \$46.64 \text{ per ton}$$

2) Determine the total processing cost for one ton of drywall
   - *As determined in the Economic Analysis for NRSWA, processing cost for one ton of drywall* = \$1.47 per ton
3) Determine the total cost for hauling processed gypsum from Sand/Land to FCS.
   - *Average hauling cost* = \$1.20 per mile
   - *Density of recycled gypsum* = 1000 pounds per cubic yard
   - *Hauling capacity of a truck* = 40 cubic yards
   - *Roundtrip distance from Sand/Land to FCS* = 64 miles

   $$\text{hauling cost per ton} = \frac{\$1.20 \times 64}{40 \times \frac{1000}{2000}} = \$3.84 \text{ per ton}$$

Total cost for the general contractor = \$46.64 per ton

Total cost for FCS = \$1.47 + \$3.84 = \$5.31 per ton

Table 7-6. Comparison of costs to each stakeholder in Citrus County

Stakeholder	Cost without recycling drywall	Cost after recycling drywall*
General contractor	$47.22 per ton	$47.57 per ton
Cement kiln	$15 to $20 per ton	$5.31to $9.14 per ton

*Dependent on how the processor charges. This is a "break-even" analysis.

The economics do exist for this market to make a recycling system work. They are not that great for separation. Therefore, further incentive must be provided to the contractors. If profit can be accrued from recycling drywall, people will be willing participants. In this case, the person most likely to gain financially is the processor.

POLICY AND OTHER FACTORS AFFECTING THE FEASIBILITY OF DRYWALL RECYCLING

Policy, market incentives, geography and population play a part in the feasibility of recycling drywall in Florida and other areas. The IRG Projects presented in this report were performed at various locations in Florida. Recycling and reuse of the drywall was hindered in all three projects because source separation and collection is not facilitated by the current operation of drywall contractors and the construction industry. Drywall contractors in these locations are not responsible for the waste produced. General contractors have not found an incentive or been forced to recycle through economic or regulatory framework. Unless policy changes are made, along with education of the industry and the potential re-use customers, drywall recycling will not likely become successful in these areas.

Policy changes to begin to facilitate recycling may be implemented at the federal, state, or local level. Some potential policy changes, incentives and situations to facilitate the recycling of drywall are listed below and discussed further in this section.

- Restrict drywall disposal in landfills
- Advance disposal fee or tax on drywall
- Implement fees for drywall disposal in permits
- Tax incentives for industries
- Restructuring of construction practices

RESTRICT DRYWALL DISPOSAL IN LANDFILLS

If gypsum drywall were restricted from being disposed in specific landfills (e.g. unlined, Class III), it would force the industry to examine recycling and reuse options or face higher disposal costs at a lined landfill. For example, it may be justifiable to restrict the disposal of drywall in unlined landfills because of environmental concerns. Drywall disposal results in the production of hydrogen sulfide gas at landfills and may result in leachate with sulfate levels above groundwater standards in Florida. The environmental issues concerning drywall disposal were addressed and discussed in Section 2.4 of this report.

The Greater Vancouver Regional District (GVRD) banned drywall from disposal in landfills in 1990 (GVRD, 2000). The successful recycling operation, New West Gypsum (NWG) with plants in Toronto and Seattle, was founded partly because of the government decree restricting drywall disposal in Canada. The amount of drywall that NWG processes has steadily increased over the past ten years. The greatest increase in the drywall waste stream came from British Columbia (when compared to the U.S. and Ontario), where the landfill restrictions are in place (NWG, 2000).

Drywall has also been restricted from disposal in Highlands County, Florida. The Sebring Landfill in Highlands County was closed in 1998 because it was generating and releasing hydrogen sulfide in such high concentrations, the gas could be smelled within five miles. Highlands County now operates a C&D debris disposal facility (Permit No. 0038570-004-SO/22) landfill that does not accept drywall (Leszkiewicz, personal communication, 2000). When Highlands County permitted the landfill through FDEP, the permit application was written such that drywall could not be accepted at the landfill. The drywall waste must be diverted to the Class I landfill on site. Contractors and haulers were educated to separate drywall out, and most had been aware of the odor problem associated with the former landfill and reacted favorably. The landfill drywall restriction creates an economic incentive to separate drywall from other C&D waste because if it is mixed together, the entire load must be disposed at the Class I landfill (a higher tipping fee than the C&D landfill). Highlands County also has a solid waste ordinance which defines waste streams. Drywall has been excluded from the definition of C&D waste for the county (Leszkiewicz, personal communication, 2000). Highlands County is a good example of policy changes that may make drywall recycling feasible. However, the changes were facilitated by the obvious odor problem that affected a large population in the county, and even though drywall is successfully separated out of the C&D waste stream, none is currently recycled because of lack of market incentives (Leszkiewicz, personal communication, 2000).

Another option to encourage recycling through disposal restrictions would be to increase the regulations for landfills that accept drywall. Operating costs at Florida C&D landfills would rise if, for example, landfill gas extraction systems were required at the landfills that accept drywall. The rise in operating costs would cause a rise in tipping fees for these landfills. The higher tipping fees would encourage generators of drywall waste to explore options other than disposal.

Recycling options have been outlined in this report, however they may require time and money to implement. A mandated ban could potentially put economic pressure on contractors or increase the cost of building a home in Florida. Increasing landfill regulations and restrictions could also put an economic burden on landfill owners. A restriction on drywall disposal would create an automatic market for collection and processing of drywall, but not necessarily a market for the processed drywall. This is a policy change that would also require legislative action and enforcement by the state or locality.

ADVANCE DISPOSAL FEE OR TAX ON DRYWALL

An advance disposal fee (ADF) is a tax that is placed on products at the point of sale or distribution level to raise revenue for the management of the waste produced from the product after use. An ADF could be placed on gypsum drywall products. The money from the tax could go to facilitating recycling programs throughout the state. If collection and recycling programs could be initiated and subsidized by this tax money, they might be feasible. ADF's have been proposed for other products including single-use disposable packaging products (e.g. cans, bottles, and jars). An ADF on disposable food service products to fund recycling programs was experimented with in Florida for a few years and allowed to expire (Tampa Tribune, 1996). ADFs were also proposed (but not passed) for the 2000 legislative session in Kentucky on containers used by restaurants providing carry-out service (Kentucky Legislative Record, 2000). One perceived problem with an ADF is that the money is not used properly or in specific programs. The ADF on containers funded recycling programs in general (and was dropped), but a fee on tires in Florida has been maintained since 1989 because the public sees results from the program. Tire piles have been reduced throughout the state and the public does not have a problem paying the $1.00 fee to provide funding for proper management of used tires (Parker, personal communication, 2001). The economic burden for this policy change would be carried by all purchasers of drywall products. This policy change would require legislative action to adjust the tax structure by the state or locality.

IMPLEMENT FEES FOR DRYWALL DISPOSAL IN BUILDING PERMITS

A permit deposit would be an economic incentive to encourage the recycling of drywall, as well as other C&D wastes. The City of San Jose, California proposed an advance disposal deposit (for C&D waste) on permits. The person that applies for a construction, demolition, or renovation permit (typically a general contractor) must pay a deposit fee based upon the amount of C&D debris that is expected to be generated from the project. To obtain a refund, the permitee must provide receipts to the City showing that the C&D waste produced was recycled by a City-approved facility. The recycling facilities in the area were evaluated and ranked according to their waste diversion rates from landfills. A reduced deposit would be returned if the lower diversion rate recycling facilities were used. The city also provided education on how to keep C&D waste out of landfills (Bantillo, 2000). In this situation, the economic burden is placed on the contractors and others who obtain building permits. Legislative action by the locality to adjust building permit fees would be required for this policy change.

TAX INCENTIVES FOR INDUSTRIES WHICH USE RECYCLED DRYWALL IN PLACE OF OTHER GYPSUM

Half of the states in the U.S. provide tax incentives to encourage recycling (U.S. EPA, 2000). Some states do not charge sales tax on equipment needed for recycling, provide tax credits for capital investment in recycling facilities, or do not charge property tax for buildings and land used for converting waste into new products. In Florida, a recycling investment tax credit of $500 is allowed for every $100,000 invested and a recycling employment income tax credit of $500 is given for each new employee added as a result of incorporating recycled products into a process (U.S. EPA, 2000). These tax incentives could be taken advantage of by all parties involved in the drywall recycling process as well as the agriculture, cement or new drywall manufacturing industries that could potentially utilize recovered gypsum drywall instead of synthetic gypsum or mined gypsum. This tax incentive could also be combined with the previously discussed policy changes.

RESTRUCTURING OF CONSTRUCTION PRACTICES

Some drywall contractors include the management of drywall waste in the bid for the project. In this situation, the drywall contractor is responsible for the cost and method of disposal or recycling of the drywall scrap. Because the contractor must gather the scraps and leave the site clean, the drywall waste is source separated. This separation promotes the initiation of services that collect the scrap/waste drywall to recover the gypsum. The building contractor is still incurring the cost for drywall removal and disposal, but it is just included in the drywall contractor's bid for the job.

Drywall contractors are encouraged to become responsible for their own waste because of certain market, geographic, population, and economic factors (Kindall, personal communication, 2000). Those include:

- High population area (greater than one million people)
- High growth metropolitan and suburban areas
- Established drywall contractor companies in competition for work
- A proven market for the recovered material

General contractors may require drywall contractors to be responsible for their own waste. The subcontractor agreements between the general contractor and the drywall contractor may be written to specify responsibility for waste management (source separation, recycling, etc.). It is then the general contractor's responsibility to provide oversight and confirm that the proper waste management techniques are followed (Dooley, personal communication, 2000). Some example text is provided by the NAHB in "Residential Construction Waste Management: A Builder's Field Guide." Similar text may be used in a subcontractor agreement to specify waste management.

The subcontractor shall at all times keep the building and the premises broom clean of debris and any other waste materials generated from the performance of this contract. The subcontractor is responsible for the removal from the site and proper disposal of all the debris created by its work (NAHB, 1997).

STUDY OF SUCCESSFUL PRACTICE

When all the facilitative factors come together, recycling services for drywall are feasible and economical. A scrap collection and recycling service was initiated near Charlotte, North Carolina because of the following factors (Davis, personal communication, 2000):

- High density growth in the Charlotte area and suburbs
- Established drywall contractors in the area
- Desire of general contractors to have a "clean site" (i.e. no debris around)
- Relatively high landfill tipping fees in the area
- Close proximity of agricultural land (e.g. cotton) to Charlotte
- Small Grant provided by the state ($13,500)
- Education of farmers by recycling operator
- Cooperation of a fertilizer company
- High poultry production area (gypsum also used as chicken bed absorbent)

The drywall policy options outlined and discussed in Section 7.6 are summarized in Table 7-7, along with the primary pros and cons for each option.

Table 7-7. Drywall Policy Options

Policy Option	Pros	Cons
Ban drywall from landfills	Mandates recycling	Large economic burden on contractors No money or incentive for market encouragement
Advance disposal fee/tax (increase price of drywall)	Provides money to subsidize and encourage markets and recycling	Economic burden does not directly encourage recycling
Implement extra fees in permits	Encourages recycling through economic burden Provides money to subsidize and encourage markets and recycling	Economic burden is specifically carried by only those that apply for permits
Require more stringent monitoring it at C&D landfills that accept drywall (e.g. require gas collection systems)	Indirectly would raise tipping fees to encourage recycling	Puts an initial large economic burden on the landfill operators Does not provide money for market incentives

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APPENDIX A
Information Dissemination

INFORMATION DISSEMINATION

A very important step in making a recycling project work is education. Informing the public of the project, how it works, and how it can benefit them helps to ensure that drywall recycling will continue into the future. The Florida Department of Environmental Protection expects that information dissemination be conducted during the progress of every IRG. Advertisement is not required by the grant, but it is very important to the longevity of the recycling program.

Coordinated IRG Activity

Four Technical Advisory Group (TAG) meetings were held during the course of the drywall recycling effort (see Table 1). The purpose of these meetings was to educate the public about the project and to report the progress and conclusions that we have made. They are also forums in which feedback is gained from experts in the industry as well as from TAG members themselves. The attendance at each meeting was very high and included representatives from state and local government, health departments, drywall manufacturers, landfill owners, concerned citizens, professors, consultants, waste haulers, and contractors. Attendance lists and agenda sheets are included.

Table 1. Technical Advisory Group (TAG) meetings information

Date	Location	Purpose
May 6,1999	University of Florida Gainesville, Florida	To inform of the intention and purpose of the drywall recycling effort.
October 19, 1999	LeVeda Brown Environmental Park (Transfer Station) Gainesville, Florida	To inform of updates in the recycling efforts.
April 7, 2000	University of Florida Gainesville, Florida	To inform of updates in the recycling efforts.
December 12, 2000	University of Florida Gainesville, Florida	To present results and conclusions of the drywall recycling project.

A web page was created and maintained during the course the drywall-recycling project. It was updated to inform of new results from each of the IRGs. It also contained many links to other pertinent recycling or drywall-related web pages. Pictures of events that were conducted for the project were also published on the web site. The URL is: http://www.ees.ufl.edu/homepp/townsend/Research/GypDW/Recycle/gypsum_recycle_main.html

An article was published in Resource Recycling, a journal that reports on all new recycling efforts, about the recycling effort in Florida (see Table 2). This article contained information about why drywall recycling is important, the markets for gypsum from waste drywall, innovative recycling grants in Florida, and conclusions made from the county recycling projects.

Table 2. Journal article written about the IRG's

Date	Author(s)	Title	Journal	Description
	Timothy Townsend and Chuck McLendon	"Exploring gypsum drywall recycling"	Resource Recycling	A general description was given about drywall recycling, the possible end-user markets, and conclusions made from the IRGs.

Citrus/Putnam County IRG

Fliers were created to inform stakeholders about the drywall recycling effort in Citrus County. Stakeholders included Citrus County waste haulers, general and drywall contractors, local government representatives and landfill owners. A copy of the flier is included. These fliers were distributed to commercial contractors by the permit office to inform them that the Citrus County Central Landfill was accepting clean drywall waste for free. This effort was anticipated to encourage the evolution of a recycling program on its own. If the contractors knew that they would not have to pay a tipping fee, perhaps they would find a way to get the drywall to the landfill. This effort was not as successful as it was predicted to be. This is mostly due to the lack of commercial construction in Citrus County. Subsequently, there were not any loads of drywall that came into the landfill as a result of the fliers.

Three newspaper articles were written about the drywall-recycling project in Citrus County (see Table 3). These articles documented two events, one of the mass sorts and the processing demonstration at the Citrus County Landfill. They informed the public that something was being done to reduce the odor that emits from the C&D landfills in the county.

Table 3. Newspaper articles written about the Citrus County IRG

Date	Title	Author	Newspaper	Description
Fall 1999	"Drywall recycling experiment is looking good so far"	Jim Hunter	Citrus County Chronicle	General description of project and possible recycling efforts for the future.
March 28, 2000	"Recycling of wallboard looking feasible"	Jim Hunter	Citrus County Chronicle	General description of project and a description of the waste composition study held on March 23rd, 2000.
April 26, 2000	"Machine designed to dump odor"	Robert Arrieta	Citrus County Chronicle	Documented the processing demonstration held at Citrus County Central Landfill on April 25th, 2000.
April 26, 2000	"Pilot gypsum project looks promising"	Josh Zimmer	St. Petersburg Times	Documented the processing demonstration held at Citrus County Central Landfill on April 25th, 2000.

NRSWA IRG

No other publications were published about the NRSWA IRG. This is due to the fact that all of the waste gypsum that was used for this project came from one source – the manufactured housing plant, Homes of Merit, in Lake City, Florida. It was not necessary to get a lot of people involved when there was only one company involved in generation.

In contrast, farmers need to be educated about this project since they are the targeted end-users of the recycled material. It is essential that they know that the material is available and of equal quality to the gypsum they currently purchase. They could also be educated about the benefits of using gypsum on their fields if they currently do not do so. Time constraints did not allow any such publications to be generated.

Okaloosa IRG

Nothing was published about the Okaloosa IRG. Individual meetings with waste haulers, drywall contractors, and C&D landfill operators were held. The project team found that this was a more effective way of educating people in this area about the project. By meeting with the key people involved in this industry, questions can be answered up front and the project can be well understood.

APPENDIX B
Putnam County Class III Waste Sort

Putnam County Class III Waste Sort
December 9-10, 1999

Summary

A solid waste composition study was conducted at the Putnam County landfill on December 9 and 10, 1999 as part of the Innovative Recycling Grant project on the recovery and recycling of gypsum drywall. Two different solid waste streams were evaluated. The first was class III debris collected at the Putnam County Class III landfill facility. The second was Construction and Demolition (C&D) debris from a private C&D landfill located near the County landfill.

The objective of the study was to perform an initial survey of these waste streams in Putnam County, with specific respect to the amount of gypsum drywall present in the waste stream. Methodologies for performing waste composition studies on bulky debris such as Class III and C&D debris are not well established as with municipal solid waste (MSW). A single load of C&D may be very different from other loads of C&D debris because the load represents only a portion of a given generator (house construction, demolition). Therefore the traditional method of mixing and dividing loads of waste and measuring the composition of small fractions of the waste (to represent the whole) is not applicable.

The approach taken during the two-day survey was to perform a visual sort on all loads of waste selected (on the entire load), and to perform a mass sort on selected loads for comparison.

	Day 1	**Day 2**
Class III Waste		
Total Loads	2	
Loads Sorted by Volume	2	
Loads Sorted by Weight	2	
C&D Debris		
Total Loads		4
Loads Sorted by Volume		4
Loads Sorted by Weight		2

Description of Work

Day 1

On December 9, 1999 three students (Paul, Allison and Brad) visually characterized and manually sorted two 40 yd^3 roll-off containers. This process took one work day, from 8 a.m. to 4 p.m. These roll-offs were from collection sites around the county, so they did not contain 100% C&D waste. The first roll-off contained a large amount of discarded textbooks (approximately 60% of the total volume), and old metallic lawn chairs. There was also a large amount of land clearing debris present in the load. It was decided to remove all of the C&D waste present in the load and to weigh only those components.

The second roll-off contained more typical C&D waste, but there was also a large amount of land clearing debris present. The lighter components (plastic and PVC) were weighed manually, while others such as dimensional wood and cardboard were weighed using the front-end loader at the landfill scales.

Day 2

On December 10, four roll-off containers that would have gone to the private landfill in the county were instead sent to the Putnam County landfill. Two of them were visually characterized and manually sorted by four students (Paul, Allison, Kenton and Brad). This also took eight hours, 32 hours cumulatively. The other two were only visually inspected because of time constraints.

The first load consisted mainly of dimensional wood with some insulation mixed in with it. The insulation was separated out and weighed manually. The weight of the insulation was subtracted from the total weight to get the weight of the wood.

The second load that came in was waste from a new commercial building. Four hours were spent picking through it but it was not completely sorted. With four students picking through the waste, the volume of the waste was reduced, but it was decided that more labor was needed to complete a job such as this one. The waste had a great deal of cinder blocks and soil in it, causing difficulties in removing the various components of the waste stream. It was decided that it would be difficult to remove any more waste, so the sort was stopped. Better results could have been obtained from the sort if there were more people involved and/or different equipment present (such as a Bobcat).

Results

The following tables summarize the results of the waste sorts. Where applicable, the percentage by both volume and mass are given. Appendix A presents graphs of the results.

Results from Day 1

Load: Day 1, Load 1 Class III
Total Volume 40 cubic yards
Tonnage 6.79 ton 13580 lb

Category	% Volume A	% Volume B	% Volume C	% Mass
Wood	0	5	10	4.6%
Drywall	**1**	**1**	**5**	**3.7%**
Ceiling Tiles	1	2	5	1.6%
Plastic	2	10	5	
Buckets	0	1	0	
Cardboard	2	6	10	
Metal	2	5	5	
Biological	10	0	0	
Paper	82	70	60	
Other	-	-	-	90.1%
Total	100	100	100	100%

Load: Day 1, Load 2 Class III
Total Volume 40 cubic yards
Tonnage 1.49 ton 2980 lb

Category	% Volume A	% Volume B	% Volume C	% Mass
Wood	75	60	50	42.3%
Drywall	**0**	**0**	**0**	**0.0%**
Plastic	1	2	5	0.4%
PVC	1	5	10	0.5%
Buckets	0	0	5	
Cardboard	23	30	30	6.0%
Other	-	-	-	50.8%
Total	100	97	100	100%

Results from Day 2

Load: Day 2, Load 1 C&D
Total Volume 16 cubic yards
Tonnage 1.44 ton 2880 lb

Category	% Volume A	% Volume B	% Volume C	% Volume D	% Mass
Wood	85	90	97	90	94.7%
Drywall	**0**	**0**	**0**	**0**	**0.0%**
Insulation	15	10	3	10	5.3%
Other	-	-	-		
Total	100	100	100	100	100%

Note: Weight of Wood Determined by Subtracting Weight of Insulation from Total Weight

Load: Day 2, Load 2 C&D
Total Volume 20 cubic yards
Tonnage 9.39 ton 18780 lb

Category	% Volume A	% Volume B	% Volume C	% Volume D	% Mass
Wood	2	0	0	10	0.0%
Cardboard	5	2	0	0	1.2%
Drywall	**2**	**0**	**0**	**0**	**3.2%**
Concrete	0	25	0	0	
Plastic	3	1	1	10	0.5%
Metal	5	5	7	10	0.5%
Insulation	3	2	13	10	0.2%
Cinder Block	15	0	25	25	16.0%
Biological	35	30	10	10	
Ceiling Tiles	30	35	35	25	0.8%
Other	-	-	-		**77.7%**
Total	**100**	**100**	**91**	**100**	**100%**

Results from Day 2 Continued

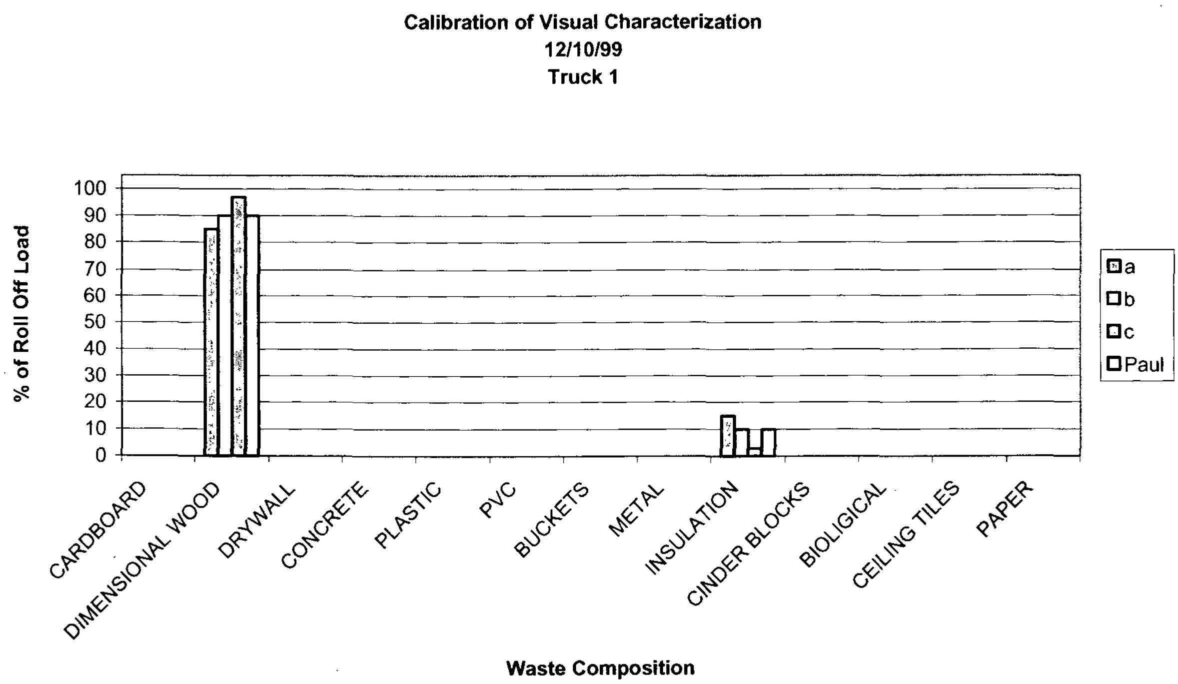
Load: Day 2, Load 3 C&D
Total Volume 20 cubic yards
Tonnage 8.57 ton 17140

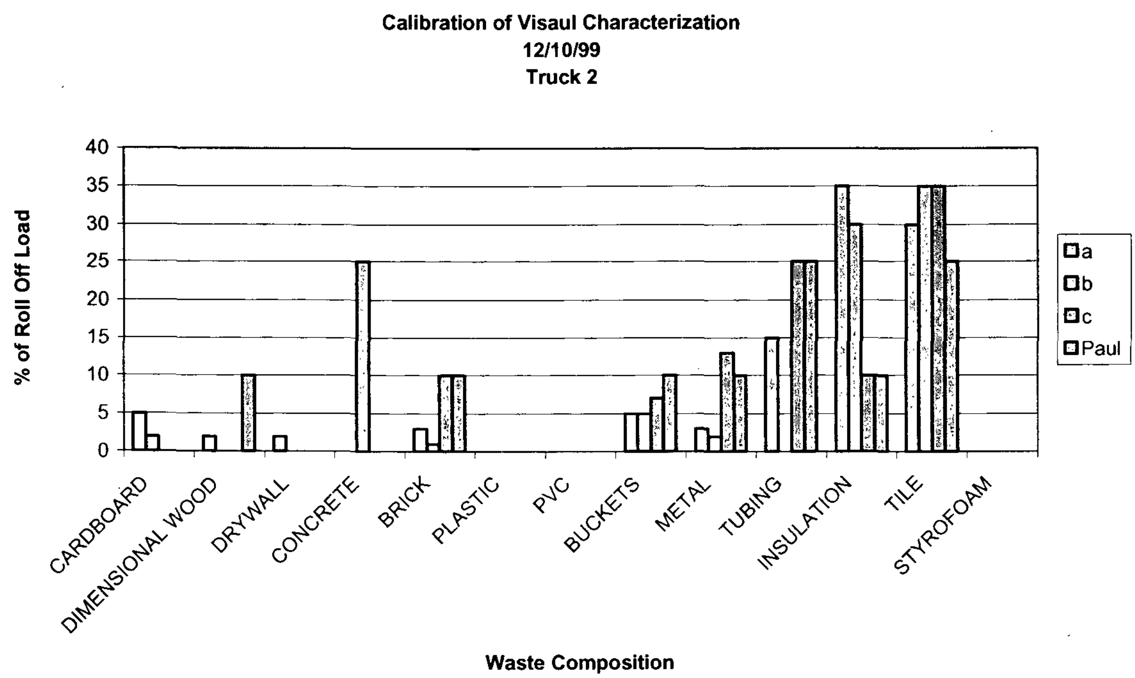
Category	% Volume A	% Volume B	% Volume C	% Volume D
Wood	5	5	5	20
Cardboard	30	2	35	20
Drywall	**10**	**10**	**10**	**0**
Concrete	40	60	45	30
Plastic	5	2	0	5
Metal	0	1	0	0
Insulation	5	0	5	0
Cinder Block	0	0	0	15
Paper	5	10	0	10
PVC	0	1	0	0
Total	**100**	**91**	**100**	**100**

Load: Day 2, Load 4 C&D
Total Volume 16 cubic yards
Tonnage 2.43 ton 4860

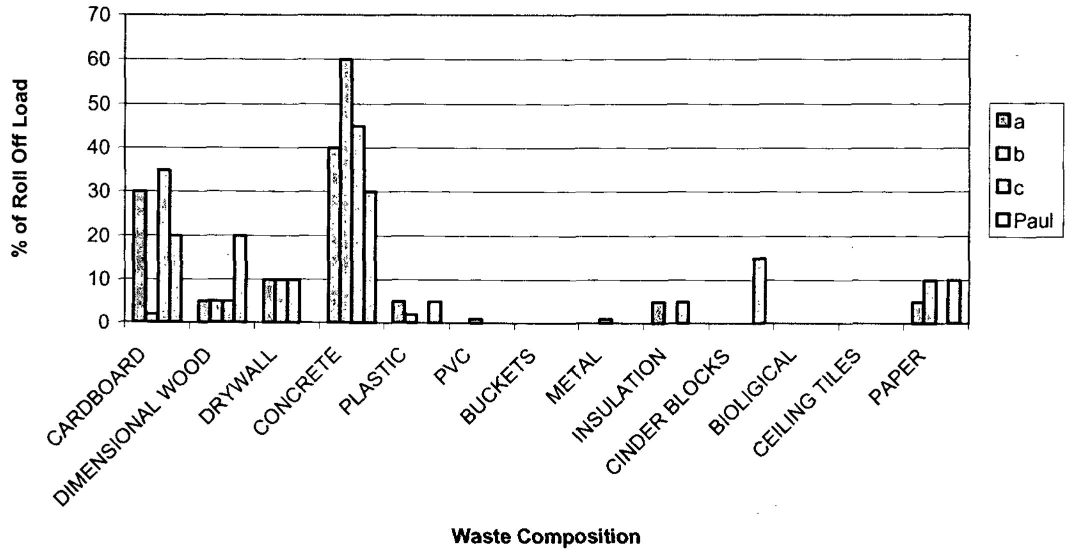
Category	% Volume A	% Volume B	% Volume C	% Volume D
Wood	10	5	0	0
Cardboard	20	2	10	20
Drywall	**20**	**3**	**0**	**0**
Concrete	0	10	10	10
Plastic	0	5	0	0
Metal	10	25	20	20
Insulation	30	50	50	40
Biological	10	0	10	10
Total	100	100	100	100

Appendix A
Visual Characterization Data

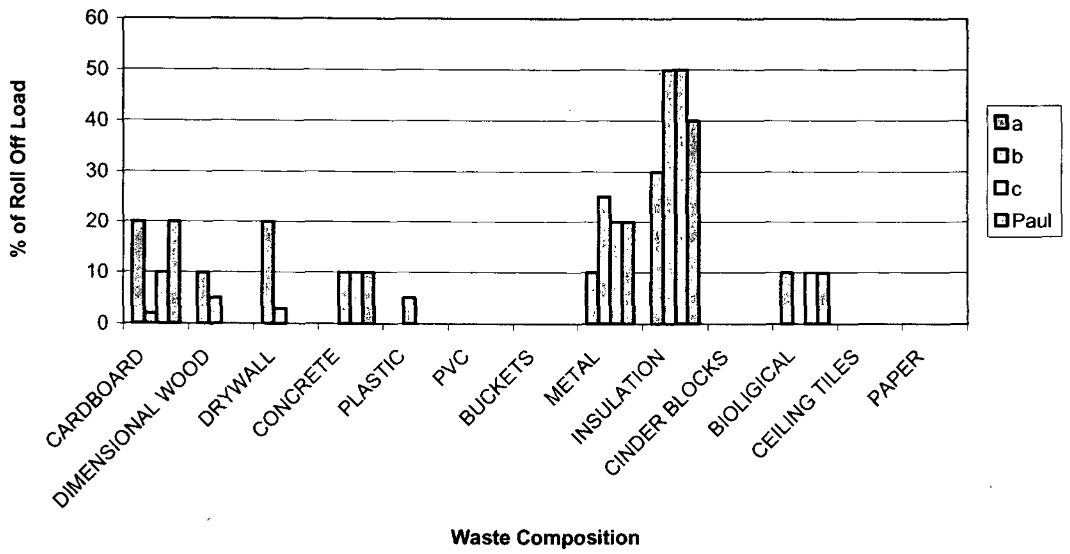

Calibration of Visual Characterization
12/10/99
Truck 1
% of Roll Off Load
100
90
80
70
60
50
40
30
20
10
0
CARDBOARD
DIMENSIONAL WOOD
DRYWALL
CONCRETE
PLASTIC
PVC
BUCKETS
METAL
INSULATION
CINDER BLOCKS
BIOLIGICAL
CEILING TILES
PAPER
Waste Composition
a
b
c
Paul

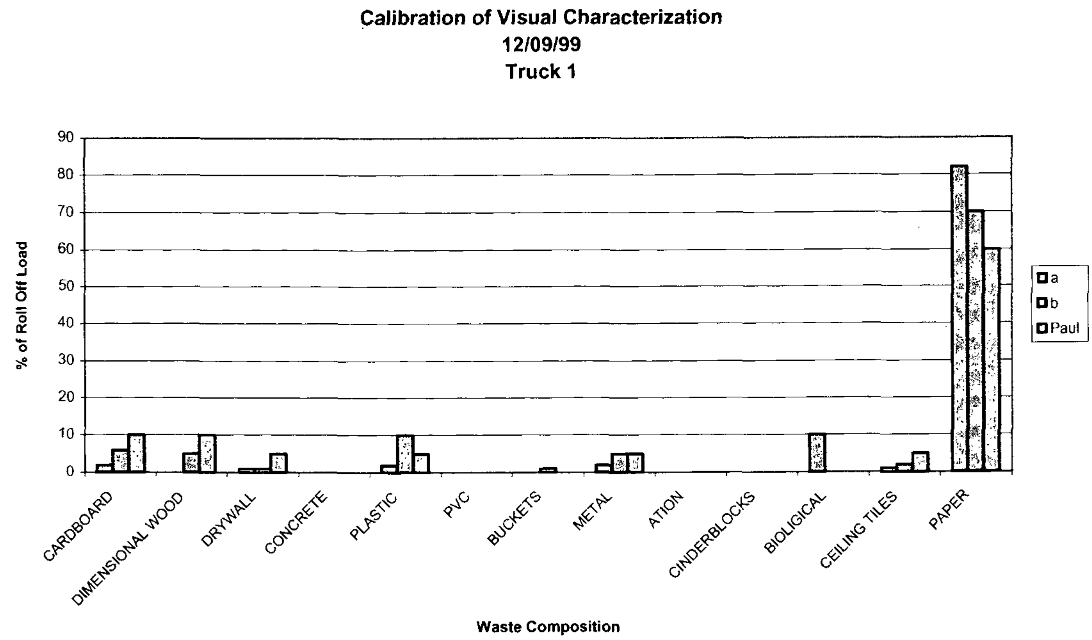

Calibration of Visaul Characterization
12/10/99
Truck 2
% of Roll Off Load
40
35
30
25
20
15
10
5
0
CARDBOARD
DIMENSIONAL WOOD
DRYWALL
CONCRETE
BRICK
PLASTIC
PVC
BUCKETS
METAL
TUBING
INSULATION
TILE
STYROFOAM
Waste Composition
a
b
c
Paul

Calibration of Visual Characterization
12/10/99
Truck 3

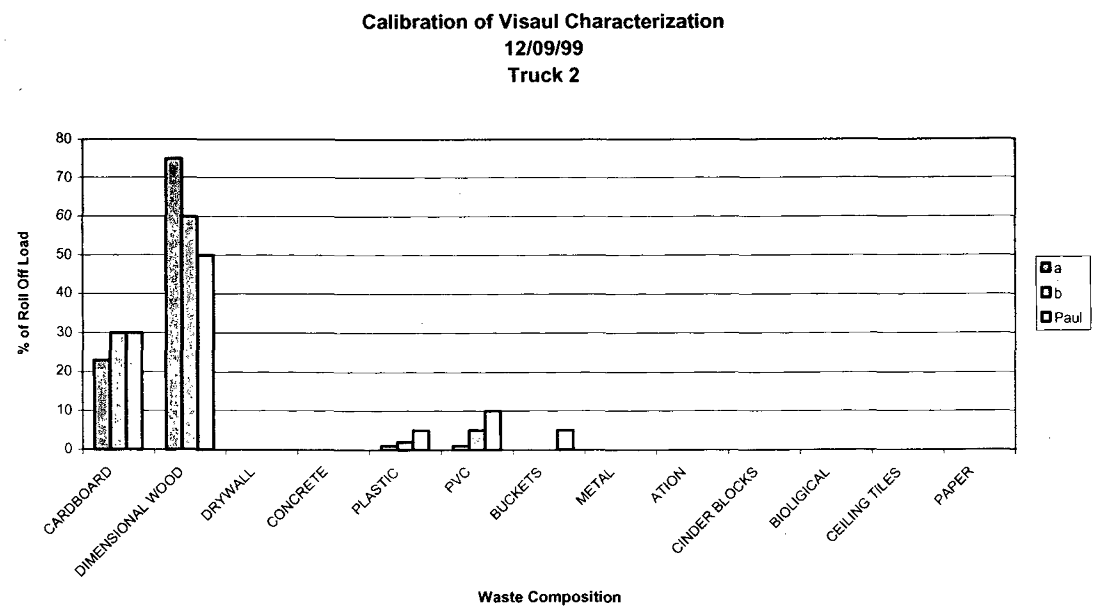


Calibration Of Visual Characterization
12/10/99
Truck 4





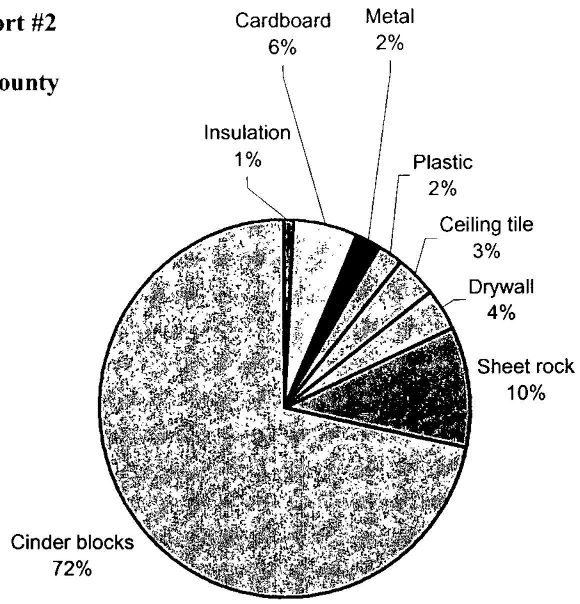
Calibration of Visual Characterization
12/09/99
Truck 1
90
80
70
60
50
40
30
20
10
0
% of Roll Off Load
a
b
Paul
CARDBOARD
DIMENSIONAL WOOD
DRYWALL
CONCRETE
PLASTIC
PVC
BUCKETS
METAL
ATION
CINDERBLOCKS
BIOLIGICAL
CEILING TILES
PAPER
Waste Composition

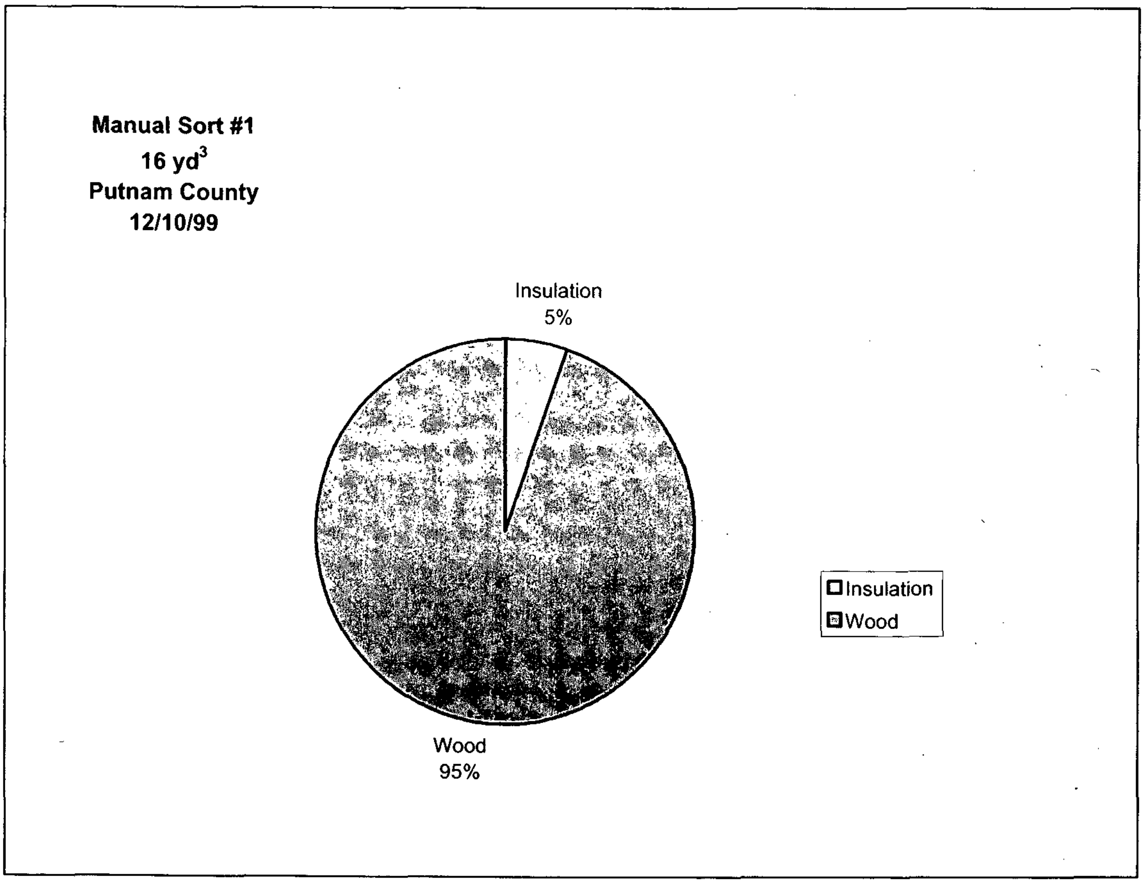


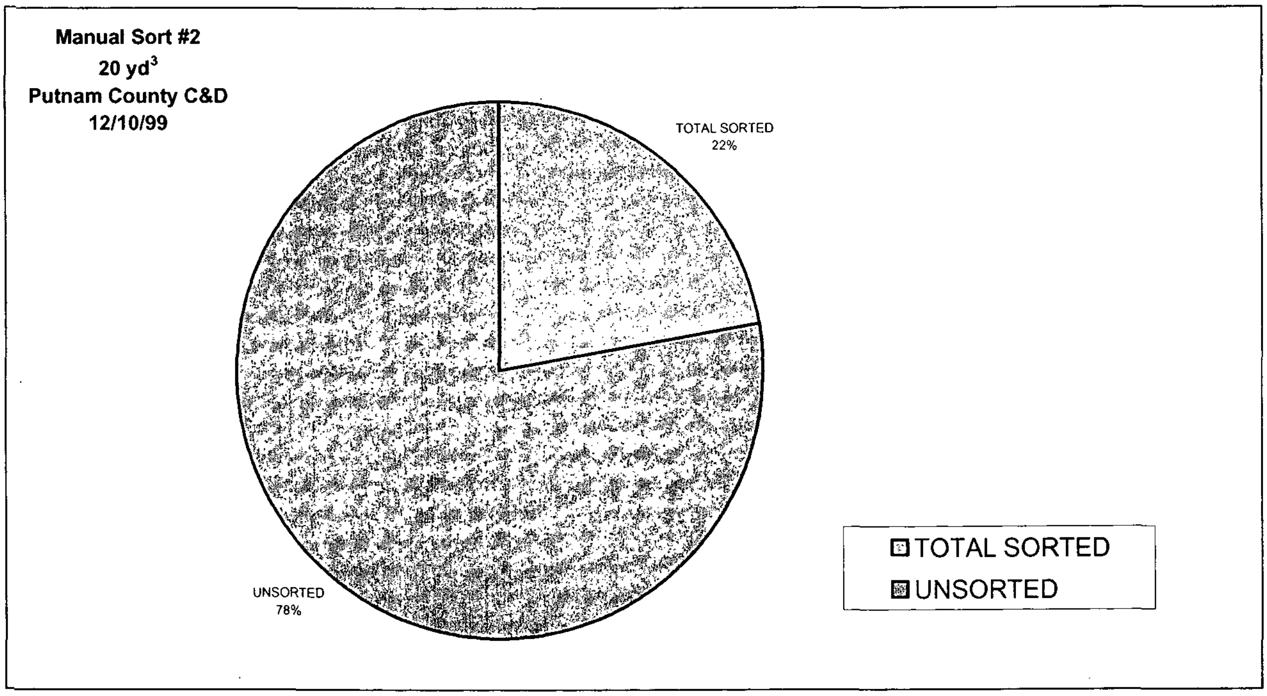
Calibration of Visaul Characterization
12/09/99
Truck 2
80
70
60
50
40
30
20
10
0
% of Roll Off Load
a
b
Paul
CARDBOARD
DIMENSIONAL WOOD
DRYWALL
CONCRETE
PLASTIC
PVC
BUCKETS
METAL
ATION
CINDER BLOCKS
BIOLIGICAL
CEILING TILES
PAPER
Waste Composition

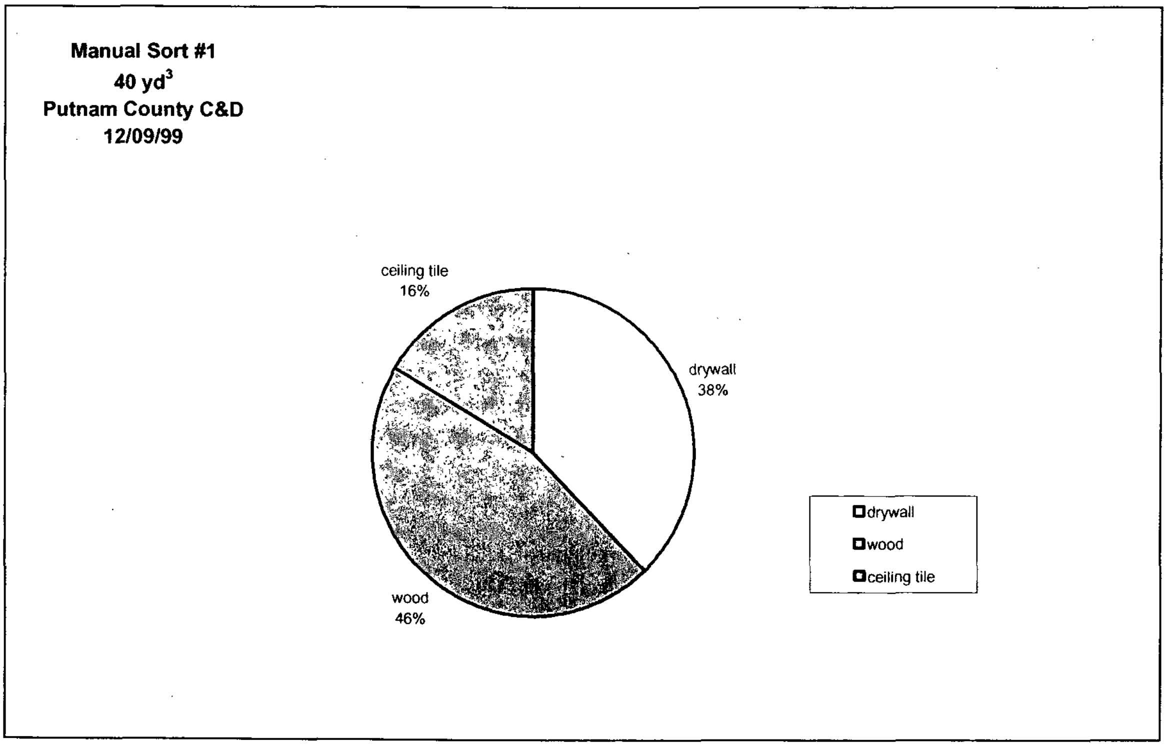
Appendix B
Manual Sort Data

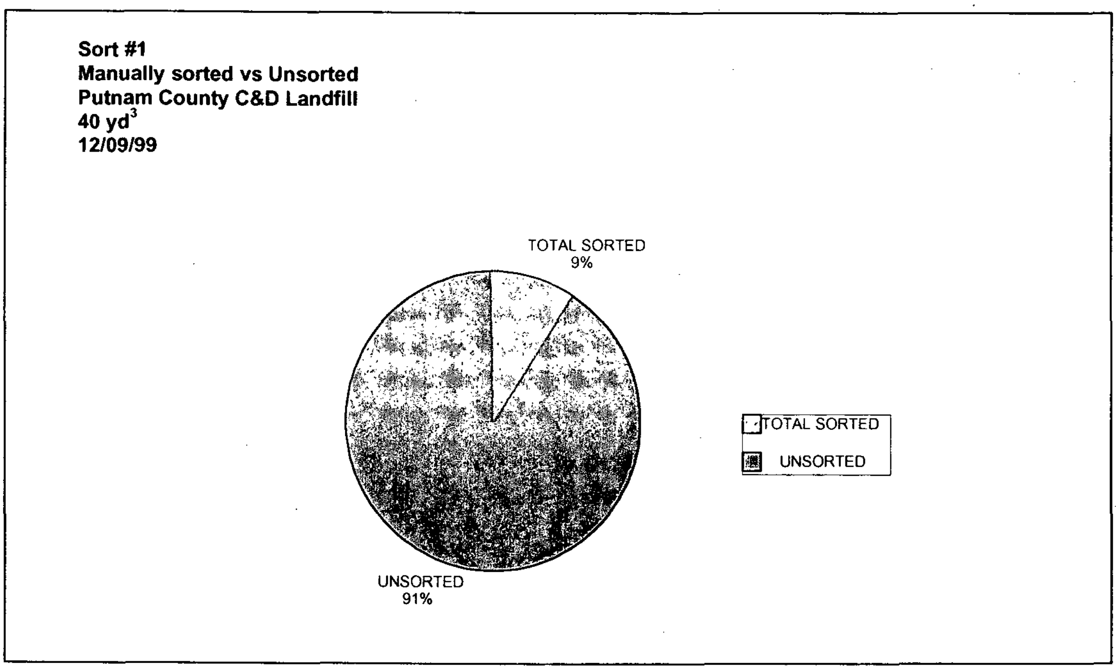
Manual Sort #2
20 yd3
Putnam County
C&D
12/10/99

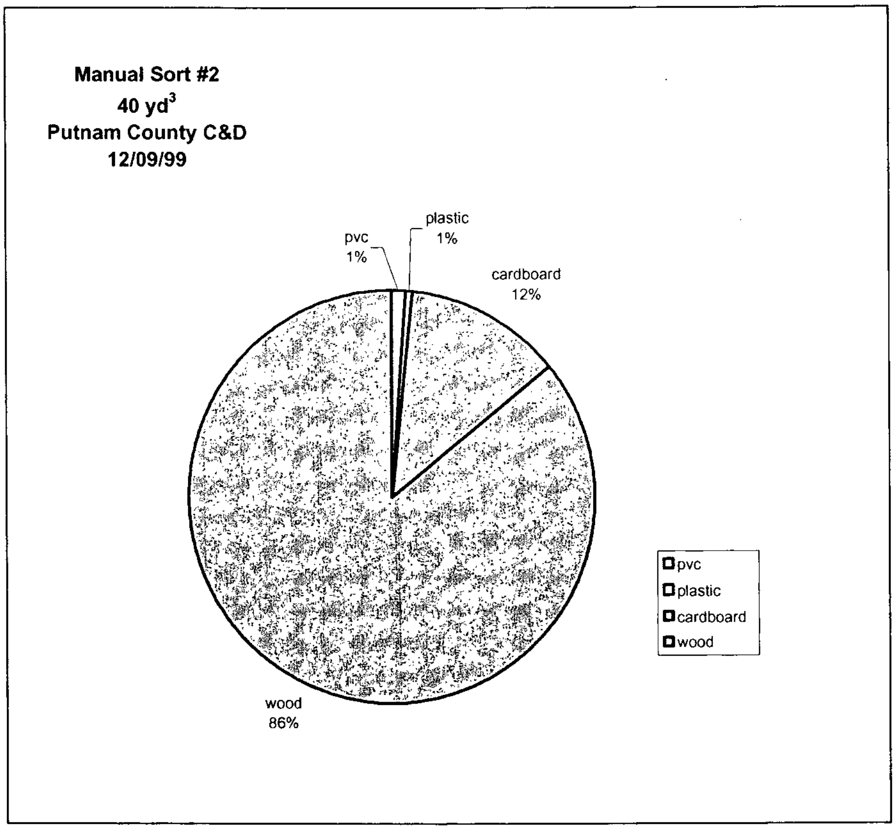


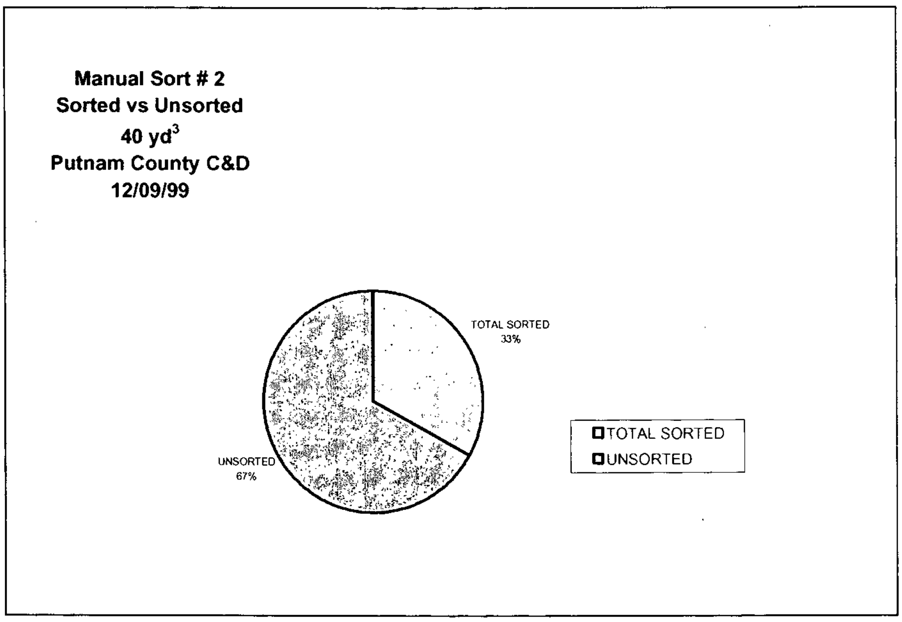

Manual Sort #1
16 yd3
Putnam County
12/10/99
Insulation
5%
Wood
95%
Insulation
Wood


Manual Sort #2
20 yd³
Putnam County C&D
12/10/99
TOTAL SORTED
22%
UNSORTED
78%
TOTAL SORTED
UNSORTED


Manual Sort #1
40 yd³
Putnam County C&D
12/09/99
ceiling tile
16%
drywall
38%
wood
46%
drywall
wood
ceiling tile


Sort #1
Manually sorted vs Unsorted
Putnam County C&D Landfill
40 yd³
12/09/99
TOTAL SORTED
9%
UNSORTED
91%
TOTAL SORTED
UNSORTED


Manual Sort #2
40 yd³
Putnam County C&D
12/09/99
pvc 1%
plastic 1%
cardboard 12%
wood 86%
pvc
plastic
cardboard
wood


Manual Sort # 2
Sorted vs Unsorted
40 yd³
Putnam County C&D
12/09/99
TOTAL SORTED 33%
UNSORTED 67%
TOTAL SORTED
UNSORTED

Appendix C
Pictures

20 yd^3 Roll-off dumping at the lower pit


View of the C&D pit from the lower level pit

After visual characterization, the manual sort begins

Placing cinderblocks into the front-end loader


Elevated view of a C&D load containing cardboard, drywall and ceiling tile

A separated pile of dimensional wood before being weighed (using the front end loader)

Piles of separated ceiling tiles and drywall before being weighed manually

Brad separating cardboard from the waste pile

This picture shows the length and height of a roll-off load. Brad (left) is at the ground level, while Paul (right) is elevated some height from the ground level.


The front-loader used to weigh heavy piles


A light pile of plastic being weighed manually

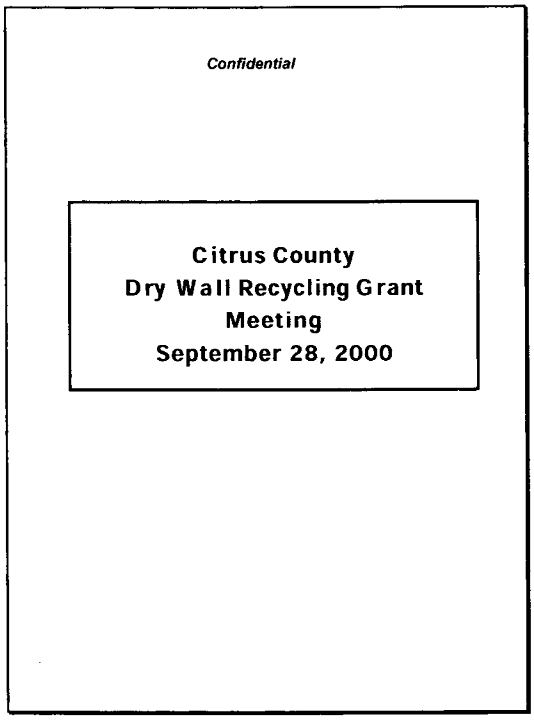
APPENDIX C
Weight-Based Composition Study Data Collection Sheet

	Component	Weight ( )											
Wood	Dimensional												
	Plywood												
	OSB												
	Pallets												
	Spools												
Concrete	Board												
	Block												
	Foundation												
	Mortar												
Paper	Paper												
	Cardboard												
Drywall	Drywall												
	Greenboard												
Metal	Ferrous Metal												
	Non-Ferrous Metal												
	Buckets												
	Wires												
	Other												
	Insulation												
g	Asphalt Shingles												
	Clay Tile Shingles												

	Asphalt Roofing Paper												
Plastic	Wrap												
	PVC												
	Buckets												
Flooring	Tile												
	Carpet												
	Padding												
	MSW												
	Dirt/Rubble												
	Land Clearing												
Other													

APPENDIX D
Stakeholder Meeting I and Economic Analysis

Slide 1


Confidential
Citrus County
Dry Wall Recycling Grant
Meeting
September 28, 2000

Slide 2

Confidential

List of Attendees

- John Warner, Superior Waste
- David Kindall, Agricyle
- Tom Edwards, R.W. Beck
- Gordon Wainwright, Citrus Cty Building Div.
- Lorie Clark, Clark Construction
- Judy Ramsey, Citrus Cty. Builders Assoc.
- Tim Townsend, Univ. of Florida
- Allison Barnes, Univ. of Florida
- Kim Cochran, Univ. of Florida
- O.N. Wheeler, Florida Crushed Stone
- Tony Fugnito, Waste Management
- Susie Metcalfe, Citrus County SWMD
- Chuck Sanders, Citrus Hills Construction
- Frank Kraft, Seaside Sanitation
- Frank Wentzel, Citrus County SWMD
- Chuck McLendon, R.W. Beck
- Larry Conrad, SandLand of Florida
- Stephanie Petro, FDEP Tampa District

Slide 3

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Proposed Agenda

1. Introduction
2. Overview - Waste Disposal System
3. Issues Map
4. Solutions

Slide 4

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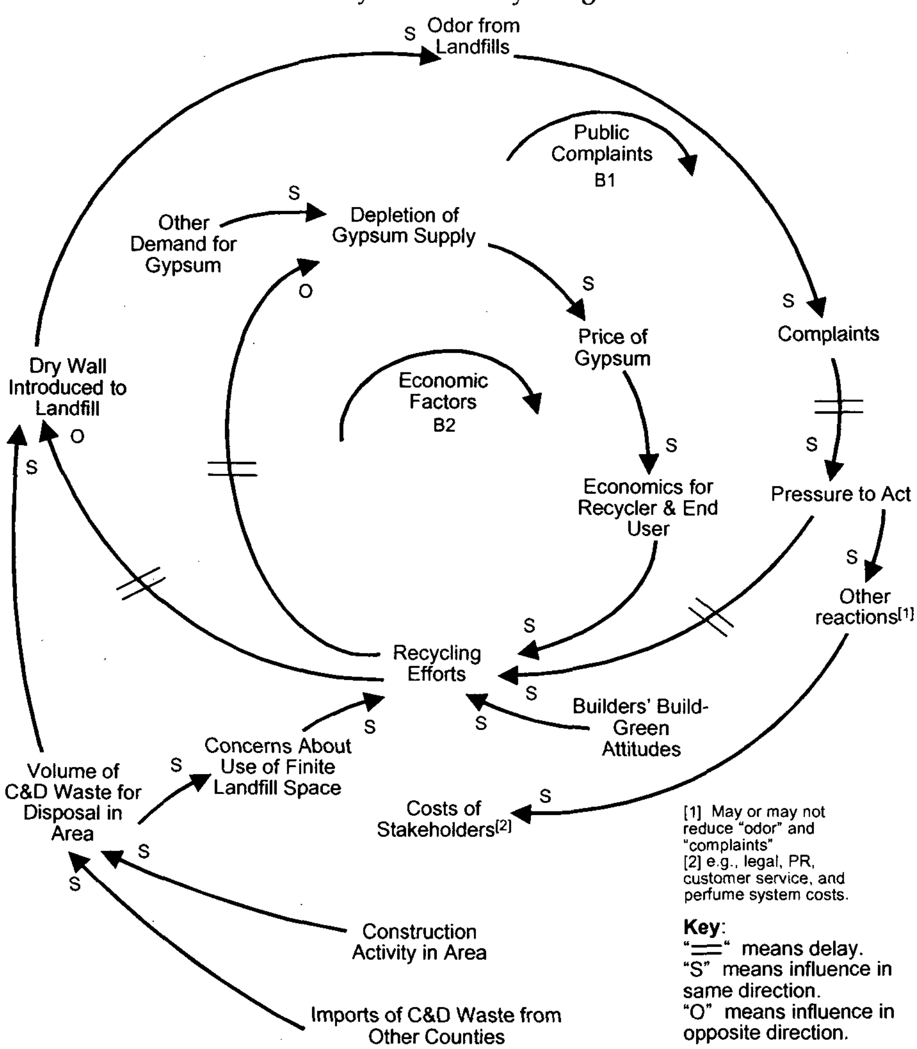
Agenda Item 1: Overview - Waste Disposal System

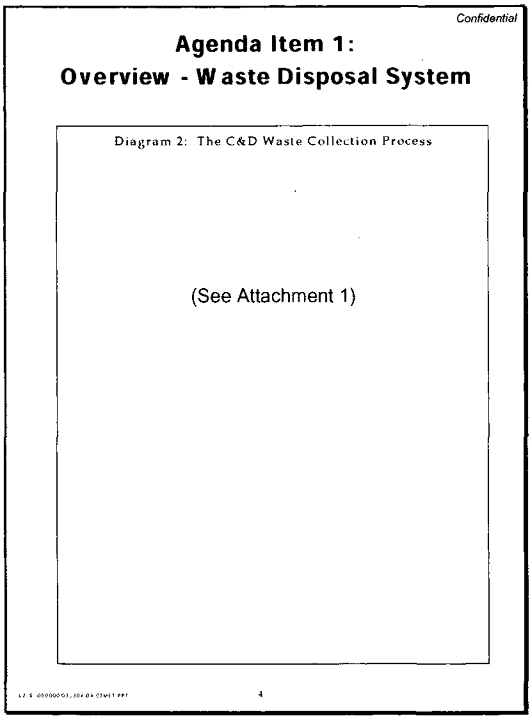
Diagram 1: Key Factors that Drive Interest in Dry Wall Recycling



[1] May or may not reduce "odor" and "complaints"
[2] e.g., legal, PR, customer service, and perfume system costs.

Key:
"=" means delay.
"S" means influence in same direction.
"O" means influence in opposite direction.

Slide 5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Agenda Item 1:
Overview - Waste Disposal System
Diagram 2: The C&D Waste Collection Process
(See Attachment 1)
4

Slide 6

Confidential

Agenda Item 3:
Issues Map - Framing Question

- What factors will be key to the attractiveness of a drywall recycling program in Citrus County.
  - Over the next year

Slide 7

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Agenda Item 3:
Issues Map Development Process

- Each meeting participant lists 3-5 answers
  - Head-line form
- Answers collected <u>one</u> at a time in turn
  - Only clarifying questions
  - No DEBATE
  - No WAR stories
  - If super important---Ask me to use a green hexagon

Slide 8

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Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year

- Contractors' Support

19
Willingness of contractors to participate
- if benefits/impacts are small

6
No added inconvenience to contractors

Slide 9

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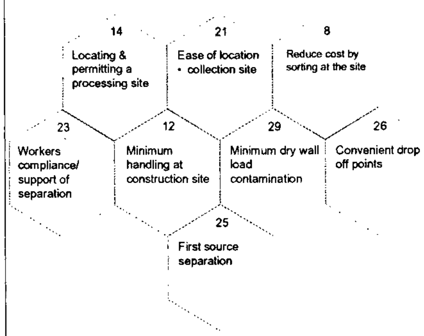
Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year

- Collection Logistics



Slide 10

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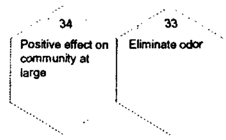
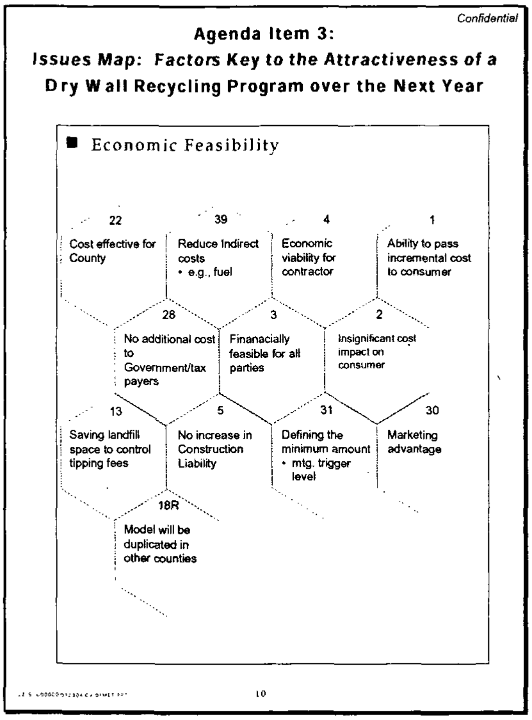
Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year

- Community Benefit



Slide 11


Confidential
Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year
Economic Feasibility
22
Cost effective for County
39
Reduce Indirect costs
• e.g., fuel
4
Economic viability for contractor
1
Ability to pass incremental cost to consumer
28
No additional cost to Government/tax payers
3
Finanacially feasible for all parties
2
Insignificant cost impact on consumer
13
Saving landfill space to control tipping fees
5
No increase in Construction Liability
31
Defining the minimum amount
• mtg. trigger level
30
Marketing advantage
18R
Model will be duplicated in other counties
10

Slide 12

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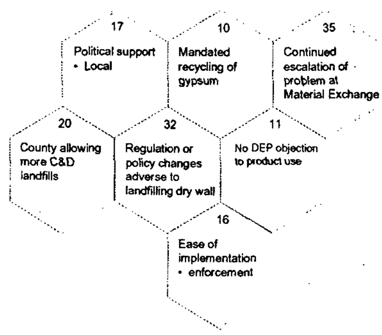
Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year

- Political/Regulatory



Slide 13

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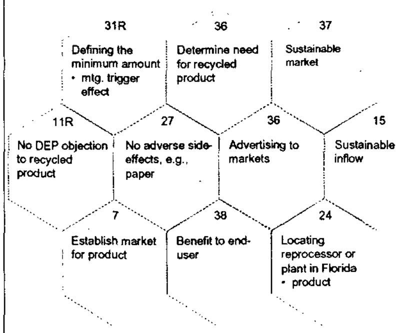
Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year

■ Market



Slide 14

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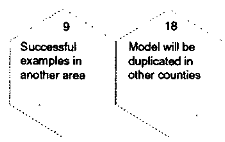
Agenda Item 3:
Issues Map: Factors Key to the Attractiveness of a Dry Wall Recycling Program over the Next Year

- Technology Transfer



Slide 15

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Agenda Item 4: Solutions to Consider

- Follow examples of other recycled materials
  - Cardboard, tires
- Choices of Point of Separation
  - Landfill, source, combination of both
- Options for Separation at Source
  - Identify loads that are mainly dry wall
    - Schedule a container swap when drywall installation process begins and ends
  - Independent collector/scrapper
  - Use 2 containers on site - one for dry wall and one for other waste
    - smaller containers
    - coordinate drop-off & pick-up of 2nd container
      - to be available during dry wall installation process
    - Change pricing so sum of charges to contractor for both containers is similar to charge for one container
  - Grind at construction site & use for soil amendment/fill
    - Requires $90k machine
  - Use split container
  - Pile separately on site/separate pick-up by recycler/hauler

Slide 16

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Agenda Item 4: Solutions to Consider

- Delivery to transfer station
  - convenient to contractor
  - County or private
  - Permit mod maybe required
    - maybe a written mod
  - Requirement that processor may become a MRF
- Contractors require source separation by subs.
  - Hangers pile it
  - Dry wallers then put in dumpster
  - 1-1/2 cents/board foot to clean up dry wall

Slide 17

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Next Steps

- Draft Potential Options (Mid Oct)
- Mail to stakeholders
- Meet again
  - 1 week after mail-out
  - 10/19/00 discussed as potential date

Slide 18

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Miscellaneous Discussion Points

- Survey of Landfills
  - Surveyed landfills in central Florida and from coast-to-coast
  - All had odor
  - Not all had complaints
- Effect of Landfill Operating Practices
  - Covering waste reduces odor
  - Doesn't solve problems
    - The odor cannot usually be fixed by changing landfill operation practices
- Chemical Solution?
  - Maybe, study & testing underway
- Recyclable Dry wall
  - New construction
  - Manufactured Housing
  - Demolition is not a good source

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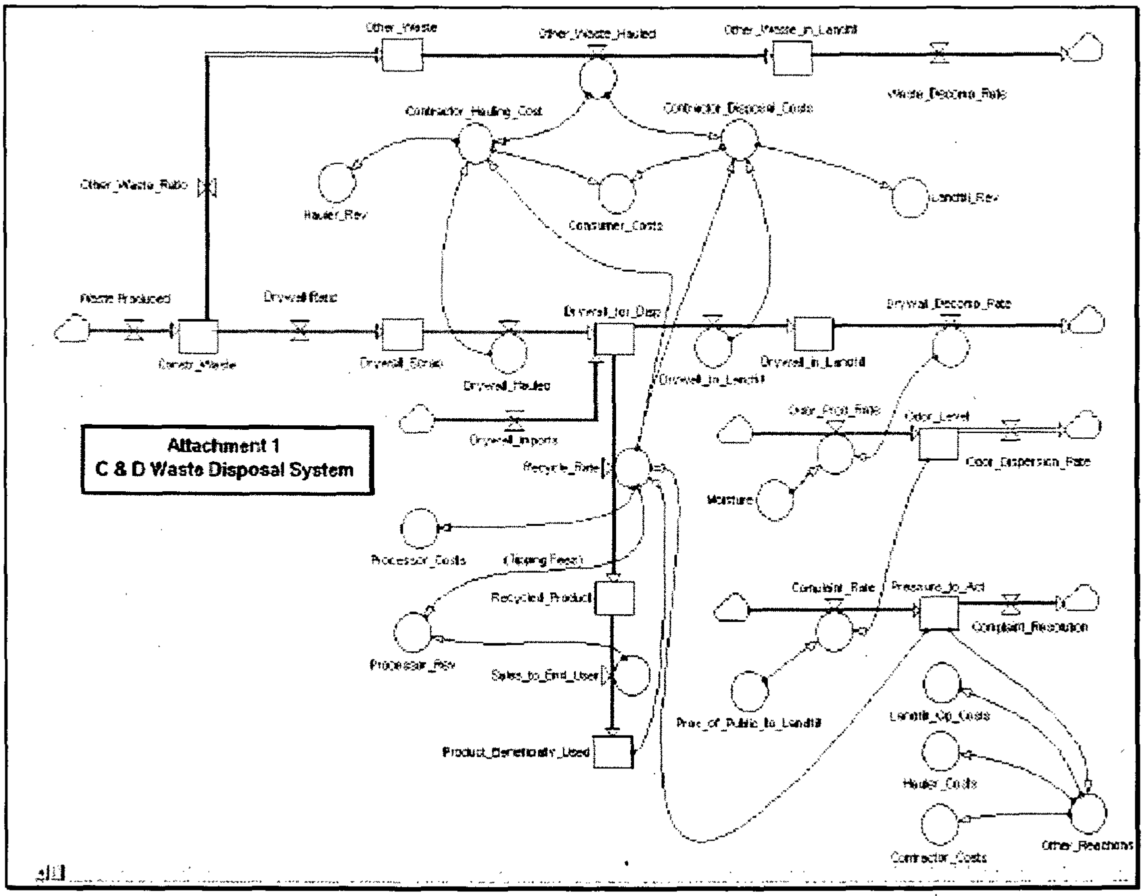
Miscellaneous Discussion Points (cont)

- Complaints
  - Normally, from public in close proximity to landfill
  - Within 1/2 mile or 1 mile
- Economics
  - Trigger points?
- Need input from dry wall contractors!
- Source of odor
  - Gypsum main source
  - Other factors (e.g., moisture) affect whether gypsum will produce odor

Slide 20


Attachment 1
C & D Waste Disposal System
Contractor_Hauling_Cost
Hauler_Rev
Consumer_Costs
Landfill_Rev
Drywall_Scrap
Drywall_Hauled
Drywall_Imports
Recycle_Rate
Drywall_in_Landfill
Drywall_to_Landfill
Odor_Level
Odor_Dispersion_Rate
Moisture
Processor_Costs
Recycled_Product
Processor_Rev
Sales_to_End_User
Product_Beneficially_Used
Complaint_Rate
Pressure_to_Act
Complaint_Resolution
Landfill_Op_Costs
Hauler_Costs
Contractor_Costs
Other_Reactions

ECONOMIC ANALYSIS: OPTIONS FOR SOURCE SEPARATION OF SCRAP GYPSUM DRYWALL AT THE RESIDENTIAL CONSTRUCTION SITE

1.0 INTRODUCTION

Gypsum drywall is one of the larger components of the waste stream at residential construction sites. The scrap drywall is typically co-disposed with other construction waste in a waste disposal roll-off box, or in some cases the mixed waste is stored in wire bins. As part of assessing the feasibility of recycling scrap gypsum drywall from new construction in Citrus County, a number of possible source separation techniques were identified. The six techniques that were identified are summarized in Table 1. The techniques are outlined in detail in this report. Advantages and disadvantages of each method are discussed.

TABLE 1. OPTIONS FOR SOURCE SEPARATING SCRAP DRYWALL

METHOD
A. Placement of two separate waste containers, with one for only drywall scrap.
B. Use of optimized (smaller) container sizes so a single container is delivered and filled up at the time of drywall scrap generation.
C. Utilize existing system, but process the one load (phase III) that contains the largest amount of scrap drywall.
D. Utilize a "scrapping" to clean up scrap drywall left in place by the drywall contractors.
E. Drywall contractors pile scrap drywall in a location such as the garage and a separate subcontractor reviews the drywall for processing.
F. Use of a partitioned container on site that will permit drywall to be separated upon disposal.

OPTION A: TWO CONTAINER SYSTEM

PROCESS DESCRIPTION

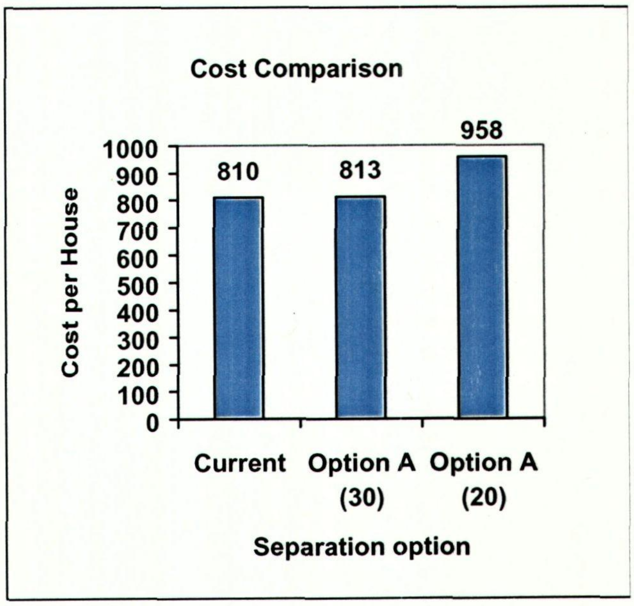
In this method, two containers would be placed at each construction site: one for scrap drywall and one for the remaining construction debris. The size of the drywall container would be sized to match the anticipated volume of drywall produced. The drywall subcontractor would be responsible for placing the scrap drywall in the drywall container.

Advantages	Disadvantages
❑ Utilizes existing equipment	❑ Requires space for additional container
❑ Potential for good separation	❑ Requires additional scheduling
❑ No dramatic change from current system	❑ Increase in number of container pulls
	❑ Slightly more expensive

ECONOMICS PER HOUSE (2500 FT^2)

CURRENT SYSTEM (ASSUMING 20 CU/YD. CONTAINERS)

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of three disposal pulls:	$435
Cost of disposal (60 yd^3):	$210
Total Cost	$810



OPTION A (ASSUMING 30 CU/YD. CONTAINERS)

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of two disposal pulls:	$290
Cost of one recycling pull:	$150
Cost of disposal (50 yd^3):	$175
Recycling Container Delivery	$30
Recycling Container Rental	$8
Recycling Pull Charge	$145
Total Cost:	$813

OPTION A (ASSUMING 20 YARD CONTAINER) $958

OPTION B: PROCESS DRYWALL LOAD FROM EXISTING SYSTEM

PROCESS DESCRIPTION

The existing waste collection system will be maintained, but the loads that contain primarily drywall will be delivered for recycling instead of disposal.

Advantages	Disadvantages
❑ Utilizes existing equipment	❑ Major increase in contamination levels
❑ Utilizes only one container	❑ Significantly higher processing costs
❑ Offers least change to existing operation	

ECONOMICS PER HOUSE (2500 FT²)

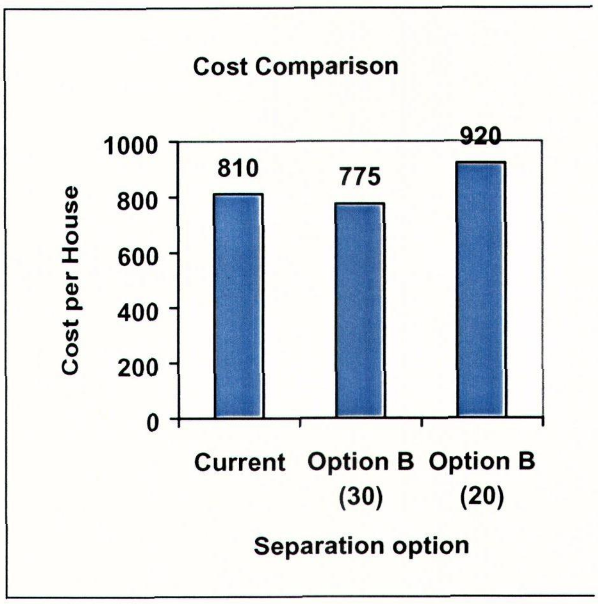
CURRENT SYSTEM

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of three disposal pulls:	$435
Cost of disposal (60 yd^3):	$210
Total Cost	$810

OPTION B (ASSUMING 30 CU/YD. CONTAINERS)

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of two disposal pulls:	$290
Cost of one recycling pull:	$145
Cost of disposal (50 yd^3):	$175
Total Cost:	$775

Option B (Assuming 20 Yard Container) $920



OPTION C: UTILIZE SCRAPPING SERVICE

PROCESS DESCRIPTION

A third party contractor would be used to collect drywall from inside the house immediately after the drywall had been hung. The "scrapper" will also be responsible for transporting collected drywall to the recycling location.

Advantages	Disadvantages
❑ More efficient use of hangers time	❑ Service not currently available
❑ Likely to result in pure loads of drywall	❑ Requires additional scheduling
❑ Cost-effective compared to current system	❑ Drywall may not be immediately picked up
❑ Should lower drywall subcontractors costs	

ECONOMICS PER HOUSE (2500 FT^2)

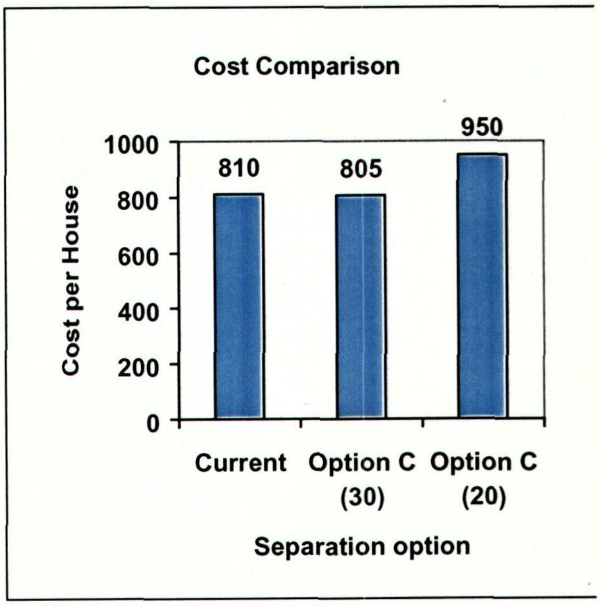
CURRENT SYSTEM

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of three disposal pulls:	$435
Cost of disposal (60 yd^3):	$210
Total Cost	$810

OPTION C (ASSUMING 30 CU/YD. CONTAINERS)

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of two disposal pulls:	$290
Cost of disposal (50 yd^3):	$175
Recycling Scrapping Service	$175
Total Cost:	$805

Option C (Assuming 20 Yard Container) $950



OPTION D: SEPARATE HAULER FOR SEGREGATED DRYWALL

PROCESS DESCRIPTION

A third party hauler would be used to collect segregated drywall that is piled outside of the house by the drywall subcontractor. The hauler will be responsible for loading the material and transporting it to the recycling location.

Advantages	Disadvantages
❑ No change in ritual for drywall subcontractor	❑ Requires additional scheduling
❑ Likely to result in pure loads of drywall	❑ Not the current practice
❑ Most cost effective recycling option	

ECONOMICS PER HOUSE (2500 FT^2)

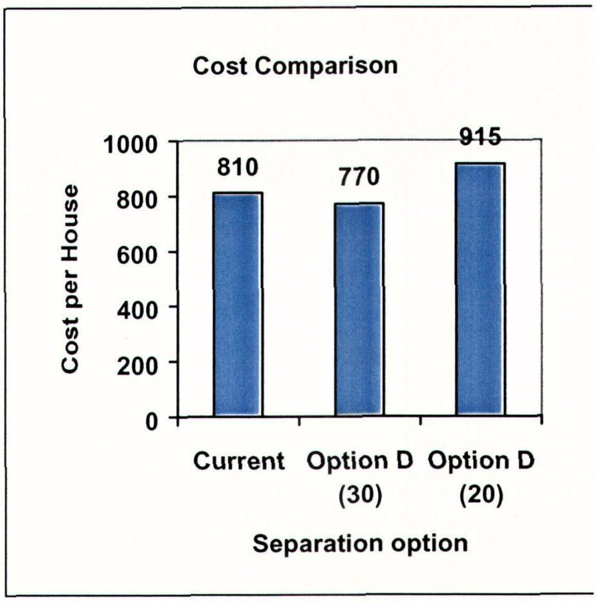
<u>CURRENT SYSTEM</u>

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of three disposal pulls:	$435
Cost of disposal (60 yd^3):	<u>$210</u>
Total Cost	$810

<u>OPTION D (ASSUMING 30 CU/YD. CONTAINERS)</u>

C&D Container Delivery	$30
C&D Container Rental	$135
Cost of two disposal pulls:	$290
Cost of disposal (50 yd^3):	$175
Recycling loading/delivery charge	<u>$140</u>
Total Cost:	$770

<u>Option D (Assuming 20 Yard Container)</u> $915



APPENDIX E
IFAS Agricultural Trial I (SVREC-Live Oak)

Evaluating the Application of Recycled Gypsum In Agricultural Production

Michael S. Sweat[1]
David A. Dinkins[2]
Robert C. Hochmuth[3]
Jacque Breman[4]

Introduction

This trial was designed to evaluate the potential agricultural use of recycled gypsum wallboard, which was obtained from waste construction debris by the New River Solid Waste Association as part of an Innovative Recycling Grant with the Florida Department of Environmental Protection.

Gypsum is a non-metallic mineral composed primarily of calcium sulfate ($CaSO_4$) and water ($2H_2O$). Gypsum is mixed with water to form a slurry, which is enclosed by two layers of paper and kiln dried to form wallboard. For purposes of this project, drywall was collected and size reduced. Paper is removed in the grinding and screening operation. Nutrient analysis of the recycled gypsum material by the University of Florida Soil Testing Laboratory indicated nutrient values of 1.48 ppm Zn, 0.16 ppm Cu, 9.56 ppm Mn, 43 ppm P, 159 ppm K, 340 ppm Mg, 4120 ppm Calcium and a pH of 7.7.

Four winter crops were selected for this trial: "Buttercrunch" bibb lettuce, "China Blue" chinese cabbage, "Bravo" green cabbage, and "Top Bunch" collards. Although the application of agricultural gypsum is not recommended on these crops in Florida, this trial was designed to evaluate the potential as an alternative method of disposal.

[1]County Extension Director, Baker County Extension Service, IFAS, University of Florida, Macclenny, FL.

[2] County Extension Director, Bradford County Extension Service, IFAS, University of Florida, Starke, FL.

[3] Multi-County Extension Agent, Suwannee Valley Research and Education Center, IFAS, University of Florida, Live Oak, FL.

[4]County Extension Director, Union County Extension Service, IFAS, University of Florida, Lake Butler, FL.

Materials and Methods

Plots were established in Lakeland fine sand at the North Florida Research and Education Center-Suwannee Valley near Live Oak, Florida. Preplant soil tests using the Mehlich - 1 extract, indicated values of 160 ppm P, 29 ppm K, 28 ppm Mg, and 560 ppm Ca. Soil pH was 6.9 using a 1:2 (soil:water) extract.

The soil was fertilized with 500 lbs per acre of 10-10-10 (N-P_2O_5-K_2O). Ground recycled gypsum was applied at six treatment rates (Table 1) and rototilled to a depth of six inches. Gypsum was hand applied to plots with 1000, 2000, and 5000 lbs/A rates. A poultry manure drop spreader was calibrated and used to apply the gypsum on plots with rates of 10,000 and 20,000 lbs/A. The crop also received an additional 80 lbs per acre of N and K_2O via weekly fertigations from 12/28/00 to harvest.

Beds were formed on 5-foot centers utilizing a Kennco mulch layer, fumigated with a 67:32 methyl bromide and chloropicrin mixture at a rate of 400 lbs per broadcast acre, and covered with Sonoco Products 48" embossed black "Enviromulch", .60 thickness, plastic mulch. Roberts Ro-Drip irrigation tubing was laid in a 1-inch deep groove in the center of the bed at the time of mulching. The final beds were 24 inches wide and 6 inches high.

Plots 20 feet in length were established on the beds. Plots were arranged in a randomized complete-block design and treatments were replicated four times. A total of 24 plots per crop were planted on 28-December 1999 with two rows per bed and plants spaced 12 inches apart in each row on the bed. Drip irrigation frequency was determined by the use of tensiometers. Water was applied to maintain a soil moisture level of -8 to -12 centibars at a 12-inch depth; this was approximately twice daily for 30 minutes. Insects and diseases were managed in accordance with a recommended pest management program consisting of weekly applications of registered fungicides and insecticides.

The entire experimental area required covering with polypropylene frost protection cover on 4 freeze events when the temperature fell below 28 degrees Farenheight. Row middles were cultivated as needed to reduce weeds.

Trials were harvested on 3/3/00, 3/16/00, 4/4/00, and 4/11/00. Ten plants from the center of each plot were evaluated and weighed, and three plants from each plot were cut and observed for internal quality problems. Representative leaf samples were taken for lab tissue analysis.

Results and Discussion

Yields (average weights) of Bibb Lettuce, Chinese Cabbage, Collards and Green Cabbage are presented in Table 2. Results indicate that the application of recycled gypsum had little effect on yield for any of the four crops planted. Internal quality evaluations of each crop found only slight internal discoloration on a few Bibb lettuce heads. This discoloration was minimal and was found in heads from plots with and without gypsum treatments. The University of Florida Plant Pathology Laboratory found no bacterial or fungal pathogens present in those samples.

Currently, the University of Florida Department of Environmental Engineering is conducting tissue analyses of each of the 96 plots. A commercial laboratory was utilized to analyze each of the collard samples from plots following harvest. The average results of the plant tissue analysis from the replicated collard trial for Boron, Zinc, Iron, Copper, Calcium, Magnesium, Sulfur, and Manganese are presented in Table 3. Only the Boron levels increased with additional levels of recycled gypsum, however, all levels were within the plant sufficiency range according to publication #SS-VEC-42, Plant Tissue Analysis and Interpretation For Vegetable Crops In Florida. The adequate range for Boron on collards at harvest is 25-50 ppm.

Soil test results from each of the 6 treatment rates of recycled gypsum are reported in Table 4. The soil pH was only minimally affected by the addition of recycled gypsum. Calcium showed an increase for all treatment rates above the control.

In summary, this trial has shown that the use of ground, recycled gypsum had little crop production effect on Bibb Lettuce, Chinese Cabbage, Collards, and Green Cabbage. It has also shown that collard plant tissue samples were only slightly affected with various rates of gypsum application.

Table 1

Gypsum Treatment Rates

Gypsum Rate (lbs/acre)	Amount of Gypsum per plot (lbs)	Plot #'s			
0	0	1	8	14	22
1000	2.3	2	10	13	19
2000	4.6	3	7	18	20
5000	11.5	4	11	16	21
10,000	23.0	5	9	17	23
20,000	46.0	6	12	15	24

Table 2

Average Weights From 4 Replicated Plots
Taken from 10 Center Heads in Each Plot

Gypsum Rate (lbs/A)	Bibb Lettuce (lbs)	Chinese Cabbage (lbs)	Collards (lbs)	Green Cabbage (lbs)
0	9.53	38.0	24.6	33.4
1000	8.93	34.8	21.5	35.2
2000	9.13	35.5	20.9	31.9
5000	9.18	37.2	24.9	37.9
10,000	9.18	36.5	25.5	38.1
20,000	9.33	37.5	22.8	35.2

Table 3

Collard Plant Tissue Analysis
(Average of 4 Replicated Trials)
Per Waters Lab Results 4/7/00

Gypsum Rate	Boron	Zinc	Iron	Copper	Calcium	Magnesium	Sulfur	Manganese
(lbs/A)	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
0	25.2	24.7	99.8	6.7	1.5	.27	.85	52.5
1000	28.7	22.7	80.5	8.0	1.6	.26	.91	51.8
2000	32.2	23.0	70.5	7.0	1.7	.27	.94	49.0
5000	37.2	24.5	83.5	6.5	1.7	.27	1.0	48.2
10,000	40.0	26.0	83.0	10.2	1.8	.27	1.0	53.2
20,000	45.2	23.0	68.0	6.0	2.0	.26	1.1	48.0

Table 4

Soil Test Results During Growing Period
IFAS Extension Soil Testing Lab
Set #2850 - 2/17/00

Gypsum Rate	pH	P	K	Mg	Ca
(lbs/A)		ppm	ppm	ppm	ppm
0	6.9	160+	29	28	560
1000	7.3	164+	18	28	652
2000	7.3	160+	14	20	640
5000	7.1	156+	13	20	688
10,000	7.1	176+	15	24	1024
20,000	7.0	110	11	16	760

APPENDIX F
IFAS Agricultural Trial II (Macclenny)

Recycling Gypsum Drywall Through Land Application For Agricultural Production

Observational Results on Cool Season Forage Crops and Clovers in Macclenny, Florida

Michael S. Sweat[1]
David A. Dinkins[2]
Jacque Breman[3]

Introduction

This observational trial was designed to explore the potential agricultural use of recycled gypsum wallboard, which was obtained from waste construction debris by the New River Solid Waste Association as part of an Innovative Recycling Project with the Florida Department of Environmental Protection.

Gypsum is a non-metallic mineral composed primarily of calcium sulfate (CaSO4) and water ($2H_2O$). Gypsum is mixed with water to form a slurry, which is enclosed by two layers of paper and kiln dried to form wallboard. Recycled drywall is collected, screened, and size is reduced. Paper is removed in the grinding and screening operation. Laboratory analysis of the recycled gypsum material indicated nutrient values of 43 ppm P, 159 ppm K, 340 ppm Mg, and 4120 ppm Calcium, 1.48 ppm Zn, .16 ppm Cu, 9.56 ppm Mn, and a pH of 7.7.

A two-acre trial was conducted to evaluate sixteen varieties of winter forage grasses and legumes after being planted in soil amended with seven rates of recycled gypsum. The trial was conducted at the Baker County Extension Office on Highway 90 in Macclenny, Florida during winter 1999 and early spring 2000. Although the application of agricultural gypsum is not recommended on these crops in Florida, this observational trial was designed to evaluate the potential as an alternative method of disposal.

[1]County Extension Director, Baker County Extension Service, IFAS, University of Florida, Macclenny, FL.

[2]County Extension Director, Bradford County Extension Service, IFAS, University of Florida, Starke, FL.

[3]County Extension Director, Union County Extension Service, IFAS, University of Florida, Lake Butler, FL.

Materials and Methods

Plots were established in an Albany fine sand at the Baker County Extension Office in Macclenny, Florida. Preplant soil tests using the Mehlich - 1 extract, indicated values of 3 ppm P, 13 ppm K, 16 ppm Mg, and 96 ppm Ca, 6.84 ppm Zn, .48 ppm Cu, and 2.28 ppm Mn. Soil pH was 5.2 using a 1:2 (soil:water) extract.

The soil was turned with a bottom plow to a depth of 6-8". A disk was utilized several times to loosen the soil and incorporate any debris. Dolomitic lime was broadcast at a rate of 1500 lbs per acre according to soil test recommendations for cool season legumes or legume-grass mixtures. The soil was fertilized with 800 lbs per acre of 10-10-10 (N-P_2O_5-K_2O).

New River Solid Waste Association provided two "roll-off" containers of recycled gypsum, which had been processed using a trommel screen. A front-end loader was used to fill a drop-type poultry manure spreader, which was used to spread the recycled gypsum. The manure spreader was calibrated for each gypsum rate using the "tarp method" to collect and weigh the actual material applied.

Ground recycled gypsum was applied at seven rates to include 0, 2000, 4000, 6000, 8000, 10,000 and 30,000 lbs/A followed by disking to incorporate to a depth of six inches. Gypsum was hand-applied to plots with 2000 lb/A rates. The poultry manure drop spreader was calibrated and used to apply the gypsum on plots with rates of 4000, 6000, 8000, 10,000 and 30,000 lb/A.

Forage variety plots, 20 feet wide and 240 feet long, were established on 5- December 1999. Treatments were arranged into 96 individual plots across a variety of rates of recycled gypsum (see Table 1). In an adjacent area, an irrigated section was established using overhead sprinklers. In the irrigated plot area, seven clover varieties (see Table 2) were planted on 13- December 1999.

A cyclone seeder was utilized with two seed applications per plot to insure uniform coverage. Immediately following seeding, the soil was lightly disked and rolled with a water filled roller to pack the seedbed and retain soil moisture.

Although Northeast Florida received below normal rainfall during the entire growing season, the observational trial flourished with limited rainfall and the addition of irrigation. Two of the clover plots were infested with wild radish, which was hand-pulled to achieve control.

Observational evaluations were conducted on several occasions and during a grower "field day" held on 13-April 2000.

Results and Discussion

Observational evaluations by Extension personnel indicated that the application of processed gypsum waste had minimal effect on the production of the sixteen varieties of cool season forages and clovers. Early and mid season growth did seem to show a taller, darker forage color on many of the grain crops, however, at maturity no observational differences in yield were noted.

On the plots with recycled gypsum applied at a rate of 30,000 lb/A, phytotoxicity was observed as a yellowing of the leaves and marginal burning on Dixie Crimson Clover and Osceola White Clover. This was not observed on these same varieties at lower rates of recycled gypsum.

In summary, this observational trial has shown that the use of ground, recycled gypsum had little effect on the production of sixteen varieties of cool season forages and clovers at rates up to 10,000 lbs per acre. It was noted that at rates of 30,000 lb per acre, clovers seem to exhibit phytotoxicity.

Additional work is needed to evaluate the use of recycled gypsum on several crops including peanuts. Peanuts are currently the only crop for which the University of Florida's Institute of Food and Agricultural Sciences recommends the application of agricultural gypsum.

Table 1

Gypsum Observational Trial
Baker County Plot Plan
Planted 12/5/99

Control	10,000 lb/A	8000 lb/A	6000 lb/A	4000 lb/A	2000 lb/A
Harrison Oats					
Chapman Oats					
Horizon Oats					
Wrens Abruzzi Rye					
AFC 20-20 Rye					
Wrens 96 Rye					
GA89-482 Wheat					
Fleming Wheat					
Redland 3 Red Clover					
Big Daddy Ryegrass					
JumboRyegrass					
Passerel Plus Ryegrass					
Cherokee Red Clover					
Rudolph Red Clover					
Osceola White Clover					
Dixie Crimson Clover					

Table 2

Gypsum Observational Trial
Baker County
Irrigated Plot Plan
Planted 12/13/99

Control	6,000 lb/A	4,000 lb/A	0 lb/Ac	10,000 lb/A	30,000 lb/A	30,000 lb/A
Rudolph Red Clover	Rudolph Red Clover	Cherokee Red Clover	Cherokee Red Clover	Cherokee Red Clover	Osceola White Clover	Dixie Crimson Clover