

Gypsum Wallboard Recycling and Reuse Opportunities
in the State of Vermont

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Executive Summary

Construction waste and demolition debris (C&D) is accountable for an estimated 30 percent of all solid waste generated nationally.¹ Unfortunately, C&D waste has not traditionally been the focus of waste reduction efforts; but here in Vermont that focus is now changing. As nearby landfills fill up and close, and the siting of new landfills becomes more difficult and expensive, the costs of waste disposal for construction and demolition debris will likely increase. Oftentimes, contractors need to evaluate projects to determine if more economically and environmentally feasible options exist than the traditional methods of disposal. As a result, alternatives to traditional disposal for construction and demolition wastes are being sought out. Thus, Vermont's current challenge is to determine and foster the most appropriate alternatives to traditional disposal methods for construction and demolition wastes.

This report focuses on one particular component of the construction and demolition waste stream, new construction gypsum drywall waste. Gypsum drywall waste, like many other forms of construction and demolition waste presents a number of opportunities for alternative uses. Drywall is composed of 92% gypsum (calcium sulfate dihydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), and 7% paper, the remaining 1% is a combination of impurities in the gypsum rock and additives.² The report focuses on opportunities associated with new gypsum drywall construction waste. New construction waste unlike demolition and renovation drywall waste does not have high levels of contaminants (lead paints, wallpaper, nails, mercury, etc.).

The purity and quantity of gypsum present in drywall provides a number of opportunities for economically and environmentally feasible recycling and reuse. Furthermore, if action is not taken and gypsum drywall is allowed to anaerobically decompose in landfills hydrogen sulfide gas production will continue to be a problem.³

Thus, the purpose of this report is to evaluate the opportunities and economics for recycling and reusing gypsum drywall waste in Vermont.

¹ Cosper, Stephan, et al. *Construction and Demolition Waste: Generation, Regulation, Practices, and Policies*. Chicago Illinois: Office of Solid Waste Management, School of Public Health, The University of Illinois, 1993.

² Turley, William. "What's Happening in Gypsum Recycling" *C&D Recycling* January/ February 1998.

³ Washington State Department of Ecology. "Gypsum Wallboard Waste (Publication # 96-1556-SWFS)" www.wa.gov/ecology/swfa/gypsum.html Viewed: 6 June 2000.

Introduction

For centuries now gypsum has played a crucial role in construction; ancient Egyptians used gypsum to decorate the interior of tombs and early American settlers recognized gypsum's potential use as plaster and as a soil amendment. Today, the United States' principal interior wall material is gypsum wallboard.⁴

Often also referred to as drywall, rock, plasterboard, gypboard, or by the trade names Sheetrock® or Gyproc®, gypsum drywall is a sheet of gypsum with a paper facing and backing. The wallboard is approximately 92% gypsum (calcium sulfate dihydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), 7% paper, and 1% impurities and additives.⁵

Nearly 1.6 million new homes are constructed annually within the United States, most of which use drywall during some part of their construction⁶. The construction of an average single family american home (2,000 square feet) generates nearly 1 ton of new, uncontaminated drywall waste.⁷ As a result construction, like that of new homes and commercial building is responsible for approximately 64% of drywall waste, the remaining drywall waste originates from manufacturing, renovation, and demolition (Figure 1).^{8,9} Drywall waste generated from construction, unlike other sources can more easily be recycled because of the low levels of contamination.

Traditionally, the waste, regardless of its source has been disposed of either in landfills or through

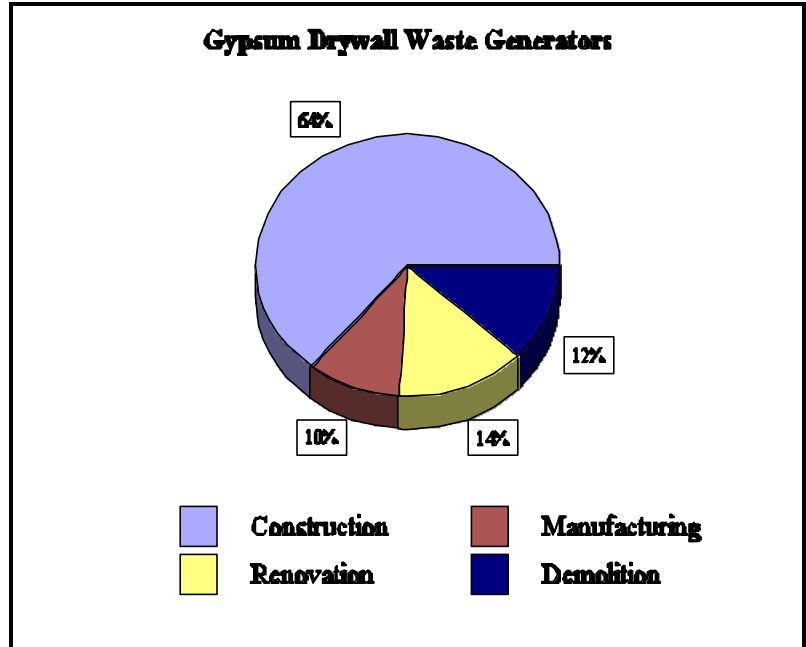


Figure 1. In 1990, 1.7 million tons of new construction drywall waste was generated in the United States and disposed of in some 2,000 landfills nationwide.

⁴ National Gypsum. "The Rock Nobody Knows." www.national-gypsum.com/html/rock.html Viewed: 18 July 2000.

⁵ Turley 1998.

⁶ United States Census Bureau. "Housing Completions" http://www.census.gov/const/c22_hist.html Viewed: 19 July 2000.

⁷ National Association of Home Builders. "Residential Construction Waste: From disposal to Management." www.nahbrc.org Viewed: 6 June 2000.

⁸ White, Edwin and Mark Burger. "Available Gypsum: Construction Drywall As a Soil Amendment." *BioCycle* July 1993: 70-71.

⁹ Robb, Casey. *Drywall Recycling* compiled for the California Integrated Waste Management Board. Revised December 1997.

incinerators. However, there are a number of problems with these forms of disposal. The moist anaerobic conditions of landfills allow bacteria to reduce the sulfate component of gypsum to hydrogen sulfide gas, carbon dioxide, and water. Hydrogen sulfide gas at low concentrations is noxious, and at higher concentrations can be dangerous.¹⁰ Regardless of H₂S generation, the 1.7 million tons of gypsum drywall waste generated nationally every year consumes a significant amount of landfill volume.¹¹ Incineration of drywall is also a poor disposal option because the sulfate present in gypsum is converted to sulfur dioxide gas. Sulfur dioxide gas reduces the alkaline scrubbers ability to remove other acidic gases.¹²

In part because disposal is problematic, gypsum wallboard recycling and reuse presents several opportunities for Vermont. Vermont generates an estimated 7,500 tons of drywall annually, of which approximately 5,000 tons is new construction drywall waste, the remaining 2,500 tons is a combination of demolition and renovation waste.¹³ There are a number of different reuse and recycling opportunities for new construction drywall waste, including recycling into new drywall or used as a soil amendment (a number of processing options are possible, however, the end product is usually applied to the land). Drywall can also be donated or resold for reuse.

The successful implementation of any recycling or reuse option depends upon the options ability to address common challenges. The gypsum drywall recycling and reuse options presented in this report are evaluated on the following criteria:

1. Processing
2. Transportation fees, gypsum wallboard is a dense, bulky material (cost is highly variable depending upon the distance to markets and amount of drywall)
3. Storage, gypsum wallboard readily absorbs moisture and dissolves as its moisture content increases (cost is highly variable depending upon other uses for the space)
4. Cost of disposal tipping fees (cost is highly variable depending upon the region of the state and the amount of waste being disposed)
5. Regulations
6. Comparable products competing within the same market
7. Stakeholders Motivations
8. Environmental Impact and other considerations

¹⁰ Washington State Department of Ecology. www.wa.gov/ecology/swfa/gypsum.html

¹¹ Robb 1997.

¹² Washington State Department of Ecology. www.wa.gov/ecology/swfa/gypsum.html

¹³ See appendix 1 for the methodology used to obtain this estimate.

Reuse

DONATION

Discarded sheets of drywall either half size or larger are often accepted by nonprofit organizations that build affordable homes.

PROCESS

1. Collect half size and larger undamaged drywall sheets
 - These sheets may be collected with smaller scraps and then transported to a transfer station to be sorted.
2. Transport drywall sheets to a secondary use site
3. Reuse drywall sheets in construction

COLLECTION OPTIONS

- Hauled by the contractor generating drywall scrap
- Hauled by the party accepting the discarded drywall
- Hauled by a third party hired to transport the drywall between sites

The drywall scrap may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization.¹⁴

COST = Source separation + Transportation + Storage

REGULATIONS

There would be no applicable air or water regulations. However, storage of the material would be regulated under solid waste rules if the drywall is stored at an intermediate site.¹⁵

COMPETING PRODUCTS

- New drywall
- Wood paneling

¹⁴ For a cost benefit analysis of collection options see Appendix 2.

¹⁵ Vermont Agency of Natural Resources, Solid Waste Management Division. "Solid Waste Management Rules" rule number 98P052: effective 20 December 1998.

STAKEHOLDERS¹⁶

Contractors

- Building contractors
- Drywall contractors

Non Profit Building and Construction Organizations

- Habitat for Humanity

Solid Waste Districts

- Especially those in high growth areas

Haulers

- Waste haulers

- Private trucking companies

Home Owners

Drywall Manufacturers

Drywall Suppliers

- Lumber yards
- Home building centers

Homeowners

Building material Exchanges

- Vermont Business Materials Exchange

CASE STUDIES

1. California Habitat for Humanity

In California several local Chapters of Habitat for Humanity are accepting donations of gypsum drywall in half size sheets and larger.¹⁷

Other Considerations and the Environmental Impact

1. Only a small fraction of drywall waste could be channeled into this option.

- Generally, if pieces of scrap are large enough to be reused the drywall contractor will keep them. In other words much of the scrap large enough to be donated/ resold would be kept by the contractor if onsite source separation occurs.
- Those pieces of drywall which do not meet the size specifications of a half sheet or larger in size or are damaged can not be handled through this outlet.

2. The best use of scrap is reuse. Reuse does not require any extra energy input, besides the energy needed for transportation. Also, reuse does not degrade the value of the product.

¹⁶ Please see Appendix 3 for a stakeholder contact list.

¹⁷ California Integrated Waste Management Board. "Construction and Demolition Debris Recycling Program" <http://www.ciwmb.ca.gov/ConDemo/> Viewed: 6 June 2000.

RESALE

Used construction building supply companies and material exchange networks may accept drywall sheets over a specified size. Generally, companies like to obtain sheets of a half size or larger. Please refer back to Donations for *Process, Collection, Cost, Regulation and Other Considerations and Environmental Impacts* information.

COMPETING PRODUCTS

- New Drywall
- Wood Paneling

STAKEHOLDERS¹⁸

Contractors

- Building contractors
- Drywall contractors

Solid Waste Districts

- Especially those in high growth areas

Haulers

- Waste haulers
 - Private trucking companies
- Drywall Manufacturers

Drywall Suppliers

- Lumber yards
- Home building centers

Homeowners

- Building Reuse Stores
- Residuum

Building Material Exchanges

- Vermont Business Materials Exchange

CASE STUDIES

1. Residuum

Cindy Blakeslee
70 Smith St
Barre, VT 05641
Telephone: 802-479-9341

Residuum is a non profit organization accepting construction scrap and architectural salvage. Currently, Residuum accepts gypsum drywall on a discretionary basis. The drywall must be significant enough in quantity and quality and must be uncontaminated. Transportation for the scrap material must be provided by the generator of the waste.

¹⁸ Please see Appendix 3 for a stakeholder contact list.

2. Vermont Business Materials Exchange (VBMX)
Telephone: 1-800-895-1930

In 1994 Pizzagalli Construction Company was hired to convert one of IBM's office buildings into a warehouse space. The project involved removing over 5,000 4' X 10' sheets of drywall each weighing approximately 100 pounds. Sending the drywall to the landfill was not an economical means of disposal because of the high tipping fees, \$74 per ton. As a result Pizzagalli Construction contacted the Vermont Business Exchange (VBMX), a state funded program that matches industrial waste generators with companies which can use the wastes. VBMX composed a press release to be placed in the Burlington Free Press advertizing free drywall for those that were willing to take 20 sheets or more. By the end of the afternoon after the press release had been printed in the paper all of the drywall had been claimed. This exchange saved Pizzagalli over \$15,000 and salvaged 75% of the drywall.

Recycling

GYPSUM WALLBOARD MANUFACTURING/ REPROCESSING

Ninety-five percent of new construction drywall waste can be recovered and turned into new wallboard.¹⁹ The nature of gypsum drywall makes reprocessing feasible, but challenging. The quantity and purity of gypsum used in manufacturing makes reprocessing attractive; however, in order to maintain the integrity of the feedstock the paper must be separated from the gypsum.

The economic feasibility of this form of drywall recycling depends heavily upon the costs of transportation and tipping fees. Gypsum drywall is a dense, heavy material that is hard to compact making transportation difficult and expensive. The feasibility also strongly depends upon the regional demand for gypsum wallboard and the costs of virgin and synthetic gypsum.²⁰

PROCESS

1. Separate drywall from other construction waste
 - The drywall must be kept dry and clean in order to guarantee meeting specifications
2. Transport the drywall to a transfer station or store until a large enough quantity has been generated to make transport to the recycling facility economical
3. Transport to the recycling facility

¹⁹ Washington State Department of Ecology www.wa.gov/ecology/swfa/gypsum.html

²⁰ Synthetic gypsum results from coal powered energy plants. The flue gas desulfurization scrubbers use a chemical reaction between limestone and the sulfur in the flue gas to produce gypsum. The byproduct or synthetic gypsum is chemically identical to raw gypsum and is used to manufacture drywall and soil amendments.

Once at the recycling facility, the load is then inspected by the loader/operator to determine the load size and whether the load meets specifications. The recycling facility will then reprocess the drywall if it meets specifications. The processing varies significantly between different drywall recyclers and is highly proprietary. However, the process generally involves the following steps:

1. Separate the gypsum from the paper (the paper must be removed because it is viewed as a contaminant)
2. Run the scrap drywall through a magnet to remove nails and other metal contaminants
3. Shred or chip gypsum
4. Combine with raw gypsum to form new gypsum wallboard

COLLECTION OPTIONS

- Hauled by the contractor generating the drywall scrap
- Hauled by the party accepting the discarded drywall
- Hauled by a third party hired to transport the drywall between sites

The drywall waste may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization.²¹

$COST = \text{Source Separation} + \text{Transportation (site of generation to transfer station)} + \text{Storage} + \text{Transportation (transfer station to processor)} + \text{Tipping fee charged by processor}$ ^{22, 23}

REGULATIONS

No Air or water quality regulations are applicable. Storage regulations are only effective if the drywall is stored off the site of generation.²⁴

COMPETING PRODUCTS

- Synthetic gypsum
- Virgin gypsum

*STAKEHOLDERS*²⁵

Contractors	- Drywall contractors
- Building contractors	Haulers

²¹ See Appendix 2 for a cost benefit analysis of collection options.

²² Please see Appendix 4 for Smugglers' Notch's economic evaluation of reprocessing

²³ Please see case study 2 under this heading for details on processor tipping fees

²⁴ Waste Management Division, VT Agency of Natural Resources. "Solid Waste Management Rules" rule number 98P052: effective 20 December 1998.

²⁵ Please see Appendix 3 for stakeholder contact list.

- Waste haulers
- Private trucking companies

Solid Waste Management Districts

- Especially those in high growth areas

Gypsum Recycling Facilities

- GP-Gypsum, Newington, NH

Gypsum Wallboard Manufacturers

- GP-Gypsum, Newington, NH

CASE STUDIES

1. Smugglers' Notch Resort

Christopher Bolen, Environmental Permits and Compliance Coordinator
4323 Vermont Rt 108 South
Jeffersonville, Vermont 05464-9599
Telephone: 802-644-1204 Fax: 802-644-1238

In 1998, Smugglers' Notch Resort received a grant from the state of Vermont's Agency of Natural Resources to divert construction waste and debris from their waste stream; gypsum drywall was one of the targeted wastes. The drywall was collected in a roll off container and then shipped 195 miles to G-P Gypsum in Newington, NH. During the first year of recycling gypsum drywall construction waste Smugglers' Notch saw a \$10.28 saving per ton of discarded drywall; in the second year their savings had increased to nearly \$60 per ton. Smugglers' Notch Resort has found recycling drywall waste is more economical than sending it to the landfill, which is a hundred miles away . Please see Appendix 4 for further economic analysis of gypsum drywall reprocessing at Smugglers' Notch Resort.

2. GP-Gypsum
122 Old Dover Rd
Newington, New Hampshire 03801
603-433-8000

The closest facility for recycling Vermont's gypsum drywall is in GP-Gypsum in Newington, New Hampshire. The specifications for recycling construction waste gypsum drywall at the Newington facility require clean, uncontaminated wallboard scrap. Drywall must have no demolition waste and be clean, paper faced gypsum wallboard. If contaminated the load will be rejected. Load sizes are determined by the loader/operator and the fees are as follows:

Pick Up Truck	\$10.00
One Ton Truck	\$20.00
Medium Truck (2 tons max)	\$40.00
Heavy Duty Truck (4 tons max)	\$60.00
Roll-off Containers (30 yard Dumpster)	\$80.00
Flat Bed Tractor Trailer/Van	\$160.00

The transportation fees are the responsibility of those participating in the GP-Gypsum Corporation's gypsum recycling program.

3. New West Gypsum Recycling Inc. (B.C.).
5620-198 Street
Langley, British Columbia
CANADA V3A 7C7

New West Gypsum Recycling Inc. has developed a process where wallboard paper can easily be separated from the gypsum. Their recycled wallboard comprises 20% of the feedstock for the mills they supply. The removed paper is returned to pulp mills in the form of noodle pulp and then recycled into paper for products, such as drywall backing. New West Gypsum claims "[they] can recycle drywall cheaper than the property owner can pay to have the material hauled to the dump."²⁶ They feel they have been able to overcome the difficulties of drywall recycling through their ability to transport, collect, and handle wet drywall waste.

4. Tom Kacandes
TKM Materials

Tom Kacandes is currently developing a technique to separate the paper from the gypsum in drywall. In order to ensure his business is a success he has setup a collection system and determined several outlet markets for the reprocessed gypsum. It is his opinion that collection and transportation in a rural area such as Vermont would be a challenge. He thinks setting up an arrangement with a manufactured home company who generates a lot of drywall waste would be the best idea for aggregation. If such an arrangement were not possible Mr. Kacandes

²⁶ New West Gypsum. www.nwgypsum.com Viewed: 8 June 2000.

believes a transfer station would have to be designed which could handle large amounts of drywall at a time and then dry spells with no drywall (drywall tends to be generated very quickly from a single source and then the supply stops).

OTHER CONSIDERATIONS/ ENVIRONMENTAL IMPACT

1. One often forgotten impact is the environmental cost of transporting scrap drywall; for example Newington, New Hampshire is 195 miles away from Burlington. This clearly is a source of resource depletion and air pollution.
2. This form of recycling has the potential to handle 100% of Vermont's drywall waste as long as scrap drywall meets the specification of the recycler (GP Gypsum). Currently, demand for recyclable drywall scrap is greater than supply.
3. From a life cycle perspective reprocessing of a product is a good solution. Reprocessing does not degrade the product's value. However, the energy put into reprocessing should be compared to the energy levels required for processing of virgin gypsum and the energy requirements for other reuse and recycling opportunities.

Land Applications

COMPOST BULKING AGENT/ ADDITIVE

Bulking agents are a necessary component of successful composting. Bulking agents are used to adjust the bulk density, aerate the piles by maintaining pile structure, and absorb moisture.

Typically bulking agents are wood chips or saw dust. Gypsum drywall can work successfully as a bulking agent, absorbing excess moisture and adding calcium, sulfur, and some carbon. Moreover, if aerobic conditions are maintained gypsum drywall can absorb odors. Composting gypsum wallboard could prove beneficial in areas with insufficient woody bulking materials and large amounts of grass clippings.^{27, 28}

Gypsum drywall can be extremely beneficial as a compost additive in places where sulfur and calcium are limiting nutrients. The calcium content of the compost rises in direct proportion with the amount of drywall present in the mixture. Gypsum drywall also has the capacity to serve as a buffering agent. Thus, it can often help to neutralize acidic compost mixtures.²⁹

Composting gypsum drywall does present several challenges. First, temperature, moisture, and oxygen within the compost mixture must be monitored to avoid anaerobic decomposition. Gypsum wallboards' tendency to absorb moisture can be problematic, as well. If the drywall is wet before it is processed moisture will be added to the compost rather than absorbed. Thus, drywall should be stored indoors and ground on an as-needed basis. The final product should be monitored for the presence of paper pieces because consumers generally dislike seeing such flecks. The Clean Washington Center has found that the pieces are unnoticeable in compost mixtures containing less than 30% gypsum drywall.³⁰

In 1995, the Chittenden Solid Waste District looked into the feasibility of composting gypsum drywall in cooperation with the Intervale Compost Project. The district submitted a proposal to collect 40 cubic yards of clean, gypsum board scrap, grind it, and compost it with the Intervale Compost Project. Soil tests were proposed to determine the impact of gypsum drywall on compost quality. The need for air quality tests was to be determined by a CWSD officer present at the grinding. However, the proposed project was never implemented.³¹

²⁷ Clean Washington Center. *Construction, Demolition & Land clearing Market Assessment: Gypsum Wallboard* (#CLD-95-1). Seattle Washington: June 1999.

²⁸ Turley 1998.

²⁹ Personal Communication with Mark Russell, Sanitary Landfill and Compost Facility Superintendent, Columbia MO.

³⁰ Clean Washington Center www.cwc.org/briefs/construction

³¹ John O'Niles, CSWD correspondence with Andy Harper and Molly Farrell, The Intervale 1995.

PROCESS

1. Separate drywall from other forms of construction waste
2. Transport gypsum drywall to the composting facility
3. Shred or chip the drywall
4. - According to the Clean Washington Center shredding is best done when mixed with yard debris to prevent dust
5. Add the shredded or chipped drywall to other ingredients of the compost mixture
6. Monitor the compost's temperature, moisture, and oxygen levels

COLLECTION OPTIONS

- Hauled by the contractor generating the drywall scrap
- The composting facility may agree to collect the drywall scrap
- Hauled by a third party hired to transport the drywall between sites

The drywall waste may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization or hired hauler.³²

COST = Source Separation + Transportation + Storage + Composting

REGULATIONS

Regulations would not differ from those currently applicable to other commercial composting facilities. The exception would be if the drywall material is ground on site and generates a significant level of dust and other particulate matter; under this circumstance the composting facility would come under regulation by the air quality control division.³³

COMPETING PRODUCTS

- Wood Chips
- Saw Dust

³² See Appendix 2 for a cost benefit analysis of collection options.

³³ Vermont Agency of Natural Resources, Air Pollution Control Division. "Vermont Air Pollution Control Regulations (including amendments through 24 August 1998). Section 5-211 Prohibition of Visible Air contaminants: 1998.

STAKEHOLDERS³⁴

Contractors

- Building contractors
- Drywall contractors
- Biosolid composting facilities (Johnson, Springfield, Barre, and Wilmington)
- Municipal Composting facilities (Rutland, Intervale, etc)
- Private composting organizations

Haulers

- Waste haulers
- Private trucking firms

Solid Waste Districts

- those projected to experience high levels of growth
- those with biosolid composting facilities
- those with composting facilities

Consumers

- Farmers
- Gardeners

Regulators

- Water Quality
- Air Quality

CASE STUDIES

1. Clean Washington Center
2001-6th Avenue, #2700, MS:TB-40
City Seattle WA 98121
Telephone: 206-464-6282 fax 206-464-6902
E-mail: eduardou@cted.wa.gov
Internet: www.cwc.org

Cedar Grove Composting located in Maple Valley, WA and the Clean Washington Center experimented with incorporating gypsum drywall into their compost mixture. The drywall was chipped along with yard debris at a one to one ratio. Dust generation was a problem. The operators found that grinding yard debris with the gypsum reduced the dust. They also found that when the loader was kept full the escaping dust was only from the discharge chute. Another recommendation was to keep the drywall under cover to protect the gypsum from becoming wet. Cedar Grove composting found that the volume of drywall increases after chipping or shredding. Since completion of the Clean Washington Center project Cedar Grove has not continued to compost gypsum drywall because Cedar Grove produces organic compost.

³⁴ Please see Appendix 3 for stakeholder contact list

2. City of Columbia City MO
Mark Russell
573-886-0722

During March 1999, the city of Columbia, Missouri began a one year pilot project composting drywall at the city's composting facility. The composting project was advertised through construction waste haulers and construction supply companies in the area. Individuals received a decreased tipping fee of \$16.25, approximately one half the fee charged for placing the waste in the landfill, if they brought in clean drywall to be composted. The composting facility has collected and composted approximately 700 tons of gypsum drywall. Quarterly water samples are taken to test for runoff; the results of these tests have not shown composting of gypsum drywall to have any negative side effects. The compost is currently being used as landfill cover. Based on the success of the pilot project the city of Columbia has decided to continue composting gypsum drywall.³⁵

3. Okaloosa County Florida

Internet: [http://www.enveng.ufl.edu/home pp/townsend/Research/GypDW/gypmainhtml](http://www.enveng.ufl.edu/home_pp/townsend/Research/GypDW/gypmainhtml)

Allison Barnes
Graduate Student at
University of Florida
352-846-3035
Email: abarnes@ufl.edu

Gerald Edmondson
Institute of Food and Agricultural
Sciences
(IFAS) Okaloosa County Extension
850-689-850

Okaloosa County Florida received a grant in 1999 for an innovative drywall composting project. The project is being carried out at Elgin Air force Base by the University of Florida Institute of Food and Agricultural Sciences and the Okaloosa Building Association. This region of Florida has experienced a boom in new housing construction causing a large increase in the amount of gypsum drywall waste generated. The project will evaluate the effectiveness of composting gypsum drywall and yard waste in both windrows and vessels. The compost being generated will be used by local peanut farmers. Currently, the data from this pilot project is being compiled by Dr. Timothy Townsend and should be published by December of 2000. To date the project has not experienced any problems with excess dust or hydrogen sulfide gas. In order to allow for further research the project grant has been extended for another year.

³⁵ See Appendix 5 for further details about the City of Columbia Missouri Composting Facility.

4. Michael J. Hill
Thelin Recycling Company
5225 Thelin St
Fort Worth, Texas 76115
Telephone: 817-926-5626
Thelin Recycling composts gypsum drywall with chipped wood and horse manure in windrows. The drywall is ground with wood, because it is too powdery to be ground alone. Water is added to the windrows. The composting process takes approximately 18 months. Thelin's composting facility has been composting drywall for nearly 4 years. The end product is sold on the retail market to homeowners, landscapers, and gardeners.

OTHER CONSIDERATIONS/ ENVIRONMENTAL IMPACTS

1. Organic farming regulations state that no manufactured products can be included in the growth or production of organic products. As a result, composters who agree to compost drywall would be unable to sell the mixture to organic farmers. This would effectively limit the potential end market for the compost mixture.
2. Composting with biosolids may be an option. However, many of the same concerns apply to the use of ground drywall on agricultural lands that apply to biosolids.
3. Drywall has less value as a component of compost than if it were added to virgin gypsum and re-manufactured into drywall.
4. Composting has the potential to handle about ninety percent of new drywall waste generated within the state of Vermont. Type X (fiberglass), moisture resistant, and laminated drywall all have additives which prevent them from being composted.³⁶ However, these forms of drywall can be visually separated from regular drywall.

AGRICULTURAL LAND APPLICATION

Since Benjamin Franklin discovered the agricultural benefits of gypsum and coined the term 'land plaster,' raw gypsum (crushed gypsum rock) has been applied to American soils as a liming agent. However, controversy has arisen over whether the benefits of ground gypsum drywall application to agricultural land are significant enough to warrant the use of drywall as a soil amendment. As a result a number of research projects have been conducted and found:

- Ž Application of gypsum drywall alters the presence of available nutrients;
 - Increases the level of available calcium and sulfur,^{37, 38}
 - Reduces sodium uptake,³⁹

³⁶ Please see Appendix 5 for a chemical analysis of gypsum drywall conducted by the University of Wisconsin.

³⁷ Korcak, Ron. "Scrap Construction Gypsum Utilization" submitted to The Gypsum Association Washington D.C.: 31 July 1996.

³⁸ Turley 1998.

³⁹ "Gypsum Remedies Winter Salt Kill of Highway Grasses." *Better Roads*. June 1975, pages 24-25.

- Increases boron, which at high levels can be toxic to plant life, but at lower levels is an important nutrient,⁴⁰
 - Excessive application creates an imbalance between the levels of calcium and magnesium,⁴¹
 - Application of synthetic (byproduct) gypsum was shown to reduce phosphorous leaching while not inhibiting a plant's uptake of phosphorous.
- Ž Hardpan (compacted soil) subsoil types can benefit from gypsum application. After allowing the gypsum to become incorporated into the soil improved rooting has occurred.⁴²
- These improvements are believed to result from gypsum's ability to loosen clay soils and allow air and water to circulate.⁴³
 - The reduction of soil surface sealing improves water entry potentially reducing erosion.⁴⁴
- Ž Gypsum has been shown to serve as an effective liming agent.
- Acid subsoils show a significant yield response to 3-4 tons/acre of gypsum, after the gypsum has had time to be absorbed by the soil and subsoil. Improved root proliferation resulted from favorable increases in Ca: Al ratio.⁴⁵
 - Application of gypsum to blueberries showed an increased root tolerance to Al.⁴⁶
- Ž There are minimal levels of heavy metals present in gypsum drywall.
- Gypsum drywall was suitable for agricultural application at least with regards to the heavy metals arsenic, cadmium, lead and selenium.⁴⁷
 - Levels of As, Cd, Cr, Cu, Mo, Zn, and Ni were well below the standards set for heavy metals by the EPA's Clean Water Act 503 Regulation of contaminants.⁴⁸

PROCESS

1. Separate gypsum drywall from other construction debris
2. Test soil to determine if application of gypsum is appropriate
3. Test sites to determine application rate. The following are two possible site tests to determine the appropriate application rate:

⁴⁰ Korcak, Ron. "Agricultural Uses of Phosphogypsum, Gypsum, and other Industrial Byproducts" *Agricultural Uses of Municipal, Animal, and Industrial Byproducts* USDA Research Rpt 44: January 1998.

⁴¹ Korcak, Ron. "Beneficial Reuse of Aggregate Mineral Fines and Scrap New Construction Wallboard" (a chapter to be published in the Agronomy Society of America's new book) Beltsville, Maryland: 3 August 1998.

⁴² Sumner Malcom E., William P. Miller, David E. Radcliffe, and William Segers. "Principles of Gypsum Use as a Soil Amendment." Georgia 1989.

⁴³ Turley 1998.

⁴⁴ Norton, L. Darrell. "Stopping Erosion with Gypsum and PAM." *Agricultural Research*. September 1997: 19-20.

⁴⁵ Sumner et al. 1989.

⁴⁶ Korcak 1996.

⁴⁷ Dixon, Robert. "Suitability of Ground Gypsum Board as a Source of Agricultural Gypsum for Application to Croplands" certified professional agronomist. 1984.

⁴⁸ Korcak 8 August 1998.

- Check root growth under conditions of soil with and soil without gypsum added, about four days of growth for a seedling should determine whether application is necessary.⁴⁹
 - Measure the changes in pH and electrical conductivity when soil samples are mixed with calcium sulfate and calcium chloride solutions. This test requires the use of a pH and conductivity meter.⁵⁰
4. Transport drywall to the grinding site (gypsum drywall may also be ground at the application site)
 5. Grind or shred gypsum into a fine powder
 6. Apply powder at predetermined rate of application

COLLECTION OPTIONS

- Hauled by the contractor generating the waste to the processor
- Hauled by the processor
- Hauled by the farmer applying the scrap gypsum to his fields
- Hauled by a third party hired to transport the drywall between sites

The drywall waste may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization.⁵¹

$COST = \text{Source Separation} + \text{Transportation} + \text{Storage} + \text{Transportation} + \text{Processing} + \text{Spreading}$

REGULATIONS

- The Vermont Department of Agriculture would most likely regulate gypsum drywall as a liming agent. This regulation mandates labeling. In order for drywall to be labeled it would have to be tested for its capacity to act as neutralizing agent.⁵²
- Water quality regulations would not differ from current regulations for agricultural runoff and/ or liming agents.
- The Vermont Air Quality Division under Vermont Air Pollution Control Regulations would regulate dust generated from processing and spreading, depending upon the levels of particulate matter.⁵³
- If the drywall was stored off the site of generation before processing, the drywall scrap

⁴⁹ Korack 8 August 1998.

⁵⁰ Sumner et al 1989.

⁵¹ See Appendix 2 for a cost benefit analysis of collection options.

⁵² Lelund, Jim, Vermont Department of Agriculture, Plant Institutions Division. Personal Communication. 21 June 2000.

⁵³ Vermont Agency of Natural Resources, Air Pollution Control Division 1998.

would be considered a waste and regulated under the Solid Waste Management Rules.⁵⁴

COMPETING PRODUCTS

Lime and other liming agents

STAKEHOLDERS⁵⁵

Contractors

- Building contractors
- Drywall contractors

Processors

Home Centers and Companies Renting
Shredding or Chipping Equipment

Haulers

- Waste haulers
- Private trucking companies

Farm Supply Companies/ Distributors

Farmers

- Dairy farmers
- Vegetable farmers

Regulators

- Vermont Department of Health
- Vermont Department of Agriculture
- Water Quality Division
- Air Quality Division

CASE STUDIES

1. New York State Study

Dr. Edwin H. White and Mark E. Burger

SUNY College of Environmental Science and Forestry

In 1990, SUNY College of Environmental Science School of Forestry studied the viability of applying pulverized gypsum wallboard to agricultural lands. Prior to application the drywall waste was analyzed to determine the level of heavy metals, pH, and plant nutrients; the results suggested that soil application was viable. One of five treatments was applied to each of the 15 20 x 20 plots of field, each plot had an initial pH of 5.0. The treatments applied were either:

- no treatment
- agricultural limestone application to increase the pH of the plot to 7
- agricultural gypsum application at a rate of 13 tons per acre
- pulverized construction drywall applied at a rate equivalent to agricultural limestones application
- pulverized construction drywall applied at twice the calcium equivalent rate to agricultural limestone.

The study found an increase in soil fertility, nutritional status, and yield of grain corn on the plots receiving a level of ground gypsum wallboard equivalent to the levels of limestone application. These results suggest that pulverized gypsum wallboard has the potential to be an effective agricultural soil amendment.

⁵⁴ VT Agency of Natural Resources, Waste Management Division 20 December 1998.

⁵⁵ Please see Appendix 3 for stakeholder contact list.

2. Richard Wolkowski (1998)
Department of Soil Science
University of Wisconsin- Madison
Telephone: 608-263-3913

A three year study at four different sites looked at the effect of ten application levels of ground gypsum drywall on alfalfa. The study was conducted in Wisconsin where the soils are generally sulfur deficient and alfalfa requires high levels of sulfur. The results showed an insignificant increase in crop production. From the results it was determined for loams, silt loams, and heavier textured soils the application rate of gypsum should be between 2Mg/hectare and 5Mg/hectare. One application every three years should supply the needed sulfur to the crop. The study's results also raised three concerns regarding gypsum drywall application: depression of pH could lead to unnecessary lime application, a depression of Mg in the soil could lead to Mg deficiency, and low Mg and high Ca forages could lead to animal health problems.

3. Florida
New River Solid Waste District, Florida
Internet: http://www.enveng.ufl.edu/home_pp/townsend/Research/GypDW/gypmainhtml

Allison Barnes
Graduate Student at
University of Florida
352-846-3035
Email: abarnes@ufl.edu

Mike Sweat
Institute of Food and Agricultural
Sciences
(IFAS) Baker County Extension Director
904-259-3520

The New River Solid Waste Management Association has received a grant for \$193,000 from the Florida Department of Environmental Protection to collect, process, and reuse gypsum drywall as a soil amendment. Scraps of drywall were collected through a free drop off program at the local landfill. The material processing was subcontracted to AgriCycle, a large drywall recycler in Columbus, Ohio; the machine used to process the material was purchased from Morbark and then modified by AgriCycle. The ground drywall was spread using a drop spreader and by hand depending upon the application level. They had very little problem with dust. Data is still being collected, but to date there have been no adverse effects on plant health or tissue. The one year grant has been extended and the final report is expected in 2001.

4. Bill Wilson
Phoenix Resources, 10313 Morse Lake Rd
Alto, MI 49302
Telephone: 616-891-9110

Phoenix Resources currently provides farmers within Michigan with construction gypsum

drywall waste. The drywall is not processed and farmers simply add the sheets of drywall to liquid manure or allow the drywall to become wet. The drywall is then spread on fields for a liming effect. So, far Phoenix Resources has been fairly successful.

OTHER CONSIDERATIONS/ ENVIRONMENTAL IMPACT

1. Nearly all of the gypsum drywall waste generated within the state of Vermont could be diverted through agricultural land application if enough farms were willing to participate and if the application rate was high enough.
2. The value of the drywall as a soil amendment is less than if it is recycled into new drywall; the value added to the virgin gypsum during manufacturing would be lost if the drywall was land applied.
3. In modern agriculture a number of high quality fertilizers and liming agents are on the market.
 - Farmers will clearly be unwilling to pay for a product which does not provide the same or better fertilizing and neutralizing ability.
 - Farmers would likely be unwilling to jeopardize the quality of their crops by introducing another variable, namely an unfamiliar soil amendment.
4. Agricultural land application has the potential to handle about ninety percent of the drywall waste generated within the state of Vermont. Type X (fiberglass), moisture resistant, and laminated drywall all have additives which prevents them from being composted.⁵⁶ However, these forms of drywall can easily be separated from regular drywall.

⁵⁶ Please see Appendix 6 for a chemical analysis of gypsum drywall conducted by the University of Wisconsin.

APPLICATION TO RECREATIONAL LANDS

Ground gypsum drywall would be applied as a liming agent on recreational lands. For information on gypsum drywall's effects on soil please refer back to the agricultural land application overview (pages 16 and 17).

PROCESS

1. Separate construction gypsum drywall scrap from other construction waste
2. Test soils to determine if application of gypsum drywall is appropriate
3. Transport gypsum drywall to processing facility (it maybe possible to have mobile processing facility which could transport the gypsum directly from the generation site to the application site)
4. Grind/ shred gypsum
5. Transport to application site
6. Apply gypsum to soil at predetermined application rate

TRANSPORTATION OPTIONS

- Hauled by the contractor generating the waste to the processor
- Hauled by the processor
- Hauled by a third party hired to transport the drywall between sites

The drywall waste may also be brought to a central transfer station by a local hauler or the contractor and then transported from there by the receiving organization.⁵⁷

COST = Source Separation + Transportation + Storage + Processing + Spreading

REGULATIONS

10. Water quality regulations would be the same as for other liming agents approved for land application.
11. Depending upon the levels of dust generated during processing and spreading of the drywall, air quality regulations might apply.⁵⁸
12. The drywall would be regulated by the Solid Waste Management Division only if the drywall is stored off the site of generation before it is processed.⁵⁹

⁵⁷See Appendix 2 for a cost benefit analysis of collection options.

⁵⁸ Vermont Agency of Natural Resources, Air Pollution Control Division 1998.

⁵⁹ Vermont Agency of Natural Resources, Solid Waste Management Division 1998.

COMPETING PRODUCTS

Lime and other liming agents

*STAKEHOLDERS*⁶⁰

Drywall Contractors
Building Contractors
Haulers
Gypsum Drywall Processors (GP- Gypsum,
Newington, NH)

Garden Supply and Home Centers
Solid Waste Districts
Golf Courses, Parks, etc.
Regulators
-Water Quality Division

CASE STUDIES

1. Ron Korcak
United States Department of Agriculture
Agricultural Research Service
Beltsville Area Director's Office

Application of drywall has produced a beneficial effect on turf grass growth where Ca or S were the limiting nutrients. No evidence of trace leaching that could cause ground water contaminations were observed.⁶¹

OTHER CONSIDERATIONS/ ENVIRONMENTAL IMPACTS

1. In today's market there are a number of effective products for neutralizing soil pH and increasing levels of calcium. Thus it is highly unlikely that recreational areas would pay the same amount for a product which does not provide all the nutrients necessary to improve soil quality.
2. The value of the drywall would be less than if it had been turned into new drywall.
3. Appearance of the greens at both recreational areas and golf courses is an important factor. The visibility of paper flecks and light color of the drywall on the turf could prevent the application of pulverized drywall on recreational areas and golf courses.
4. Unlike with agricultural land application, pulverized gypsum drywall application to recreational lands faces fewer concerns and regulations because the ground drywall is not being applied to crops being grown for human or livestock consumption.
5. Composting has the potential to handle about ninety percent of the drywall waste generated

⁶⁰ Please see Appendix 3 for stakeholder contact list.

⁶¹ Korcak 1996.

within the state of Vermont. Type X (fiberglass), moisture resistant, and laminated drywall all have additives which prevents them from being composted.⁶² However, these forms of drywall can easily be visually separated from regular drywall.

ONSITE LAND APPLICATION

At new home construction sites ground gypsum drywall can be applied to the land surrounding the building site. Waste gypsum board needs to be pulverized in order to allow the drywall's absorption into the soil. Pieces smaller than ½ inch sq. can generally be applied to the soil. The shredded gypsum drywall should be spread evenly over the soil and must be applied in areas with adequate drainage and aeration, so that no anaerobic reaction occurs.⁶³ Onsite application requires a mobile processing machine, as well as a mechanism to spread the shredded drywall.



Figure 2. Onsite grinding of drywall

PROCESS

1. Determine the appropriate application rate
2. Keep gypsum drywall scrap separate from other construction waste materials
3. Grind or shred the gypsum drywall with a portable shredder or chipper⁶⁴
 - Wood shredders or chippers rented at your local garden center work well (these machines cost about \$50 a day to rent and several hundred dollars to buy.)
4. Spread gypsum around site at predetermined application rate



Figure 3. Spreading ground drywall.

Photographs from Backyard Magazine⁶⁵

TRANSPORTATION OPTIONS

Drywall does not need to be transported off site.

COST = Source Separation + Processing + Spreading

REGULATIONS

Air quality regulations would come into effect only if the level of dust generated by processing causes ambient air quality levels of particulate matter to be exceeded.⁶⁶

⁶² Please see Appendix 6 for a chemical analysis of gypsum drywall conducted by the University of Wisconsin.

⁶³ Turley 1998.

⁶⁴ Please see appendix 7 for further details about the economics of onsite processing.

⁶⁵ Perry, Jean. "From Trash to Treasure: Recycling Drywall as a Soil Amendment and Conditioner." *BackHome Magazine* (Hendersonville, NC), 46 (May/June 2000).

⁶⁶ Vermont Agency of Natural Resources, Air Pollution Control Division 1998.

COMPETING PRODUCTS

Not applicable

*STAKEHOLDERS*⁶⁷

Drywall Contractors

Building Contractors

Home Owners

Mobile drywall facility operators/ owners

Solid Waste Districts

Regulators

- Water Quality Division

- Air Quality

Home Centers

CASE STUDIES

1. According to Peter Yost of Environmental Building News, Georgia's Habitat for Humanity acquired a permit from the Solid Waste Management Program to pulverize the material and apply it onsite. They diverted 13.2 tons of scrap wallboard from the landfill.⁶⁸

2. South Carolina

Department of Health and Environmental Control

Richard Chesley

Telephone: 803-896-4209

Email: chesler1@columb34.dhec.state.sc.us

South Carolina Department of Health and Environmental Control developed a pilot project with Mungo Homes to determine the effectiveness of gypsum drywall application at the construction site. The construction sites were tested to determine the appropriate application level, the drywall was then separated, ground, and applied by Mungo Home's crew. The project while sponsored by the state was highly successful. The responses from homeowners and contractors was very positive. However, construction site application of gypsum drywall has been slow to catch on with home builders.

⁶⁷ Please see Appendix 3 for stakeholder contact information.

⁶⁸ Korcak August 1998.

OTHER CONSIDERATIONS/ ENVIRONMENTAL IMPACTS

1. Excess energy is not spent collecting and transporting the drywall. The only additional energy needed for the drywall to be reused in this case is that need to grind and then apply the drywall.
2. The drywall waste maybe processed and applied to the site by the homeowner. Thus effectively decreasing the disposal cost. However, one consequence of onsite application of drywall may be the increased tendency to dispose of contaminated wastes (painted drywall, pressure treated wood, etc) onsite which should be disposed of in other manners.
3. This project may be difficult to sustain after the grant money has run out because the economic incentive may not be significant enough to motivate the homeowner to take initiative to apply the drywall on site.

ATHLETIC FIELD MARKER

Currently, raw gypsum is a component of athletic field marker. However, gypsum wallboard may be ground to a fine white powder and applied instead of lime or used as a component of a field marking product.

The primary challenge with turning gypsum drywall into athletic field marker is the economic feasibility of such an operation. Transportation costs are quite high and the monetary value of the resulting field marker is quite low. One option which does seem quite feasible would be to have a cooperative transportable chipper or shredder that could be brought to school construction sites. The drywall construction scraps could be ground and placed in bags to be mixed with standard field marker or alone as a field marker, essentially this would be a form of onsite application.

PROCESS

1. Separate construction drywall scraps from other forms of C&D waste
2. Transport to place of processing or process on site
3. Grind into a fine powder
4. Transport to schools and recreational areas
5. Apply to fields as a line marker in the same manner lime would be applied

TRANSPORTATION OPTIONS

- Could be processed on site making transportation unnecessary
- Hauled by the contractor generating the waste to the processor
- Hauled by the processor
- Hauled by a third party hired to transport the drywall between sites

The drywall waste may also be brought to a central transfer station by a local hauler or the

contractor and then transported from there by the receiving organization.⁶⁹

COST = Source Separation + Processing + Storage

REGULATIONS

None, unless the material is stored off the site of generation in which case the material comes under regulation as solid waste and special rules for storage apply.⁷⁰

COMPETING PRODUCTS

Athletic field markers: paints, lime, etc.

*STAKEHOLDERS*⁷¹

Drywall Contractors	Solid Waste Districts
Building Contractors	Regulators
School Athletic Departments	Suppliers of Athletic Field Markers
School Districts	Onsite Drywall Processors

CASE STUDIES

No known field studies have been conducted to test the effectiveness of ground gypsum drywall as an athletic field marker. However, John Reindl of the Wisconsin Department of Natural Resources cites Richard Anthony of San Diego, California as stating “gypsum is used to mark playing fields on grass and can be used for football, soccer etc. It is better than herbicide or burning the field with gasoline.”⁷²

OTHER CONSIDERATIONS/ ENVIRONMENTAL IMPACTS

1. Drywall is better for the grass and has fewer chemicals than other forms of athletic field markers.
2. This use of drywall actually turns drywall scraps that were once considered a waste for schools and others into a valuable product they can put to use onsite without having to transport it long distances.

⁶⁹ See Appendix 2 for a cost benefit analysis of collection options.

⁷⁰ Vermont Agency of Natural Resources, Solid Waste Management Division 1998.

⁷¹ Please see Appendix 3 for stakeholder contact list.

⁷² Reindl, John. *Bibliography on Gypsum Drywall*. Dane County Dept of Public Works: Madison, Wisconsin, November 1999.

3. The onsite processing of drywall at schools could serve as a demonstration for local builders and homeowners.

Other (low priority options for Vermont)

ANIMAL/ LIVESTOCK BEDDING

Ground gypsum drywall can be used alone or in combination with wood shavings or paper as animal bedding.⁷³ Incorporating ground gypsum drywall in animal and livestock bedding has shown a decrease in feet problems in cows and chickens, as well as increases udder health for cows. However, the resulting ground gypsum manure mix should not be stored in manure tanks because of probable anaerobic reactions which produces hydrogen sulfide gases. This clearly makes storage of gypsum drywall animal bedding a problem.⁷⁴

CEMENT PRODUCTION

Ten percent of all new cement is made up of gypsum; gypsum is used to control the set time. Currently, recycled gypsum can not be used as a cement additive because of the high paper content. However, there seems to be a general consensus that if the paper content were below one percent, recycled gypsum could successfully be included.

FACILITATE SODIUM LEACHING

Damage caused to soil next to roadsides by winter salt can be reduced by adding gypsum.⁷⁵ The sodium reacts with the sulfur facilitating the leaching of the salt from the soils. For gypsum drywall to be effective in removing salt from soils the soils must be well drained.

CASE STUDIES

1. Maine Department of Transportation

A three year study was conducted to determine the effectiveness of using finely ground gypsum to alleviate the effects of road salt on roadside vegetation. Gypsum was found to be effective; the sodium in the soil is replaced by the calcium from the gypsum and the sodium sulfate leaches out of the soil.⁷⁶

FLEA POWDER

No information currently available on this option.

GREASE ABSORBENT

⁷³ Wyatt, C.L. and T.N. Goodman. "Research Note: The Utilization of Recycled Sheetrock (refined gypsum) as a Litter for Broiler Chickens." *Poultry Science* 71(1992): 1572-1576.

⁷⁴ Washington State Department of Ecology www.wa.gov/ecology/swfa/gypsum.html

⁷⁵ Turley 1998.

⁷⁶ *Better Roads* June 1975.

For oil and other small spills gypsum is a better absorbent than typical clay absorbents. However, the white color of gypsum is not preferred by facilities that do not clean up after spills because the absorbent is highly visible. This option would be most feasible at construction sites where gypsum drywall is generated and a potential for spills exists, because secondary gypsum is more valuable as an agricultural amendment and gypsum is expensive to transport.

CASE STUDIES

2. Bill Wilson
Phoenix Resources, 10313 Morse Lake Rd
Alto, MI 49302
Telephone: 616-891-9110

Bill Wilson has helped to set up several facilities in Rhode Island and Long Island, NY for processing gypsum into grease and spill absorbent. Bill Wilson owns a gypsum drywall processing company in MI. The company until recently processed gypsum drywall as a grease absorbent and now sells gypsum drywall to farms as an agricultural soil amendment.

MUSHROOM GROWING

Mushroom growers commonly add raw gypsum to their compost to reduce the greasiness of the mixture. Gypsum has been found to increase clumping of specific chemicals within the compost. Gypsum is also believed to aid the circulation of air within the compost because of the manner in which it adheres to the straw within the mixture.⁷⁷

MINE RECLAMATION

No information is currently available on this option.

ODOR REDUCTION

Gypsum's chemical properties foster the absorption of odors. Washington state has conducted some studies which have produced mixed results.⁷⁸ The greatest obstacle when using gypsum as a odor reducing agent is controlling any decomposition which may occur.

WATER TREATMENT

Gypsum drywall can help to settle turbid water. When gypsum is added to muddy ponds the suspended clay particles precipitate out and settle to the bottom.

Processing Machinery

Andela Tool & machine Inc
493 State Route 28
Richfield Springs, New York 13439

Telephone:315-858-0055 Fax: 315-858-2669
The Andela system is completely enclosed.
The machine consists of a conveyor belt in

⁷⁷ Mushroom Council. "How They Grow: The Six Steps to Mushroom Farming"
<http://www.mushroomcouncil.com/grow/sixsteps.html> Viewed: 6 June 2000.

⁷⁸ Washington State Department of Ecology www.wa.gov/ecology/swfa/gypsum.html

feed, an impact separator, an intermediate conveyor belt, and a trommel screen. The system produces fine 1/8" ground gypsum to coarse 1/2" gypsum and paper. The system can process 10 tons of material an hour. They have been able to reduce the paper content of the gypsum to below 5%.

Concet Products Corporation
Paoli Corporate Center
16 Industrial Blvd, Suite 110
Paoli, Pennsylvania 19301
610-722-0830

This company produces both a machine to shred gypsum drywall and a mobile job site processing machine.

GP Research Ltd
Jim Dooley, Federal Way Office
1911 SW Campus Drive #545
Federal Way, Washington 98023-6641
253-838-3496
GP Research has designed an in plant delaminator.

Gyp-Pack Container Inc.
P.O. Box 1415-1-0099
Tonawanda, New York 14150
Telephone: (716) 694-1900
Gyp-Pack Container Inc builds trucks for gypsum drywall recycling. The trucks require three people to operate properly. The trucks

work as follows: the drywall material is collected from the construction site and brought to the truck, the paper is separated from the gypsum, the gypsum is then ground into a powder and placed in square closed containers for transport.

New West Gypsum Inc
Bryan Harker, 1321 54th Ave
Fife, Washington
206-922-9343

New West Gypsum Inc produces a machine designed for use within a gypsum drywall waste processing facility.

Premier Gear & Machine Works
1700 N.W. Thurman
Portland, Oregon 97209
Telephone: 503-227-3514
Premier Gear & Machine Works sells a machine designed for use within a gypsum drywall waste processing facility.

Recycling Dimensions
2600 W. Sahara Ave #116-293
Las Vegas, Nevada 89102
Telephone: 1-800-884-8814
Recycling Dimensions' machine is mobile and meant to be used on site.

Further information on processing machine companies is available in *Resource Recyclers* "Buyers Guide Section" of the July 2000 issue.

Resources

Literature

Clean Washington Center. *Construction, Demolition & Land clearing Market Assessment: Gypsum Wallboard* (#CLD-95-1). Seattle Washington: June 1999.

As part of an effort to develop markets for recycled construction, demolition and land clearing (CDL) materials, the CWC conducted a comprehensive assessment of markets for recycled CDL materials in Washington State. The fact sheet includes potential markets but does not include results and conclusions.

Clean Washington Center's Recycling Technology Assistance Partnership (ReTAP). *Evaluation of the Potential for Composting Wallboard Scraps* prepared by E&A Environmental Consultants Inc. Seattle Washington: 25 June 1997.

The report clearly outlines the challenges and opportunities of composting gypsum drywall. The report provides temperature, oxygen, and moisture level data for a composting mixture which included drywall. The report concludes that gypsum drywall can be successfully composted without hindering the end mixtures quality.

Cosper, Stephan, et al. *Construction and Demolition Waste: Generation, Regulation, Practices, and Policies*. Chicago Illinois: Office of Solid Waste Management, School of Public Health, The University of Illinois, 1993.

Dixon, Robert. "Suitability of Ground Gypsum Board as a Source of Agricultural Gypsum for Application to Croplands" Certified Professional Agronomist. 1984.

Gypsum Association. *Treatment and Disposal of Gypsum Board Waste* (Industry Technical Paper) Washington D.C.: January 1991.

This paper provides an overview of the problems associated with placing gypsum wallboard in landfills. It also briefly reviews the chemical reactions which occur to produce the noxious H₂S gas.

"Gypsum Remedies Winter Salt Kill of Highway Grasses." *Better Roads*. June 1975, pages 24-25.

This article describes several research projects testing gypsum's ability to reduce salt damage to roadside vegetation. The projects presented appeared to have fairly positive results.

Korcak, Ron. "Agricultural Uses of Phosphogypsum, Gypsum, and other Industrial Byproducts" *Agricultural Uses of Municipal, Animal, and Industrial Byproducts* USDA Research Rpt 44: January 1998.

Korcak, Ron. "Beneficial Reuse of Aggregate Mineral Fines and Scrap New Construction

Wallboard” (a chapter to be published in the Agronomy Society of America's new book) Beltsville, Maryland: 3 August 1998.

This paper provides a synopsis of the research that has been conducted to date on scrap new construction wallboard use in agriculture. The paper covers everything from composting to animal bedding to direct land application. The literature cited section is complete resource in itself. It should also be noted that to date this paper has not been published, however, it is to be published shortly as a chapter in a book put out by the Agronomy Society of America.

Korcak, Ron. “Scrap Construction Gypsum Utilization” submitted to The Gypsum Association Washington D.C.: 31 July 1996.

The report is composed of two parts a literature synthesis and experimental results. The literature synthesis reviews reprocessing, composting, moisture control, and agricultural uses of gypsum drywall. While the experimental results discuss the affects of gypsum application on agricultural products. Korcak found that ground construction waste gypsum had a positive impact on the Ca levels of turf and found that ground gypsum had no significant impact on tomato growth or fruit.

National Association of Home Builders (NAHB) Research Center. “On-Site Grinding of Residential Construction Debris:The Indiana Grinder Pilot.” Upper Marlboro, MD: February 1999.

New York State Department of Environmental Conservation, Division of Solid & Hazardous Materials. *Management and Disposal Practices for Gypsum Wallboard Waste in the United States*. Albany, New York: July 1997.

This is a national survey on the management and disposal practices for gypsum wallboard waste. Several states, in addition to New York State, have experienced hydrogen sulfide gas at noticeable levels in landfills that accept Gypsum wallboard waste. The possible causes given for the generation of H₂S gas in most cases are those that support the anaerobic decomposition of gypsum (calcium sulfate). The possible causes were excessive amounts of moisture, organics mixed with gypsum, and large volumes of disposed gypsum.

Niles, John O. Letter to Molley Farrell and Any Harper of Intervale Compost Project. 25 September 1995.

The letter discusses the possibility of creating a pilot project to study the feasibility of composting gypsum drywall in cooperation with the Intervale Compost Project. However, the pilot project was never implemented.

North Carolina Department of Environment and Natural Resources, Division of Pollution Prevention and Environmental Assistance. *Markets Assessment: Construction and Demolition Commodity Profile*. Raleigh, North Carolina: 1998.

This report provides an overview of the percent composition of residential and

commercial construction and demolition waste. The report also details the current disposal opportunities for each form of C&D waste generated within NC.

Norton, L. Darrell. "Stopping Erosion with Gypsum and PAM." *Agricultural Research*. September 1997: 19-20.

This article briefly describes the research currently evaluating gypsum's potential to stop erosion.

Oregon Solid Waste Department. *1993/94 Gypsum Market Profile*. Portland, Oregon: August 1994.

This article provides an overview of gypsum recovery in Oregon. Recovery is expected to increase steadily over the next several years. Current viable secondary use markets are in new wallboard and as a soil amendment.

Perry, Jean. "From Trash to Treasure: Recycling Drywall as a Soil Amendment and Conditioner." *BackHome Magazine* (Hendersonville, NC), 46 (May/June 2000). backhome@ioa.com.

This article describes how onsite application of gypsum drywall can be done by the homeowner. The article provides tips for both grinding and spreading the drywall.

Reindl, John. *Bibliography on Gypsum Drywall*. Dane County Dept of Public Works: Madison, Wisconsin, November 1999.

This bibliography contains 191 references to articles, publications, documents and communications pertaining to gypsum wallboard information.

Ritchey, K.C., C.M. Feldhake, R.B. Clark, M.A. Elrashidi, V.C. Baligar, W.L. Stout, A.N. Sharpley, L.D. Norton, and R.F. Korcak. "Recent Developments in Agricultural Uses of Gypsum." Fifth International Conference on FGD and Other Synthetic Gypsum. ORTECH Corp, Mososaiga, Ontario, Canada: 14 May 1997.

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This fact sheet is an overview of recycling wallboard into new products. It answers common questions about wallboard recycling. Its purpose is to help create business opportunities, save money for builders, contractors, 'do-it-yourselfers', and other purchasers of drywall, as well as to help local governments meet their goal of reducing disposal by 50% by the year 2000.

Sumner, Malcom E., William P. Miller, David E. Radcliffe, and William Segers. "Principles of Gypsum Use as a Soil Amendment." Georgia 1989.

The paper provides research on three aspects of gypsum application: absorption, acidic soil, and hardpan soils. The results show that industrial gypsum dissolves most quickly and that both crops planted in acidic and hardpan soils can benefit from gypsum application.

Turley, William. "What's Happening in Gypsum Recycling" *C&D Recycling* January/ February 1998.

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The U.S. Environmental Protection Agency, Municipal and Industrial Solid Waste Division Office of Solid Waste. *CHARACTERIZATION OF BUILDING-RELATED CONSTRUCTION AND DEMOLITION DEBRIS IN THE UNITED STATES* (Report No. EPA530-R-98-010) prepared by Franklin Associates under subcontract to TechLaw, Inc. Prairie Village, KS: June 1998.

This report provides data on the composition of construction and demolition waste within the United States. The report briefly discusses drywall recycling options and drywalls the composition of the C&D waste stream. The report provides the methodology used for determining the proportion of drywall waste within the C&D waste stream.

Vermont Agency of Natural Resources, Solid Waste Management Division. *Recycling Construction and Demolition Waste in Vermont* prepared by C.T. Donovan Associates Inc. Burlington, Vermont: December 1990.

Vermont Agency of Natural Resources, Solid Waste Management Division. "Solid Waste Management Rules" rule number 98P052: effective 20 December 1998.

White, Edwin and Mark Burger. "Available Gypsum: Construction Drywall As a Soil Amendment." *BioCycle* July 1993: 70-71.

This article provides a brief overview of the 1990 study conducted in Tully, New York which found that pulverized drywall application supplies calcium to soil and may serve as a suitable soil amendment.

Wolkowski, Richard. "Demonstration of Land Application of Crushed Gypsum Wallboard waste for Alfalfa. A final Report Prepared for the Wisconsin Department of Natural Resources Waste Reduction and Recycling Grant Program and Dane County Department of Public Works." Wisconsin: 12 August 1998.

The paper identifies some concerns with gypsum application to alfalfa fields and concluded that modest application rates do not negatively impact crop growth or quality.

Wyatt, C.L. and T.N. Goodman. "Research Note: The Utilization of Recycled Sheetrock (refined gypsum) as a Litter for Broiler Chickens." *Poultry Science* 71(1992): 1572-1576.

Web sites

California Integrated Waste Management Board. "Construction and Demolition Debris Recycling

Program” <http://www.ciwmb.ca.gov/ConDemo/> Viewed: 6 June 2000.

This page lists individuals to contact within the California Integrated Waste Management Board regarding construction and demolition waste recycling. The page also provides a copy of California’s *Meeting the 50 Percent Challenge: Recycling Market Development Strategies Through the Year 2000*.

Clean Washington Center. “Construction: Fact sheets and Reports.”

www.cwc.org/briefs/construction Viewed: 6 June 2000.

This page provides copies of *Evaluation of the Potential for Composting Gypsum Wallboard Scraps* both in the form of a fact sheet and a report. The page also contains information on recycling other forms of construction and demolition waste.

Gypsum Association. www.gypsum.org Viewed: 6 June 2000.

The Gypsum Association is a not-for-profit trade association established in 1930. The Gypsum Association represents manufacturers of gypsum board in the U.S. and Canada and provides technical information and assistance to the construction industry and code enforcement community regarding gypsum board.

Mushroom Council. “How They Grow: The Six Steps to Mushroom Farming”

<http://www.mushroomcouncil.com/grow/sixsteps.html> Viewed: 6 June 2000.

This web page describes in detail the process involved in growing mushrooms. It also briefly describes the industry’s use of raw gypsum.

National Association of Home Builders. “Residential Construction Waste: From Disposal to Management.” <http://www.nahbrc.org> Viewed 6 June 2000.

This page provides an overview of some available options for handling construction and demolition waste disposal. The page discusses some options available for gypsum wallboard.

New West Gypsum. www.nwgypsum.com Viewed: 8 June 2000.

This page advertizes the New West Gypsum's Recycling's services. Through pioneering several proprietary technologies New West Gypsum has become a leader in recycling and reprocessing gypsum. This page discusses some aspects of the New West Gypsum operation and provides an overview of the gypsum drywall reprocessing industry.

North Carolina Department of Environment and Natural Resources. "Information Sectors: Waste Reduction in Construction and Demolition." <http://wrrc.p2pays.org/construct.htm> Viewed: 8 June 2000.

This page provides a list of resources containing information on construction and demolition waste both within North Carolina and within the United States.

South Carolina Department of Environmental Health and Control. "Environmental Quality Control General Information: List of Publications." <http://www.state.sc.us/dhec/eqc/lwm/> Viewed: 8 June 2000.

This site lists South Carolina state publications regarding construction and demolition waste as well as other environmental concerns.

United States Census Bureau. "New Privately Owned Housing Units Authorized Unadjusted Units for Regions, Divisions, and States Annual 1999" Updated: 24 May 2000
<http://www.census.gov/const/C40/Table2/tb2u1999.txt> Viewed: 15 June 2000.

University of Florida. "Research on the Management of Waste Gypsum Drywall Management Projects." http://www.ees.ufl.edu/homepp/townsend/Research/GypDW/Recycle/gypsum_recycle_main.html Viewed: 6 June 2000.

This page contains information on current research and pilot projects being conducted within Florida. The page also contains a number of links to other sources of information on gypsum and gypsum drywall.

Washington State Department of Ecology. "Gypsum Wallboard Waste (Publication # 96-1556-SWFS)" www.wa.gov/ecology/swfa/gypsum.html Viewed: 6 June 2000.

This page provides an overview of some of the concerns associated with traditional methods of gypsum wallboard disposal. The page also discusses some of the alternative methods of disposal, as well as the regulations governing these alternative forms of gypsum drywall disposal.

Contacts

Columbia City, MO Municipal Composting
Facility

Mark Russell

Telephone: 573-886-0722

Georgia Pacific Gypsum

122 Old Dover Road

Newington, New Hampshire

Mary Anne

Telephone: 603-433-8000

Clean Washington Center

2001-6th Avenue, #2700, MS:TB-40

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Appendices

APPENDIX 1. Calculations for the Generation of Gypsum Drywall within Vermont:

13.4% (Gypsum drywall's average percent composition of C&D waste)⁷⁹

56338 tons (The State of Vermont's Solid Waste Management Plan 1999 Revision's estimated level of solid waste generated within the State)⁸⁰

64% (average estimated percent construction drywall accounts for in drywall waste)⁸¹

$13.4\% \times 56338 = 7549$ tons of gypsum drywall waste

$64\% \times 7549 = 4832$ tons of construction gypsum drywall waste

APPENDIX 2. Transportation Options Considerations:

- Hauled by the contractor generating the waste
 - The contractor generating the waste may be willing to haul the waste if an economic incentive exists; ie. the avoidance of high tipping fees for waste disposal, payment for the scrap, etc.
 - The contractor incentive to haul recyclable or reusable drywall scrap maybe increased by an opportunity for back hauling. In other words if the contractors can pick up new drywall while at the same time and place dropping off gypsum drywall waste.
 - The contractor's willingness to haul waste may decrease if the location he has to haul the material to changes constantly (hauling directly to site) or has inconvenient hours.
- Hauled by the party accepting the discarded drywall waste
 - The party accepting the discarded drywall waste maybe willing to haul the waste if the material they are receiving is regularly to their specifications, the reusable drywall is in high demand, or if they have developed the infrastructure necessary to support collection of drywall.
 - The party accepting the discarded drywall waste maybe willing to haul the waste if they can pick the waste up from a transfer station.
- Hauled by a third party hired to transport the drywall between sites
 - The third party's fee must be such that neither of the two parties can haul the material for a lower cost. The third party's fee must also be such that it is not greater than the cost of general waste disposal.
- The drywall waste may also be brought to a central transfer station by a local

⁷⁹ Shore, Sally. "Homebuilders Recycling Initiative Final Report." Woodbin II: 19 November 1997.

⁸⁰ Vermont Agency of Natural Resources, Solid Waste Management Division 1998.

⁸¹ Robb, Casey December 1997.

hauler or the contractor and then transported from there by the receiving organization. This option provides the opportunity for a variety of secondary uses.

APPENDIX 3. Stakeholder Contact List

<p>Drywall contractors Don-Vac Inc 7 Blair Park, Williston 05495 802-878-5006</p> <p>East Shore Drywall Inc. 16 Gregory Dr. S. Burlington 05403 802-860-5040</p> <p>Poulin Construction Inc 102 Kimball, S. Burlington 05403 802-864-6922</p>	<p>Towne Drywall Inc 31 Hillside, Essex 05452 802-879-3261</p> <p>Best Drywall Rutland 05701 802-773-1683</p> <p>Green Mnt Drywall Co Inc 2 Depot, Wallingford 05773 802- 446-2491</p>	<p>802-655-3166</p> <p>Composting Facilities Champlain Valley Compost Co, Charlotte 05445 802-425-5556</p> <p>The Intervale 282 Intervale Rd Burlington 05401 802-660-4949</p> <p>Vermont Natural Ag Products 559 Lower Foote Street Middlebury, Vermont 05753 1-800-639-4511</p>
	<p>Drywall Supply Companies Trowel Trades Supply Co. Inc 71 Troy Ave Colchester 05446</p>	

APPENDIX 4. The Economics of Recycling Gypsum Drywall at Smugglers’ Notch Resort.

Year	Tonnage	Haulage	Capital	Tipping Fees**	Recycling Cost Per Ton	Landfill Cost Per Ton***	Total Savings	Savings Per Ton
1998	5.76	\$575.00	\$0.00	\$80.00	\$113.72	\$124.00	\$59.24	\$10.28
1999	9.31	\$524.00	\$547.96*	\$80.00	\$123.73	\$124.00	\$2.48	\$0.27
			\$0.00	\$80.00	\$64.88	\$124.00	\$550.44	59.12

*One time capital expenditure on a cover for a waterproof, removable roll-off cover for the gypsum drywall recycling box. **The tipping fees paid by Smugglers’ Notch Resort are a flat fee for a 30 to 40 ft box of drywall waste. *** The landfill fee paid by Smugglers’ Notch Resort is also a flat fee. The fee covers the costs of hauling, disposal, and box rental.

APPENDIX 5. Personal Correspondence with Mark Russell Regarding the Columbia Missouri

Gypsum Drywall Composting Pilot Project and Facility.

Mark Russell

Personal communication on June 5, 2000

537-886-0772

He was hesitant at first because of control issues. He was afraid of a contaminated waste stream. Columbia is a city located in the central part of Missouri with a population of approximately 80,000 people and a foot print of about 120,000 people. The composting facility is 8 acres of windrows and 2 acres of holding basins. The composted waste is composed of mostly yard waste and wood. The gypsum's pH of 7 acts as a buffering agent for the acidic nature of the waste stream. The increase in nutrients provided by adding gypsum drywall is not large enough to create the odor problems which were initially a concern to many.

The waste stream is handled at the scales. For landfill materials the fee is \$32 per ton will for clean construction drywall and yard waste the fee is reduced by half to \$16.25 per ton. The facility processes 130,000 tons annually generally about 3,000 tons of yard waste and 700 tons of drywall. The resulting compost is used as a soil amendment at the landfill. Dust from the grinding of the gypsum is a big irritant. The gypsum drywall is dropped on a paved pad along with yard waste after being weighed. The yard waste and gypsum are ground together either in a tub or horizontal grinder. The gypsum is not covered so the moisture level depends on climatic events.

Storm water basins all controlled and water quality data to back up the fact that there has been little chemical change in the composition of the water runoff.

Outfall and sampling national pollution discharge.

He was also concerned that people would come after the facility under part 70 of the clean air act, but so far that has not occurred. He was also concerned with fugitive emissions. However, Missouri law states that if the fugitive emissions exist once the pollution has cross the property's boundary, so the facility has not had any problems with fugitive emissions.

To deal with these concerns consider how closely locate you are to the nearest neighbors. He suggests that several hundred yards should be enough to eliminate much of the concern. Also, check into the number of odor complaints that have been filed. A high number of odor complaints would suggest that individuals will likely also have a low tolerance for visible dust.

APPENDIX 6. Drywall Chemical Composition⁸²

These samples included both regular drywall and Type X drywall.

Material	Composition (ppm)
P	<21.7
K	<62.1
Ca	160,360
Mg	8,475
S	133,821
Zn	11.49, 16.63
B	42.45
Mn	44.5, 45.64
Fe	857.9, 941.8
Cu	7.06, 11.62
Al	294.6
Na	<61.2

Material	Composition (ppm)
Cd	3.08
Cr	11.61
Co	9.17
Mo	2.65
Ni	20.10
Li	<2.49
As	<27.9
Pb	15.60
Se	<19.0
N	280.0
Cl	193.5

Type X: The form of drywall containing fiber glass. The drywall is designed to meet one hour fire resistance standards.

Predecorated: This form of drywall has a vinyl face.

Moisture Resistant: This form of drywall has an emulsifier treated facing on one side and is generally used in the construction of bathrooms.⁸³

⁸² UW-Extension Solid and Plant Analysis Lab. Analysis completed on June 1, 1994, June 7, 1994 and June 8, 1994.

⁸³ Korcak 8 August 1998.

APPENDIX 7. Cost Comparison of Services: With Pilot Project Conditions⁸⁴

Service Type	Annual Costs (\$)				Maximum # of houses served(per year)	Cost for service(per house)
	Machine	Labor	Tip Fees	Total		
Grinding for production builders only	39,719	121,466	60,000	221,185	333	\$ 664
Grinding for production and custom builders	38,662	112,430	45,000	196,092	250	\$ 784
Landfilling with Clean-Up service	18,400	84,120	132,000	234,520	183	\$ 1,282
Landfilling with Roll-off trucks	51,125	40,000	540,000	631,125	750	\$ 841

⁸⁴ NAHB Research Center. "On-Site Grinding of Residential Construction Debris: The Indiana Grinder Pilot." Upper Marlboro, MD: February 1999.

If any wallboard recycling was done in the 80s, it was rare. Hell, it is rare today as a percent of total drywall manufactured. Wet gypsum that is deprived of oxygen (which is what commonly occurs in landfills) can emit hydrogen sulfite that can be fatally toxic at high levels. Why Aren't We All Using Recycled Drywall? There are no alerts that I am aware of that state there is such contamination in currently offered products. There had been asbestos in varying degrees in pre-1970s gypsum board and in popcorn ceiling textures of the distant past, and therefore vigilance and testing is required when working with older installations, as well as assuming asbestos until testing says otherwise. Fire-rated assemblies would have had a higher asbestos content. Gypsum Wallboard Recycling and Reuse Opportunities in the State of Vermont, Paper by Emma Marvin, VT DNR. Gypsum pictures, Jim Taylor. Looking Up, Armstrong Ceiling Tile Recycling Program, Anita Snader, C & D, September/October 2009. Learn more about Construction and Demolition (PDF) in the Solid Waste Management Plan. Content last updated December 16, 2020. Policies. Gypsum recycling is the process of turning gypsum waste into recycled gypsum, thereby generating a raw material that can replace virgin gypsum raw materials in the manufacturing of new products. Gypsum waste primarily consists of waste from gypsum boards, which are wall or ceiling panels made of a gypsum core between paper lining. Such boards are also referred to as sheetrock, plasterboards, drywall, wallboards and gyprock. Gypsum waste in some countries also consists of gypsum blocks and plaster "Gypsum Wallboard Recycling and Reuse Opportunities in the State of Vermont." Vermont Agency of Natural Resources, Waste Management Division, August 4. 1998. Korcak, R. (1998). "Agricultural Uses of Phosphogypsum, Gypsum, and Other Industrial Byproducts." in Agricultural Uses of Municipal, Animal and Industrial Byproducts. Conservation Research Report No. 44, US Department of Agriculture, Agricultural Research Center, 135 pages. Wolkowski, R. (1998). "Utilization of Crushed Gypsum Drywall Waste for Potato Production in Wisconsin." "A Feasibility Study and Cost Analysis of Recycling Construction Site Gypsum Wallboard Waste." Master of Science Thesis, University of New Hampshire, September. 1990.