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A Review of Manufacturing Uses for Gypsum Produced by Flue Gas Desulfurization Systems

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EPRI Project Manager

Kenneth Ladwig

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Contributors to this report were:

K. J. Ladwig
EPRI

D. M. Golden, P.E.
Consulting Civil Engineer

S. Kimber
Consultant

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ABSTRACT

Gypsum is widely used as a source material to manufacture products for building construction applications—primarily wallboard, cement, and concrete—and has a number of other commercial applications. The mineral is mined throughout the world (natural gypsum) and also is produced as a result of various industrial processes (synthetic gypsum). The largest source of synthetic gypsum used for manufacturing applications is flue gas desulfurization (FGD) gypsum, the product of wet flue gas desulfurization systems with forced oxidation at coal-burning power plants. Use of FGD gypsum has been steadily increasing in recent years. In 2004, U.S. utilities produced 10.8 million metric tons of FGD gypsum, 76% of that amount used (American Coal Ash Association figures). Statistics on total production and use in Europe are roughly comparable. The supply of FGD gypsum is expected to increase substantially over the next ten years as power plants make changes to their emission control equipment in response to clean air initiatives. Expanding existing markets and creating new markets for FGD gypsum as alternatives to disposal are, therefore, high priorities for the industry. By presenting recent information and statistics and discussing market trends, this report serves as a starting point in the evaluation of expanding existing markets or creating new markets for FGD gypsum in manufacturing applications.

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1
INTRODUCTION

In 1994, EPRI funded a project to develop a guide for the utility industry on the use of gypsum produced in flue gas desulfurization (FGD) systems. That study[1] covered the production and marketing of gypsum on a worldwide basis, and reviewed potential markets for the use of FGD-derived gypsum. At that time, production and use of FGD gypsum was just emerging; there have been many changes in the market over the past dozen years. Many more utilities are now producing high quality FGD gypsum from scrubbers installed to comply with the Clean Air Act Amendments of 1990. Because the amount of FGD gypsum is expected to increase substantially over the next ten years in response to clean air initiatives, the expansion of existing markets and the creation of new markets for FGD gypsum as an alternative to disposal are a high priority for the industry.

The purpose of the present study is to update and summarize current information on the production and use of FGD gypsum in manufacturing applications. The study approach was to focus primarily on a web-based search on gypsum production and markets. The data collected include a very broad overview of the current uses of gypsum, and are intended as a starting point in evaluation of the potential market for FGD gypsum in manufacturing. Gypsum chemistry and products were covered extensively in the 1994 EPRI study[1] and are discussed only briefly here. The scope of this preliminary assessment is restricted to manufacturing applications. Civil engineering applications, which account for less than 1% of the total FGD gypsum use, are not discussed. Use of FGD gypsum as an agricultural soil amendment is being evaluated in a separate EPRI report.

2
GYPSUM SUPPLY

Natural and Synthetic Gypsum

Gypsum is a hydrous calcium sulfate mineral ($CaSO_4 \cdot 2H_2O$), commonly associated with sedimentary sequences that include evaporites such as rock salt. Anhydrite ($CaSO_4$) is a similar calcium sulfate mineral but without water in its crystalline structure. In a pure state, gypsum is white to transparent, but it can take on different colorations depending on impurities that may be present. Natural gypsum is found and mined in most parts of the world. It has been used as a building material for centuries, and is also used to a much lesser extent as fine filler in a variety of products ranging from drilling muds to toothpaste. In North America and Europe, gypsum is used primarily for the manufacture of wallboard and plaster, and as an additive in the production of portland cement.

The term *synthetic gypsum* refers to gypsum produced from any of several different industrial processes, including gypsum from FGD systems (FGD gypsum), titanogypsum, phosphogypsum, fluorogypsum, and citrogypsum.[2] Of the various types of synthetic gypsum, FGD gypsum is by far the largest contributor to the gypsum market. Titanogypsum, produced during the manufacturing of titanium dioxide pigments, finds some limited-use applications.[3] Phosphogypsum is a by-product of the production of fertilizer from phosphate rock; it is generated in very high volumes but its use is limited in North America, due primarily to radionuclide concerns.[2,4]

FGD gypsum is produced from wet FGD systems using lime or limestone reagents and forced oxidation to reduce sulfur dioxide emissions from coal-fired power plants. Tthe sulfur in the flue gas reacts with the calcium in the reagent to form calcium-sulfur compounds. In systems with forced oxidation, the primary product of the reaction is FGD gypsum, which is calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). This material is readily substituted for mined gypsum in manufactured products, as described below. In wet FGD systems without forced oxidation (inhibited or natural oxidation systems), calcium sulfite or a combination of calcium sulfite and calcium sulfate compounds form. The resultant product, generally referred to as scrubber sludge or wet FGD sludge, is difficult to dewater and is not as easily utilized as FGD gypsum from forced oxidation systems. Scrubber sludge is typically either managed in ponds, or stabilized with fly ash and/or lime (fixated scrubber sludge, FSS) and used for structural fill or disposed of in landfills. Most FGD systems currently being installed or planned are of the forced oxidation type, and will produce marketable FGD gypsum, which is the focus of this report.

FGD gypsum is chemically similar to natural gypsum in overall composition, and can be used in many of the same manufactured products as natural gypsum. However, there are differences between the two which can either restrict or enhance the substitution of FGD gypsum for natural gypsum. For example, FGD gypsum has higher moisture content which, combined with fine grain size can affect handling and processing, especially at existing manufacturing facilities designed for natural gypsum.[2] On the other hand, FGD gypsum requires less grinding than natural rock gypsum due to the finer grain size. The newer plants for producing wallboard are generally designed to accommodate FGD gypsum, either solely or in combination with natural gypsum.

Both natural gypsum and FGD gypsum contain impurities. In natural gypsum these include clay and other minerals, and in some cases soluble salts; impurities in FGD gypsum include ash and soluble salts. Ash, along with iron and manganese compounds, can cause color variation that makes FGD gypsum undesirable for some products and applications. Since these impurities are integral to the gypsum, they are difficult to control after the gypsum is formed. Important parameters that can be controlled are moisture content and soluble salt content. Initial high moisture content of the FGD gypsum is reduced by drying prior to shipment, generally to about 10% free moisture. Soluble salts (such as chlorides) in FGD gypsum are usually reduced by washing the FGD gypsum prior to the drying process.

Gypsum Production

Gypsum is mined from sedimentary deposits in more than 90 countries worldwide. According to United States Geological Survey (USGS) statistics, global production of natural gypsum in 2004 was estimated to be at least 110 million metric tons.[5] Countries producing more than 1 million metric tons are listed in Table 2-1. The United States was the leading producer of mined gypsum at more than 17 million metric tons, followed by Iran, Spain, and Canada. Due to the high cost of transportation versus the value of the material, most gypsum is consumed in the country in which it is mined, with less than 20% of the world's crude gypsum production being exported.

Domestic mines are currently the largest source in the U.S., supplying just under half of the total gypsum consumed, or about 17 million metric tons in 2004. In 2004, gypsum mines were operating in 19 states,[5] extending across much of the U.S. (Figure 2-1). Top producing states in the U.S. were Oklahoma, Nevada, Texas, Iowa, California, Arkansas, and Indiana, accounting for more than 80% of mined gypsum. Fewest mines are found in the northwest, north central, eastern Gulf coast, and along the eastern seaboard.[5]

Of the total U.S. gypsum supply, about 28% (10 million metric tons in 2004) is imported, primarily from Canada and Mexico. Canada accounted for 68% of the total imports between 2001 and 2004, mostly from Nova Scotia supplying the east coast markets.[6,7] Imports from Mexico accounted for 22% of the total imports, primarily serving California and the southwestern U.S.[7]

Synthetic gypsum currently accounts for about 25% (9 million metric tons) of the total supply in the U.S.[a] That percentage has grown substantially over the last ten years and is expected to continue to grow over the next several years.[5,8,9] FGD gypsum accounts for nearly all the synthetic gypsum used in the U.S. FGD gypsum used for wallboard in 2004 was produced at 18 power plants in primarily the eastern and east-central U.S.[5]

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[a] This only includes synthetic gypsum that was used. It does not include synthetic gypsum that was stockpiled or disposed of.

Table 2-1
Worldwide Production of Natural Gypsum, 2000–2004 (thousand metric tons)[5]

	2000	2001	2002	2003	2004
United States	19,500	16,300	15,700	16,700	17,200
Iran	10,700	10,890	10,380	12,000	13,000
Spain	9,929	11,909	11,218	11,500	11,500
Canada	9,232	7,821	8,809	8,376	9,339
Thailand	5,830	6,191	6,326	7,291	8,000
China	6,800	6,800	6,850	6,850	7,000
Mexico	5,654	6,237	6,703	6,986	7,000
Japan	5,917	5,874	5,645	5,764	5,765
Australia	3,800	3,800	4,000	4,000	4,000
France	4,500	4,500	3,500	3,500	3,500
India	2,210	2,250	2,300	2,300	2,350
Egypt	2,000	2,000	2,000	2,000	2,000
Germany	2,300	2,000	1,761	1,748	1,750
Brazil	1,498	1,507	1,614	1,515	1,515
United Kingdom	1,500	1,500	1,500	1,500	1,500
Poland	1,282	1,094	1,147	1,328	1,272
Italy	1,300	1,300	1,300	1,200	1,200
Uruguay	1,076	1,127	1,130	1,130	1,130
Austria	1,000	1,000	1,000	1,000	1,000
All Others	12,285	10,974	10,691	10,596	10,627
Total	**108,313**	**105,074**	**103,574**	**107,283**	**110,648**

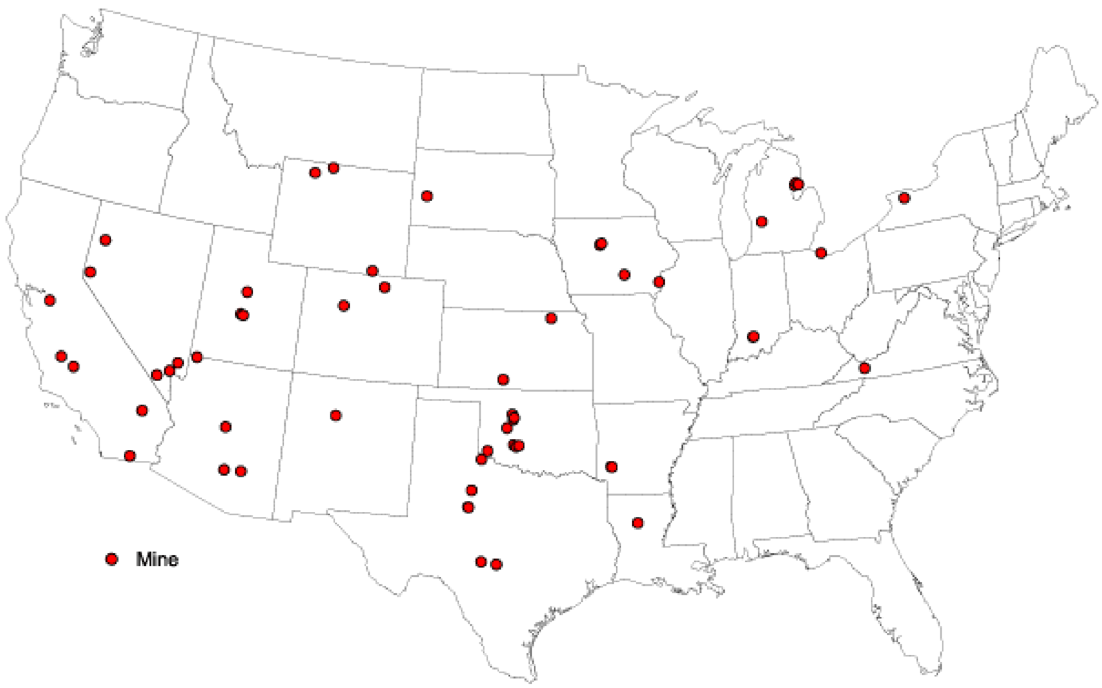

Figure 2-1
Approximate locations of gypsum mines in the United States in 2004.[5]

The total FGD material produced from all types of wet and dry scrubbers in the U.S. in 2004 was about 28 million metric tons.[10] The largest component by type was wet FGD sludge, at almost 16 million metric tons or 56% of all FGD material (Figure 2-2). However, very little of this material is used, only about 7%, primarily in fill and other low value applications. FGD gypsum production in 2004 was almost 11 million metric tons, or 38% of total FGD production. Most FGD gypsum is used, nearly 76% in 2004, primarily in wallboard. Besides wet FGD sludge and FGD gypsum, the remaining 6% of FGD material consists of dry FGD solids and other types, with a utilization rate of less than 10%. This report is focused only on FGD gypsum, because of its utilization rate and because it is the product that will be produced in most of the new FGD systems in the next several years.

Worldwide, the total production of synthetic gypsum (including that stockpiled and disposed of) exceeds the total production of natural gypsum, but the synthetic total includes a large proportion of phosphogypsum, estimated at greater than 100 million metric tons, which has a relatively low utilization rate. In the U.S., 30 million metric tons of phosphogypsum are produced annually, and about 1 billion metric tons is currently stockpiled in Florida alone.[4] Worldwide FGD gypsum production is about 50 million metric tons, and titanogypsum production is about 7 million metric tons.[11]

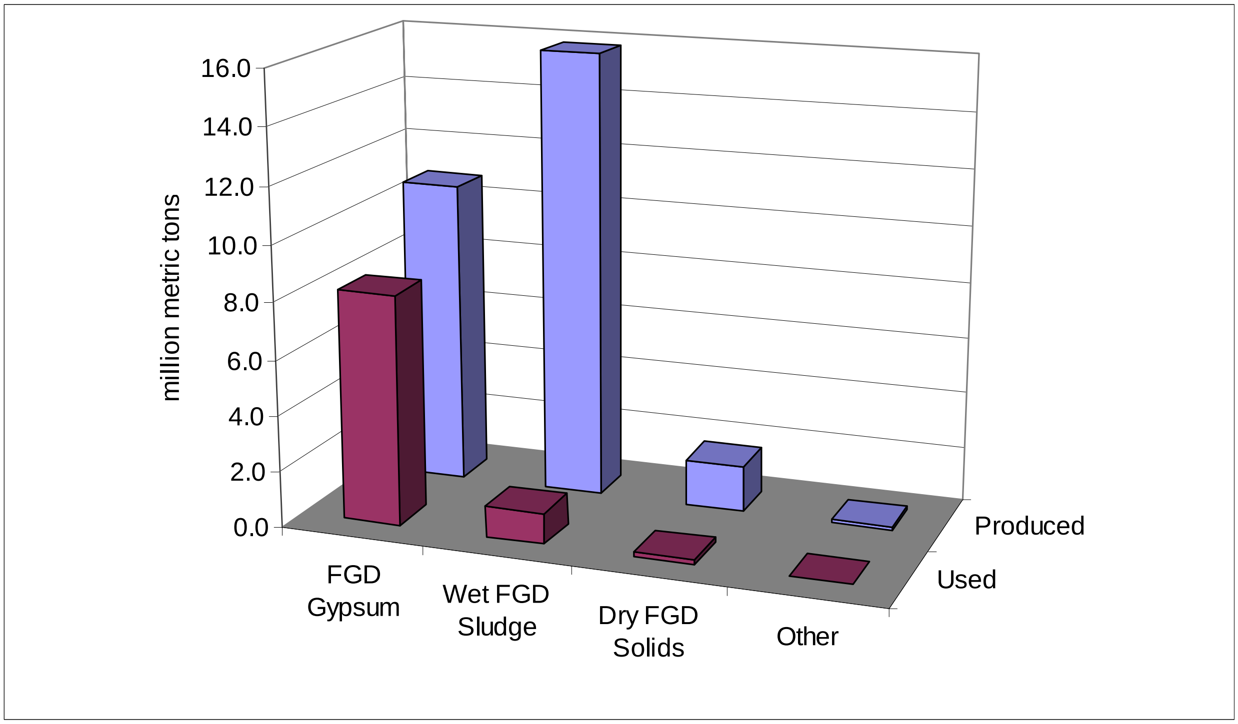

Figure 2-2
FGD material produced and used in the United States in 2004.[10]

Figure 2-3 shows the apparent consumption of gypsum by source in the U.S. for the ten-year period from 1994 through 2004. Total use increased from just under 27 million metric tons in 1994 to just over 36 million metric tons in 2004.[5] During that time period, use of mined gypsum fluctuated between 15 and 20 million metric tons, and imports ranged from about 8 to 10 million metric tons. A large portion of the increase in total production can be attributed to increased use of synthetic gypsum, which rose from just under 2 million metric tons in 1994 to over 9 million metric tons in 2004. On a percentage basis, synthetic gypsum increased from slightly more than 6% of the total gypsum use in 1994 to about 25% in 2004. This increasing trend in the use of FGD gypsum is expected to continue as power plants install new limestone forced-oxidation scrubbers or retrofit older systems, and wallboard plants are constructed in geographic proximity to the plants. This is particularly true in the eastern U.S., where several new scrubbers are planned and sources of natural gypsum are limited.

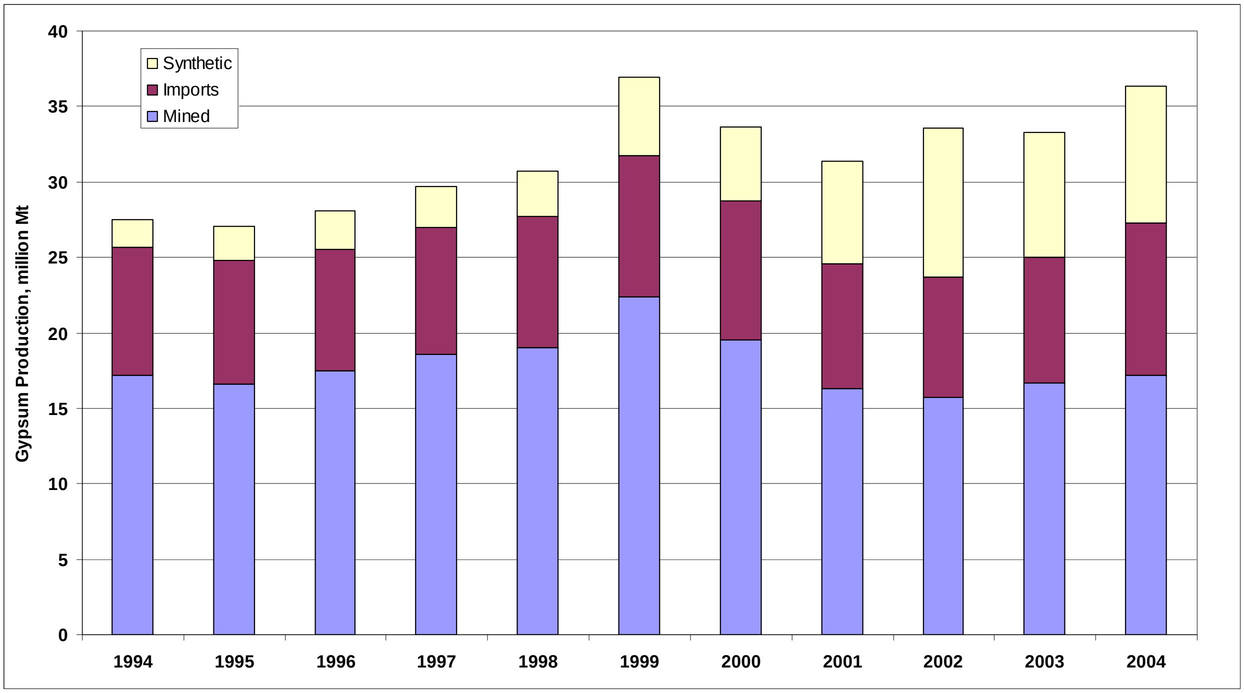

Figure 2-3
Gypsum production in the U.S. from 1994 through 2004.[5] (Synthetic gypsum includes only the amount used, not the total amount produced.)

Gypsum Calcination

Most gypsum in the United States is calcined prior to use. Gypsum calcination refers to the removal of one and one-half waters of hydration, yielding calcium sulfate hemihydrate ($CaSO_4 \bullet 0.5H_2O$). When the powdered hemihydrate is mixed with water, it rehydrates, recrystallizes, and hardens. Calcined gypsum forms the basis for most of the gypsum products in the U.S. It is used in plaster and wallboard-related products, which comprise by far the largest product category.

There are two broad types of hemihydrate, depending on the calcination process used. Beta hemihydrate is formed by heating the gypsum under atmospheric pressure conditions; alpha hemihydrate is formed by heating the gypsum under induced pressure. Beta hemihydrate—commonly referred to as plaster of paris, stucco, or industrial plaster—is the more common type and is used in standard wallboard. Alpha hemihydrate, sometimes referred to as gypsum cement, is more expensive to produce and therefore less frequently used. It is well suited to applications such as floor screeds and high strength materials.

Alpha and beta hemihydrates have different crystalline forms that result in different properties.[12,13,14] Alpha hemihydrate crystals tend to be regularly shaped and nonporous, while beta hemihydrate crystals are smaller, more porous, and irregularly shaped. The most important differences between the two types involve water absorption and strength. Alpha hemihydrates require less water to rehydrate (22 to 45 lb of water per 100 lb of gypsum cement) and produce harder and stronger casts with higher strength. Beta hemihydrates require more water to rehydrate (65 to 160 lb of water per 100 lb of plaster) and the casts produced are softer than alpha hemihydrate casts and easier to mold. There are several different calcination processes, and many additives that yield different material properties and end products. Frequently, beta and alpha hemihydrates are mixed to obtain intermediate properties for specific applications.

FGD gypsum is commonly used to produce beta hemihydrate, and can also be used to produce alpha hemihydrate. Conventional alpha hemihydrate can be formed using wet or dry methods.[13] The dry method utilizes only rock gypsum. The wet method can use FGD gypsum as well as ground rock gypsum. Both processes are more expensive than production of beta hemihydrate. A recently developed technology (U.S. Patent 6,964,704) purports to produce high quality alpha gypsum at a lower cost than conventional methods, using either rock gypsum or FGD gypsum.

3
MARKETS

Natural gypsum is used in a wide range of manufacturing applications, and FGD gypsum can be readily substituted for natural gypsum in many of these applications. The primary uses for gypsum are plaster and wallboard products, and cement additives. This section describes the major uses of gypsum and discusses market trends.

Current U.S. Markets

The USGS tracks statistics for products made using gypsum in the U.S.[5] Most of the gypsum used in the U.S. market is calcined and goes to the production of a variety of prefabricated products, primarily wallboard (Table 3-1). Smaller amounts are used in portland cement and in agriculture.

Table 3-1
Statistics for Gypsum Products in the U.S. in 2004.[5]

Use (All Gypsum)	Metric Tons Used	Percent of Total Use
Portland Cement	*3,160,000*	*9.1%*
Agriculture and Other	*1,030,000*	*3.0%*
Total Uncalcined Uses	**4,190,000**	**12.1%**
Plasters	*906,000*	*2.6%*
Prefabricated Products[a,b]	*29,500,000*	*85.3%*
Total Calcined Uses	**30,400,000**	**87.9%**
Total Use	**34,590,000**	**100.0%**

a. Wallboard represents 97% of prefabricated products
b. Includes weight of paper, metal, and other materials

The American Coal Ash Association (ACAA) keeps statistics specific to the production and use of FGD gypsum.[10] Of the 10.8 million metric tons of FGD gypsum produced in 2004, 8.2 million metric tons (76%) were used, again primarily for wallboard (Table 3-2). ACAA statistics on FGD gypsum use presented in this section do not differentiate between the calcined products, grouping all such products as wallboard. Once the FGD gypsum is delivered to a calcination plant, it may be blended with other sources of natural and synthetic gypsum in development of the final product.

Table 3-2
FGD Gypsum Used in the United States in 2004 (ACAA)[10]

Use (FGD Gypsum)	Metric Tons	Percent of Total Use
Wallboard	7,390,307	90.1%
Cement/Raw Feed for Clinker	407,300	5.0%
Concrete/Concrete Products/Grout	264,335	3.2%
Agriculture	118,870	1.4%
Miscellaneous/Other	22,963	0.3%
Total Use	8,203,774	100%

Calcined Gypsum Uses

From Table 3-1, calcined gypsum products currently account for almost 90% of the gypsum products in the U.S. Raw natural and synthetic gypsum are delivered to one of more than 60 calcination plants around the country for processing. More than four-fifths of the calcined gypsum in the U.S. in 2004 was produced by four companies: US Gypsum, National Gypsum, Georgia-Pacific, and BPB.[5] The calcined gypsum is made into a variety of products, primarily several varieties of wallboard, with smaller amounts going into other products such as plaster, gypsum cement for flooring, and joint compounds.

Wallboard

Prefabricated products command the lion's share of the gypsum market, accounting for nearly 30 million metric tons, or 85%, of gypsum products (Table 3-1). Wallboard, used here to refer to a wide variety of board products, consists of a layer of plaster sandwiched between two sheets of cardboard.[15] After calcining, a slurry of stucco (hemihydrate), foam, and other additives is blended in a mixer. Set retarders may be added to the mixer to prevent premature hardening of the plaster. The slurry is then placed between two continuously moving sheets, one above and one below, and allowed to harden, forming the board. As the material hardens, gypsum crystals form and bond to the cardboard. After hardening, the still-wet boards are sent to a dryer, where additional moisture is removed, for about 45 minutes. After drying, the boards are cut to lengths typically ranging from 8 to 14 feet.

There are many types of board for different applications. They can vary in thickness, strength, fire retarding capability, durability, and moisture resistance.

FGD gypsum can readily replace natural gypsum in wallboard manufacture, provided the plant is equipped to accept FGD gypsum as a raw material. Table 3-3 provides a listing of general specifications for FGD gypsum used in wallboard. These specifications will vary by manufacturer and product, and provide only a general guide. As previously discussed, FGD gypsum is increasingly assuming a larger share of the gypsum board market, where color variations are not generally important because the gypsum is covered by the cardboard sheathing. The 2004 data (see Figure 2-4) suggest that the FGD gypsum market has substantial room to grow as a replacement for natural and imported gypsum. FGD gypsum currently represents only about one-quarter of the raw material for calcined gypsum products.

Table 3-3
General Specifications for FGD Gypsum for Use in Wallboard[1]

Property	Range in Specification
Purity, $CaSO_4 \cdot 2H_2O$ (min.)	92% – 97%
Fly Ash (max.)	1.0%
SiO_2 (max)	1.0%
$CaSO_3$ (max.)	0.5% – 1.0%
Free Moisture (max.)	9% – 15%
Particle Size (average)	9 – 70 µm
Chloride (max.)	100 – 400 ppm
Sodium (max.)	25 – 250 ppm
Total Water Soluble Salts (max.)	325 – 500 ppm
Blaine Surface Area (max.)	3000 – 3500 cm^2/g
pH	6 to 8 pH units

Plaster

Plaster is a dry powdered form of calcium sulfate hemihydrate (calcined gypsum). When mixed with the appropriate amount of water, plaster rehydrates and hardens. Historically, plaster was used to form interior wall surfaces by spreading it over a structure formed of wooden laths, mesh, or metal.[14] In the U.S., the use of plaster for walls has been almost entirely replaced by the use of wallboard. A significant advantage of both plaster and gypsum wallboard in building construction is that these materials retard fire spread due to the water in their crystalline structure. Plaster has a variety of other minor uses including specialty products, sculptures, medical casts, industrial molds, and decorative trim.

Plaster products accounted for 0.9 metric tons, or 2.6%, of the total U.S. gypsum use in 2004 (Table 3-1). The percentage attributable to FGD gypsum was not reported.

Self-Leveling Floor Screeds

Self-leveling floor screeds represent a market that is presently important in Europe but that has not been significantly exploited in the U.S.[16] Poured gypsum floor underlayment systems provide several advantages, including light weight, fire resistance, and sound-proofing properties. Self-leveling floors can be used in new construction or replacement flooring, in both commercial and residential properties. Gypsum cement (alpha gypsum) is often used in flooring products due to better self-leveling characteristics, fire resistance, good strength, abrasion resistance,[1] as well as quick access for subsequent construction steps.

FGD gypsum is well-suited for self-leveling floor applications. One potential constraint is that the calcium carbonate content must be kept relatively low (recommended below 1.2%) to avoid blistering on the surface as carbon dioxide is released.[16] The USGS and ACAA statistics do not list floor screeds as a separate category for gypsum use in the U.S. In statistics for Europe for 2003, about 1.4 million metric tons of FGD gypsum were used for self-leveling floor screeds, comprising 12% of total FGD gypsum use.[17]

It is believed that self-leveling floors represent a small part of the total current U.S. gypsum market, on the order of a few hundred thousand metric tons annually. Increasing this use for FGD gypsum in the U.S. will require market development by gypsum product suppliers.

Joint Compounds

Joint compounds are used to fill the space between adjacent wallboard panels, typically in combination with paper or fiberglass tape. There are two types of joint compounds, a “setting” type containing calcined gypsum, non-gypsum fillers and thickeners; and a drying ready mix type joint cement containing a resin binder, fillers such as carbonates, talc, and sometimes gypsum and thickeners. The calcined gypsum in the setting type allows the joint to harden in 30-90 minutes whereas the ready mix compound requires several hours to dry.

Separate statistics for gypsum utilization in joint compounds were not available, but it is presumably a small amount relative to other uses. Typically, white color is important in joint compounds because the substance is often not concealed beneath cardboard or paper. This can limit the use of FGD gypsum in joint compounds, since impurities such as fly ash and iron and manganese can impart color variations. Particle size is also a consideration.[1]

Uncalcined Gypsum Uses

As noted in Table 3-1, about 12% of the gypsum used in the U.S. in 2004 was uncalcined. About 75% of this uncalcined gypsum was used for portland cement production and concrete, and the remaining 25% was used primarily for agriculture. Small amounts of high purity gypsum also were used in a wide range of industrial operations, including the production of foods, glass, paper, and pharmaceuticals.

Cement and Concrete

Gypsum is used as an additive to portland cement to retard early setting, and to improve grinding characteristics of the clinker. The gypsum is typically added to the cement in a proportion of about 2 to 6%.[5] It can also be used directly with concrete to control the setting time. Although in the U.S., cement and concrete accounted for only about 9% of the total gypsum use in 2004, this application represents the largest use of gypsum worldwide, accounting for 50 to 60% of global gypsum consumption. It is commonly used in developing countries where wallboard has not yet become well established.[5]

FGD gypsum can be readily substituted for natural gypsum in both these applications. Cement production accounted for 5% of the FGD gypsum use in 2004, and concrete products accounted for 3.2% (Table 3-2). An important consideration is chloride concentration, which can affect its use in steel-reinforced concrete. Another consideration is particle size and shape. Some testing is required to evaluate the substitution of FGD gypsum at plants that have been designed to use natural gypsum.

Comparing the total gypsum use in cement in 2004 reported by USGS (3.1 million metric tons)[5] to the use of FGD gypsum in cement and concrete reported by ACAA (0.67 million metric tons)[10] suggests that there is room for additional penetration in this market. FGD gypsum represented only 21% of the total.

Gypsum Blocks

According to statistics prepared by the European Coal Combustion Products Association (ECOBA), high strength gypsum blocks made up 2.3% of the European FGD gypsum use in 2003,[17] but this market has not been developed in the U.S. FGD gypsum is a good raw material for these blocks, due to its fine crystalline nature and relative purity, provided magnesium levels are not too high.[16] Soluble salts of magnesium above 200 ppm can result in efflorescence on the surface of the blocks.[16]

Physical Fillers and Extenders

A physical filler/extender is a substance that can be used either to reduce the amount of a more expensive substance used in a product, or to enhance the product by modifying its physical characteristics.[1] Gypsum has the potential to replace other inorganic fillers in a variety of applications. Common fillers/extenders include calcium carbonate, talc, silica, kaolin, and mica, in products such as paper, paints, sealants, adhesives, plastics, and carpet backing.[18] The total size of this market in 1992 was estimated as 11.5 million metric tons, and, depending on the product, these fillers may command a price of several hundred dollars per metric ton.[1] High purity gypsum has been used as a filler in food and pharmaceutical products, but this niche is considered unlikely for exploitation by FGD gypsum. Gypsum offers some advantages over calcium carbonate fillers by not dissolving at in acidic conditions and being less abrasive.

The degree to which FGD gypsum can penetrate the filler and extender market is difficult to predict. It is not separately reported in the USGS, ACAA, or ECOBA use statistics. While FGD gypsum meets many of the general physical requirements for inorganic fillers and extenders, there does not appear to have been significant penetration between 1992 and 2004. Given the potential market size and high value, use of FGD gypsum in inorganic fillers may be a market worth pursuing when specific applications are identified.

Drilling Muds/Cements

Natural gypsum is used in some drilling muds by oil and gas companies to replace bentonite clays and barite.[1] This is a relatively low volume and fluctuating market, likely representing a maximum of less than 1 million metric tons of gypsum use. Rapid increases in the viscosity of gypsum muds limited their use in the past. Gypsum cements are used to cement oil well casings in permafrost environments due to the lower heat generated on setting when compared to Portland cement. An opportunity for growth of this application outside the permafrost regions may exist.

Gypsum Value

The value of gypsum depends on the form and the use, as well as on supply and demand. In 2004, the average value of crude (mined) gypsum was around $7/metric ton, while the average value of calcined gypsum was about $21/metric ton.[5] With respect to uncalcined uses, agricultural gypsum ($28) was valued higher than gypsum used in cement ($13).

Figure 3-1 shows the price for the various forms of gypsum from 2000 to 2004 from the USGS statistics. Crude gypsum prices dropped by about 17% during this period, while calcined gypsum prices increased by about 23%. The average price for gypsum in cement was relatively stable, while agricultural gypsum was the most variable, doubling during the five-year period.

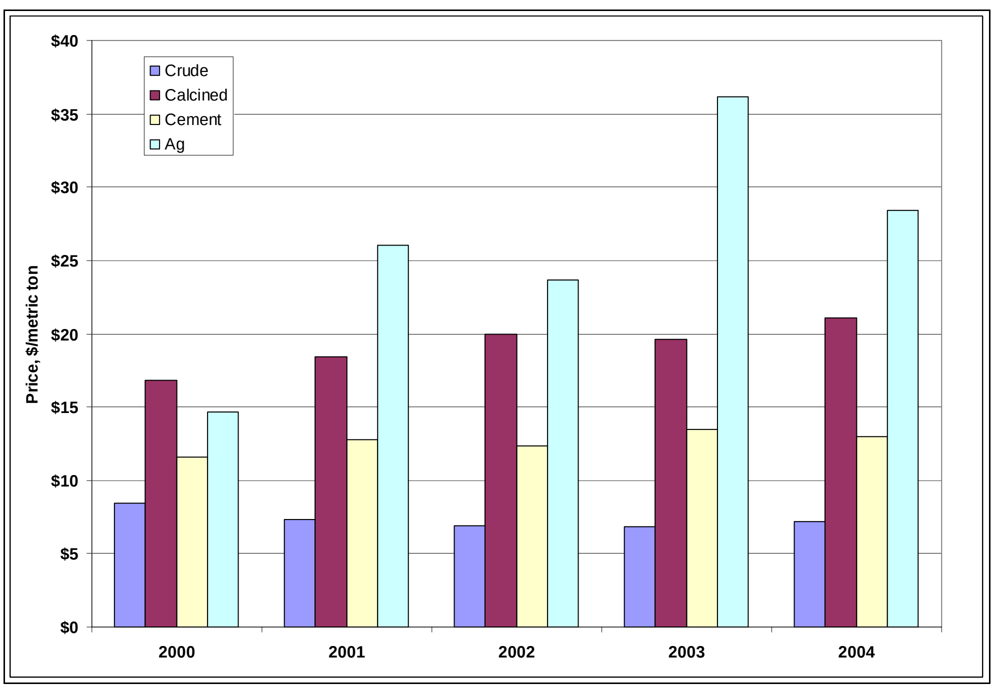

Figure 3-1
Average value for gypsum in the U.S. (2000 to 2004).[5]

World Markets

Total global consumption of gypsum in 2003 was estimated as about 150 million metric tons.[11] Calcined products are not as dominant, however, as worldwide more than half of all gypsum is used in cement and concrete.[5] The use of calcined gypsum in board products is increasing, particularly in industrialized countries, now accounting for about one-third of all use.[11] However, use in cement and concrete, particularly in developing countries in the Middle East and Asia, will continue to be the primary market.

As is the case in the U.S., worldwide the use of FGD gypsum is increasingly replacing the use of mined gypsum.[11] Compared to the U.S., Europe has a longer history with management of FGD products, dating to the late 1970s. ECOBA tracks FGD gypsum use in 15 European countries.[17] Total production and utilization rates of FGD gypsum in 2003 were similar to those in the U.S., at 11.3 million metric tons and 71%, respectively. Germany produces by far the largest amount of FGD material, at roughly half the total output.[16] The highest volume use was in gypsum board and plaster (58%), followed by reclamation (17%), self-leveling floors (15%), cement (7%), and blocks (3%) (Figure 3-2)[17] Reclamation, self-leveling floors, and gypsum blocks are uses that were not listed in the ACAA statistics for the U.S. They may represent markets for further exploitation.

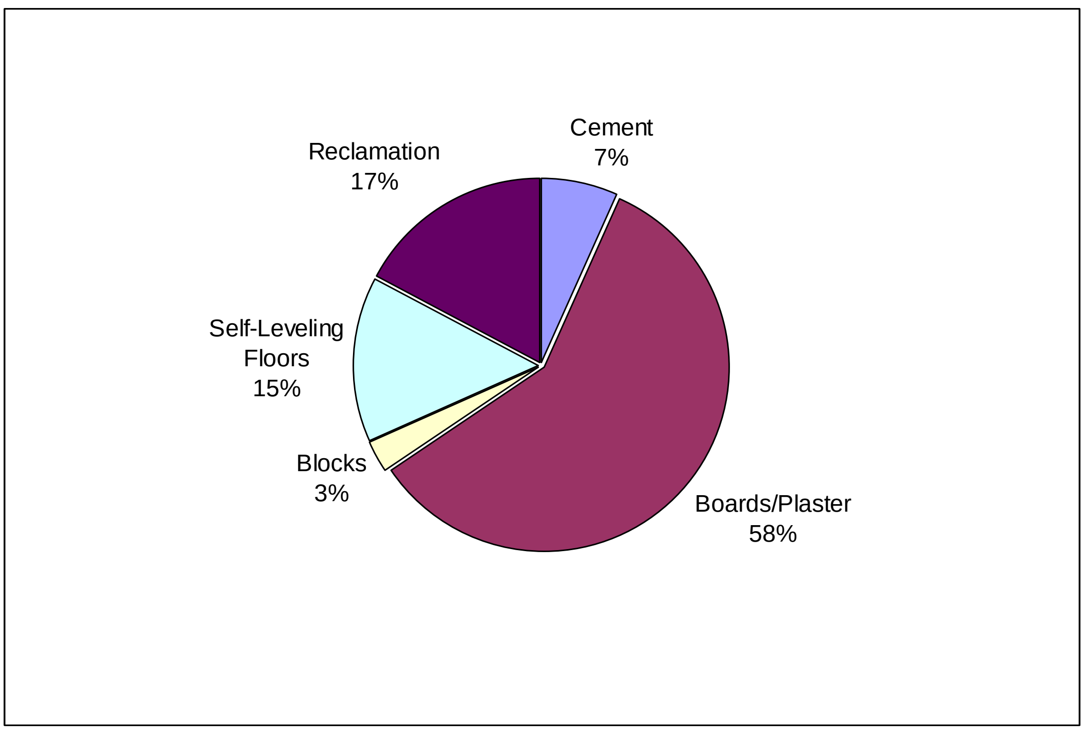

Figure 3-2
FGD gypsum use in the Europe.[17]

Industry Trends

Demand for gypsum products in the U.S. is largely driven by wallboard use in the housing market. Approximately 7.3 metric tons of gypsum are used in wallboard for an average 2,000 square foot house.[5] Demand will vary by region, as shown in Figure 3-3. Acute needs, caused by events such as the recent hurricanes along the Gulf Coast, can affect the overall demand as well as the regional picture.

The gypsum market has recently grown at a rate of about 3% per year.[19] Future projections by the Freedonia Group are for continued growth at a slightly lower rate of 1.7% per year through 2009.[8] Assuming an apparent consumption of 36.2 million metric tons in 2004,[5] and 1.7% annual growth, gives a projected annual U.S. consumption of just over 40 million metric tons by 2010. Gypsum used as an additive for cement is largely driven by nonresidential construction in the U.S. This market is expected to grow by about 3% per year through 2007.[8] Other gypsum products are also expected to show some growth, including building plasters and industrial gypsum used as a filler in manufacturing operations.

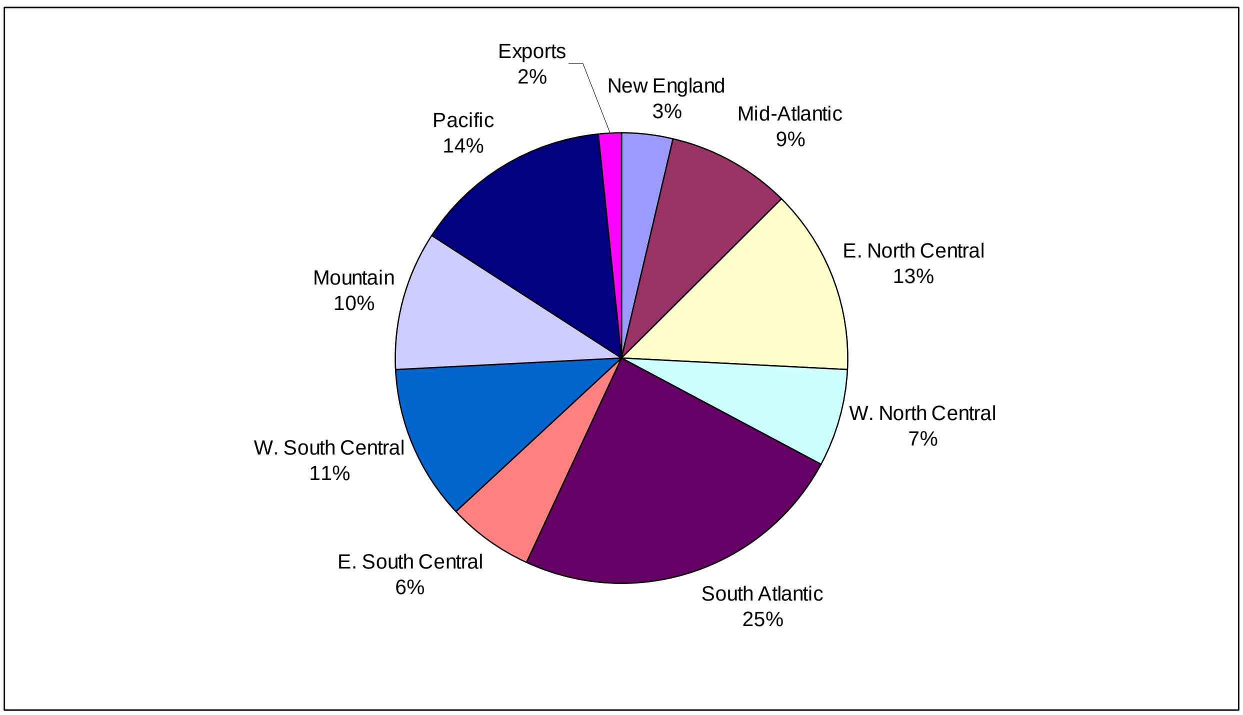

Figure 3-3
2004 sales of gypsum board by U.S. region.[9]

Use of FGD gypsum grew steadily between 2001 and 2004, increasing by about 2 million metric tons (Figure 3-4).[10] Most of that growth was in the wallboard market. Cement/concrete and agriculture use were both higher in 2004 compared to 2001, but the totals were more variable. FGD gypsum use is expected to continue to grow significantly over the next several years, to meet increasing demand as well as supplant other existing sources.[5,8,19] New wallboard plants are generally larger than old plants, and are constructed to allow use of multiple sources of gypsum.[4] In some cases, wallboard plants are being constructed near power plants that will be the sole source of gypsum. Five new wallboard plants announced in 2005 were all located in the eastern U.S.,[20] where gypsum mines are notably lacking.

While the increased use of FGD gypsum is promising, supply of FGD gypsum is also expected to increase significantly over the next several years as electric utilities install more scrubbers to meet clean air regulations. One analysis suggests that there will likely be a significant surplus in FGD gypsum by 2010.[19]

Most of the new scrubbers will be limestone forced oxidation systems that produce high quality FGD gypsum. In addition, some plants are planning to retrofit older inhibited or natural oxidation systems to produce gypsum. Projections suggest the total FGD material production could double within the next five to ten years to about 50 million metric tons per year.[19,21] If all of the new production is FGD gypsum, the total available to the market will triple, from about 10 million metric tons to 30 million metric tons. Retrofitting forced oxidation systems on existing plants that currently produce sulfitic sludge will further increase the total FGD gypsum produced. Assuming a total gypsum market of 40 to 45 million metric tons per year, 100% utilization would require FGD gypsum to capture about 75% of the total gypsum market, a significant increase from the current 25% market share in the U.S., and to more than triple the current tonnage volumes. Given these and other considerations, such as plant and mine locations relative to demand, and requirements for maintaining operational mines, it has been forecast that FGD gypsum supply will exceed demand.[19]

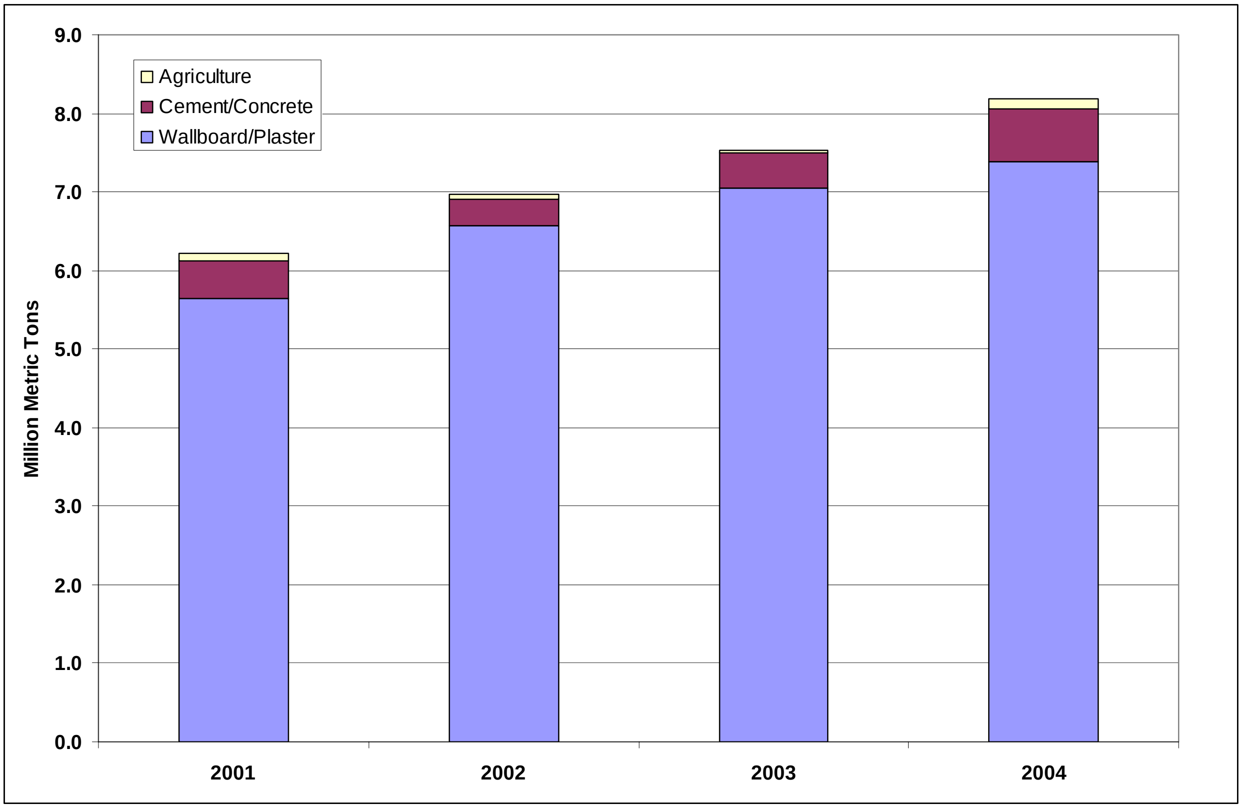

Figure 3-4
FGD gypsum use, 2001 through 2004.[10]

The current trend toward large calcining plants designed for using FGD gypsum should significantly increase the percentage of FGD gypsum used in board products. Obstacles to increasing the use sufficiently to meet the increased supply of FGD gypsum are the regional nature of the calcined gypsum market, transportation costs, and consistent quality control of the FGD gypsum suitable for manufactured products.[21] It is likely that further development of markets other than wallboard will be necessary to fully utilize the FGD gypsum supply. Agricultural use is one potentially large market that is being addressed. As previously noted, there is room to increase usage by a million metric tons or more in cement, where FGD gypsum currently accounts for about 21% of total gypsum use. Use of gypsum in cement is subject to some of the same market factors as wallboard with respect to location, quality control, and equipment modification. Since gypsum is a minor component of cement, it is less likely that the cement industry will change to accommodate FGD gypsum use. Less developed product uses that are exploited to a greater degree in Europe are self-leveling floor screeds and gypsum blocks. Self-leveling floors in particular currently use more than 1 million metric tons of FGD gypsum in Europe. Filler and extender applications do not currently represent a large market for mined or synthetic gypsum, and would likely require more extensive development to become a significant target for FGD gypsum use.

Other Factors

Several other factors have the potential to impact the FGD gypsum market in coming years. These include increased mercury capture in power plant scrubbers, wallboard recycling and disposal, and "green building" initiatives. Each of these is discussed briefly below.

Oxidized mercury is readily captured in wet scrubbers. Although mercury concentrations in FGD gypsum are presently low, they are likely to rise at some plants in future years as these plants comply with the Clear Air Mercury Rule issued in 2005.[22] The potential impact of increased mercury concentrations on the use of FGD gypsum is the subject of current research, including an evaluation of the loss of mercury during the calcination and drying processes at wallboard plants.[23] Additional work may consider the potential for release of mercury from the finished board products, as well as leaching and anaerobic decomposition of waste board in construction and demolition landfills. These research efforts are expected to be provide a significant amount of information in the 2006-2008 timeframe.

Wallboard waste consists of scrap wallboard generated during new construction, demolition, manufacturing, and renovation. Scrap from new construction is the most significant source, accounting for nearly two-thirds of the total waste.[24,25] Demolition and renovation scrap accounts for about one-quarter, and manufacturing scrap for about 10%. Recycling waste scraps into new wallboard requires removal of the paper from the gypsum, which is a difficult process[25] but is now becoming more commonly done. It is more easily done for new construction scraps since there is less contamination with other building materials (for example, paints, insulation, and nails).[24] However, newer technology is able to recycle both new construction scraps and demolition scraps and produce new wallboard with 100% recycled material. Two leading recyclers are New West Gypsum Recyclers[26] and Gypsum Recycling International.[27] Both National Gypsum and US Gypsum have recently entered into agreements with Gypsum Recycling International for using recycled gypsum.[28,29] Recycling scrap wallboard for use as a soil amendment is a less common application, and is generally limited to new construction scrap.

A possible impact of increased recycling of wallboard scraps on the FGD gypsum market is decreased demand. One National Gypsum facility, located in Portsmouth, NH, estimates using up to 27 metric tons of waste gypsum. About 10 to 12% of gypsum board used on new construction becomes waste. As a first-level estimate, assuming total annual use of gypsum in wallboard is 30 million metric tons, and 10% becomes new construction scrap that is recycled, a total of about 3 million metric tons is the maximum amount of natural or FGD gypsum that could be displaced. This does not account for demolition scrap recycling, which would be a significantly smaller annual quantity. Realistically however, transportation and other constraints will probably limit the total amount of recycled feedstock to a much lower proportion in the foreseeable future, and will only impact demand for other sources of gypsum on a very localized basis.

Wallboard not recycled is often disposed of in municipal solid waste landfills (MSWs) or construction and demolition (C&D) debris landfills. There is some concern that gypsum board, made from either natural gypsum or FGD gypsum, can lead to hydrogen sulfide gas production under wet, anaerobic conditions that may exist in either type of landfill.[24] There is also a possibility that similar conditions could also release organomercury species. The significance of these issues specifically with respect to FGD gypsum is currently being investigated.

One factor favoring the use of FGD gypsum is a significant effort to increase the use of recycled materials in buildings and building products. The U.S. Green Building Council (USGBC) has developed a rating system, the Leadership in Energy and Environment Design (LEED®) Green Building Rating System, to stimulate and promote green building concepts.[30] The system, which is entirely voluntary, provides a numerical rating to buildings based on a wide variety of considerations, including the recycled content of building materials.

4
SUMMARY AND CONCLUSIONS

Gypsum is mined throughout the world and is also generated as a product of various industrial processes. FGD gypsum, the product of wet flue gas desulfurization systems with forced oxidation, represents a significant percentage of the total supply of gypsum that is utilized in commercial applications. There have been many changes in the market for FGD gypsum in recent years, and significant changes are expected to continue in the future. EPRI has prepared this report in order to assemble current information and comment on some projected trends involving manufacturing applications for FGD gypsum. Selected conclusions follow.

Utilization Statistics

- Total U.S. market utilization of gypsum in 2004 was slightly over 36 million metric tons. Synthetic gypsum accounted for about 25% of this total. Nearly all of the synthetic gypsum utilized in the U.S. is FGD gypsum.
- FGD gypsum production in the U.S. in 2004 was 10.8 million metric tons. The utilization rate for FGD gypsum has been increasing steadily since the early 1990s and was nearly 76% in 2004.
- Total global consumption of gypsum in 2004 was estimated at about 150 million metric tons. Worldwide, as in the U.S., the use of FGD gypsum has been increasing. In Europe, total production and utilization rates are fairly comparable to those in the U.S., at 11.3 million metric tons and 71%, respectively (2003 figures).

Markets

- In the U.S. and in Europe, the largest percentage of utilized gypsum goes into the manufacture of wallboard and plaster used for building construction. In the U.S. these uses represent nearly 90% of the total gypsum market.
- Cement and concrete are other significant product areas. Of the total U.S. market utilization in 2004, about 9% went into these two applications. Worldwide, concrete and cement are the largest market, accounting for over 50% of the gypsum use.
- Gypsum is also used in certain other building applications, in a range of fillers and extenders, and in agricultural applications. In Europe, self-leveling floor screeds and gypsum blocks account for 15% and 3% of the FGD gypsum use, respectively.

Trends and Outlook

- The gypsum market in the U.S. has recently grown at a rate of 3% per year. Future projections in one analysis call for continued growth at a somewhat lower rate of 1.7% through 2009. The U.S. market is largely driven by the demand for wallboard in the housing sector.

- Utilization of FGD gypsum grew steadily between 2001 and 2004, increasing by about 2 million tons in the U.S. A growth rate higher than the growth of the overall gypsum market is expected to continue over the next several years. A major factor in this trend will be increased use of FGD gypsum in wallboard manufacturing. New wallboard plants are designed to accommodate FGD gypsum, and in some cases, wallboard plants are being constructed near power plants that will be the sole source of gypsum.
- Although the increased use of FGD gypsum is promising, supply of FGD gypsum is also expected to increase significantly over the next several years as electric utilities install more scrubbers to meet clean air regulations. One analysis suggests that there will likely be a significant surplus of FGD gypsum in some geographic markets by 2010.
- It is likely that further development of markets other than wallboard will be necessary to fully utilize the FGD gypsum supply. Manufacturing applications that offer room for growth include cement and two product areas that are currently exploited in Europe but not in the U.S.: self-leveling floor screeds and gypsum blocks.
- Filler and extender applications do not currently represent a large market for mined or synthetic gypsum, and would likely require more extensive product development to become a significant target for FGD gypsum use.
- Concentrations of mercury in FGD gypsum are likely to increase at some plants in response to air emissions regulations. The impact of increased capture of mercury on the use of FGD gypsum in manufactured products is currently being investigated
- Use of recycled board from new construction and demolition scrap is expected to continue to increase, but is unlikely to command a large proportion of the gypsum market in the near future.
- Looking beyond manufacturing applications, agricultural use of gypsum, currently a very small percentage of total gypsum use, is one potentially large market.

5
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