

GYPSUM MARKET RESEARCH STUDY

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**for submission to
Generation Environmental Management Department,
Eskom Holdings Limited**

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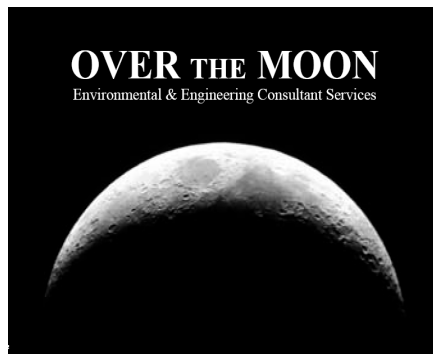


TABLE OF CONTENTS

1	Executive Summary	3
2	Introduction	4
3	Research/Study Approach	6
4	Current and Future Status of the South African Gypsum Market	7
4.1	Current Gypsum Supply	7
4.2	Current Market Status	11
4.2.1	Construction	13
i.	Cement (Portland cement)	13
ii.	Plasters, floor screeds and self leveling flooring	15
4.2.2	Building Related Applications	16
4.2.3	Agriculture	17
4.3	Potential Future Market Status	19
5	Physical and Chemical Properties of Gypsum Produced by Various FGD Processes	21
5.1	FGD Processes	22
5.1.1	Wet FGD Processes	23
i.	Limestone-Forced Oxidation	24
ii.	Limestone-Forced Oxidation/Organic Acid	25
iii.	Lime Dual Alkali Process	25
iv.	Magnesium-Promoted Lime	25
v.	Seawater Processes	26
vi.	Sodium Scrubbing	26
vii.	Ammonia Scrubbing	26
5.1.2	Dry FGD Processes	26
i.	Lime Spray Drying	27
ii.	Duct Sorbent Injection	27
iii.	Furnace Sorbent Injection	27
iv.	Circulating Fluidised Bed	28

Please refer to References (Section 9) for footnote details as denoted by numeric superscript

OTM Confidential Final Report: FGD Gypsum Market Study, April 2009 – original printed on recycled paper

5.2	FGD Gypsum Properties	28
5.2.1	Chemical and Mineralogical Properties of FGD Gypsum	29
i.	By-product from wet FGD systems	29
ii.	By-product from dry FGD systems	33
5.2.2	Physical Properties of FGD Gypsum	34
i.	By-product from wet FGD systems	34
ii.	By-product from dry FGD systems	35
6	Potential Demand for Synthetic Gypsum in South Africa	36
7	Quality of Gypsum Required by Different Users	39
8	Costs and Benefits of establishing an FGD Gypsum Market in South Africa	43
8.1	Handling of FGD Gypsum by Producer	45
8.2	Potential Impact of FGD Gypsum on Current Mines	49
8.3	FGD Gypsum Market Projection	50
9	Conclusions	54
10	References	55

1. EXECUTIVE SUMMARY

South Africa's recent legislative requirements have emphasised the need for industries to implement flue gas desulphurisation (FGD) to meet more stringent sulphur dioxide (SO₂) emission standards. Environmental and economic best practice tends to steer that implementation towards producing commercially viable gypsum instead of opting for long term disposal. Gypsum waste dumps form significant ecological risk factors and the global trend by synthetic gypsum producers, is towards dump avoidance (Kostic-Pulek et al., 2008).

Gypsum is currently utilised in three main sectors in South Africa: Construction, building related applications and agriculture. Most of the technical difficulties in producing commercially viable FGD gypsum have been addressed internationally and the operating changes required to utilise the material in commercial applications are quite well established (Berland et al., 2003). However, structuring successful relationships between FGD gypsum producers and purchasers remains a significant challenge.

Raw gypsum suppliers in South Africa are keen to purchase FGD gypsum due to the potential for a consistent, high quality product. The main disadvantage with the current gypsum supply in South Africa is the cost of transport between the source areas and the market. The considerably shorter distances from Kusile (and other inland coal fired new build projects) to Gauteng makes the possibility of growing South Africa's already existing synthetic gypsum market, very viable.

The FGD technology employed by Eskom and the quality of the gypsum produced are critical to the effective growth of the gypsum market in Southern Africa, particularly the existing plasterboard sector of the market which shows the most potential for sustained growth. The introduction of FGD gypsum, of the correct quality, into this growing sector would facilitate further optimisation of FGD gypsum usage and increase the potential for sustainable FGD gypsum market growth in South Africa. In addition, the potential for a new gypsum utilisation sector to be developed in the mining field, exists.

2. INTRODUCTION

Eskom Holdings Limited (Eskom) has publicly stated that flue gas desulphurisation (FGD) will be installed at Kusile Power Station being constructed near Witbank in order to reduce sulphur dioxide (SO₂) emissions¹. A by-product of the FGD process is synthetic gypsum.

To this end, Over the Moon Consulting (OTM) was tasked by Eskom's Generation Environmental Management Department (GEM) to perform a gypsum market study in order to ascertain the demand for gypsum produced by various FGD processes and the feasibility of establishing a synthetic gypsum market in South Africa.

The scope of the study addresses the:

- i. Current and future status of the South African gypsum market
- ii. Physical and chemical properties of gypsum produced by different FGD processes
- iii. Potential demand for synthetic gypsum in South Africa
- iv. Quality of the gypsum required by the different users
- v. Costs and benefits of establishing a market for gypsum produced during the FGD process in South Africa

As detailed in the initial study plan presented to GEM by OTM, preliminary investigations indicated that there are three main market areas where gypsum related products and specifically synthetic gypsum related products, need further research *viz.:*

i. Construction:

Cement (Portland cement)

Plasters, floor screeds and self-levelling flooring

ii. Building related applications (i.e. applications required for the finishing of a building project but not necessary for the actual construction):

Ceilings

Wallboards

Mouldings

iii. Agriculture:

Soil conditioning

Nutrient addition

The construction and building related application market areas, uses 99% of locally supplied gypsum with about 1% of very high purity processed gypsum being imported for ceramic and other building related uses, as well as for medical products². 100% of gypsum used in agriculture is supplied locally.

Additional research indicated that FGD by-product utilisation has several potential applications which have not yet been considered in the South African context and which are expanded upon in Section 5 of this report.

The following comparisons of per capita consumption of gypsum, further indicate the potential for growth in the market:

United States of America	-	45.90	kg
United Kingdom	-	22.35	kg
Thailand	-	4.40	kg
Republic of South Africa	-	3.30	kg
Peoples Republic of China	-	3.00	kg
Philippines	-	0.30	kg
India	-	0.10	kg

3. RESEARCH/STUDY APPROACH

OTM approached the two main suppliers of 'raw' gypsum in the country i.e. Lafarge Gypsum and Saint Gobain Construction Products South Africa (also known as Gyproc) with regards to the workings of markets and the projection of future markets in South Africa.

The expertise of the staff and consultant specialists in Lafarge Gypsum and Gyproc were drawn upon and information gained in this way was compared and collated with research from desktop studies of publications, academic papers and symposia presentations.

Agricultural associations and other industry 'end users' (e.g. ceiling board suppliers) were also contacted to source current and future domestic market trends, as well as end-user requirements.

4. CURRENT AND FUTURE STATUS OF THE SOUTH AFRICAN GYPSUM MARKET

Gypsum plasterboard was patented in 1899 and whilst plasterboard manufacturing technology has made dramatic improvements in the processing and quality of the product, there has been no change in the gypsum core of the board in the past 109 years².

Worldwide, the demand for plasterboard continues to grow as new applications and building requirements demand better performance or faster construction methods.

The future of gypsum is secured in the long term, due to a move to lightweight construction methodologies². In addition, the embodied energy of gypsum plasterboard is 10 times lower than that of masonry construction², thus reducing greenhouse gas emissions and supporting the South African Government's commitment to the Kyoto Protocol.

4.1 Current gypsum supply

In South Africa, gypsum is available from natural deposits or as a synthetic by-product such as phosphogypsum, FGD gypsum and titanogypsum (Roskill Consulting Group, 2004). By-product gypsum resources form strong competition to natural gypsum deposits. High-grade gypsum by-product is generated during the salt recovery from seawater near Port Elizabeth in the Eastern Cape Province. One of the more common lower purity gypsum by-products is phosphogypsum, an inexpensive by-product from phosphate fertiliser and phosphoric acid manufacture (Griffiths 1989).

Although there are several small suppliers of synthetic lower grade gypsum into the current South African market, such as Sasol, Lonmin Platinum, Sappi and potentially Anglo Coal, these actual and potential suppliers produce minor volumes which are insignificant in terms of overall market trends in the country². In addition, in the case of Sappi's FGD plant and Anglo Coal's water treatment plant in eMalahleni, projects have been initiated during 2007 and 2008, respectively, to investigate the conversion and use of gypsum by-products in other applications but no information regarding any

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significant commercial implementation of these projects was found at the time of research for this report. In the case of Lonmin Platinum, the product formed is calcium sulphite hemihydrate ($\text{CaSO}_3 \cdot \frac{1}{2}\text{H}_2\text{O}$) which is one oxidizing step away from gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and is disposed of on an on site dump². Section 5.2.1 details the chemistry of gypsum formation.

Synthetic gypsum supply in the South African context is, therefore, currently dominated by the fertiliser and phosphoric acid producers, located in the Phalaborwa, Phokeng and Richard's Bay areas.

The two main raw gypsum suppliers are Gyproc, holding 80% of the South African market share and Lafarge Gypsum, holding 20%. The current gypsum market in South Africa is maintained primarily by natural gypsum deposits and to a lesser degree, by synthetic gypsum dumps (most of which are phosphogypsum waste dumps).

All natural gypsum deposits in South Africa form approximately 3 m thick layers and are found close to the surface, therefore requiring relatively simple quarrying operations to access³. These terrestrial deposits are found in arid to semi-arid environments, concentrated in the Northern Cape Province and the northern section of the Western Cape Province, with smaller deposits in the Eastern Cape Province and KwaZulu-Natal Province (Oosterhuis 1998).

Gypsum forms in the upper region of the weathering profile in salt pans and in shales of the Ecca Group of the Karoo Supergroup (Figure 1). These types of deposits form in areas where evaporation rates are high and precipitation rates are low. Gypsum precipitates largely in clay layers.

The richest natural gypsum fields in South Africa are found west of Van Wyksvlei in the Northern Cape Province i.e. the so-called Bushmanland.

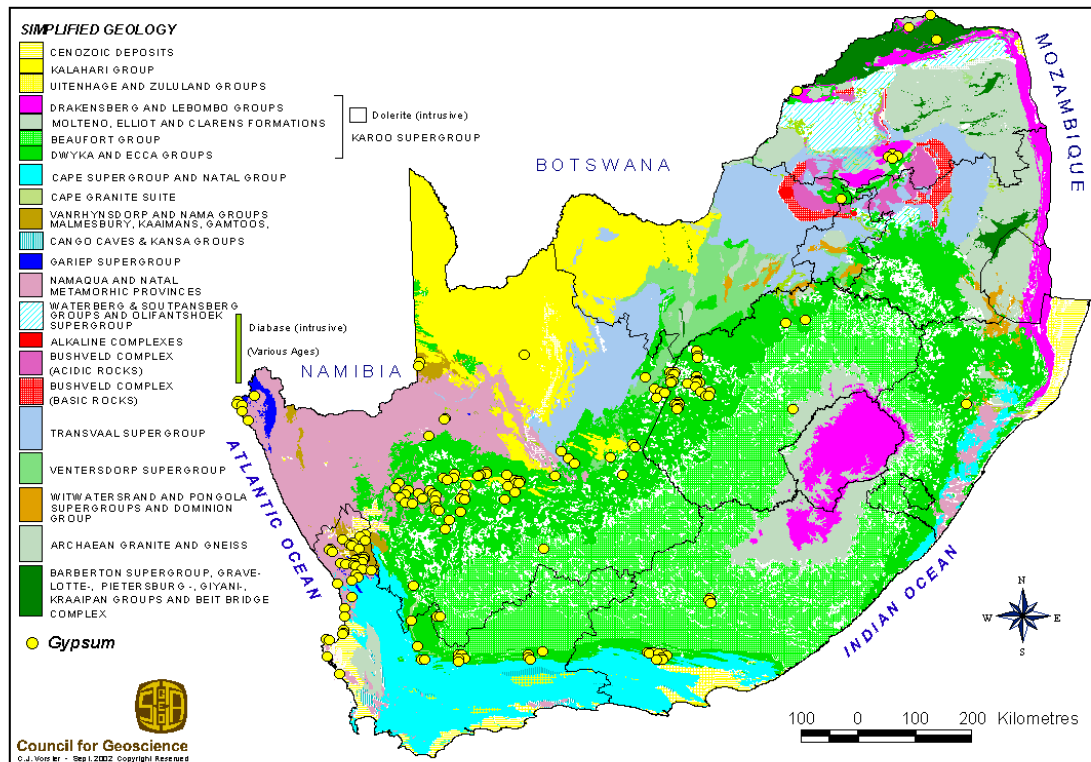


Figure 1: Basic geology and indication of natural gypsum deposits in South Africa, Lesotho and Swaziland

(Source: <http://www.geoscience.org.za/images/stories/gypsum.gif> 08/12/2008)

The country's gypsum deposits consist of several 'types' of gypsum, from high-grade powdery gypsum which contains about 90% pure gypsum, to gypsum mixed with clay containing around 65% to 85% gypsum (Oosterhuis 1998). The deposits at Vanrhynsdorp, the West Coast and Steytleville-Jansenville are all comparatively small in size.

Most phosphogypsum resources are in the form of waste dumps which are located in Modderfontein, Phokeng, Potchefstroom and Phalaborwa². Not all dumps are accessible for recovery and currently, the Modderfontein (in Midrand) and Potchefstroom dumps are inactive as fertilizer production in that area ceased many years ago².

The economic viability of any gypsum deposit is related to the cost of transport rather than the cost of mining which is usually low³. The cost of transportation for both Gyproc and Lafarge Gypsum, from the Northern Cape Province to Gauteng, is approximately R500.00 per tonne (i.e. R0.50/ton/km x 1000 km)³. Lafarge Gypsum

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transports raw gypsum 100% by road and Gyproc transports 50% by road and the remaining 50% by rail under a concession they were granted to use the Sishen/Saldanha (Oryx) railway line³. Figure 2 indicates that primary road and railway routes used to transport gypsum from these areas.



Figure 2: Populated regions and major rail infrastructure used to transport South African gypsum

(Source: http://www.uoguelph.ca/~geology/rocks_for_crops/49south_africa.PDF)

Often the costs associated with the monitoring and maintenance of a gypsum dump can be high³ and disposal off site may take place at great cost whether financial or environmental (refer to Section 8).

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4.2 Current market status

The gypsum market in South Africa is well established in the construction and building applications industries as there are no comparable competitive products². The cement industry has no alternative to the use of gypsum as a set retarder additive to cement clinker⁴. With respect to plasterboard, alternatives such as a fibre-reinforced cement board in which, historically, asbestos was used as the reinforcement material, does not offer the same advantages as gypsum² with respect to the flexibility of the board, although, it is favoured in exterior applications where weathering is of concern⁴.

Gyproc have been active in the gypsum industry in South Africa since 1929 and have three processing plants: one in the Cape and two in Gauteng.

Lafarge Gypsum have been in the South African market for less than five years and have two processing plants in Gauteng and one located at their mine dump site in the Northern Cape. .

It should be noted that Dracon Contractors, who are considered the largest supplier of end-product ceiling and partitioning in South Africa, mentioned that Chinese and Spanish ceiling and wallboards can be imported at competitive prices albeit at a usually poorer quality⁵. However, currently, due to the weaker Rand, sales and imports have declined. It is anticipated that after the market slump, imports will increase again. In the January to February 2009 period, the decrease in gypsum end-product sales by Dracon Industries, due to the global economic decline, was approximately 50% lower than the same period in 2008.

In the agricultural sector, lime is an alternative to the use of gypsum but lime alters the pH of the soil after several years of application, whereas gypsum does not². Lime retail costs are determined by the source of the lime, the processing to which the lime is subjected, as well as the particular region to be supplied (Source: <http://www.salimeandgypsum.co.za/products.asp>). The cost difference between the application of lime and gypsum for inland agricultural sectors (as of March 2009) is summarised in Table 1 below:

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Table 1: Cost of bulk and bagged agricultural lime and gypsum

Soil Conditioner	Bulk (R/t)* supplied in 28 t truckloads	Bagged (R/t)* supplied in 50 kg bags
Dolomitic Lime		
Mpumalanga (Olifantsfontein)	R93.00	R375.00
Gauteng (Pretoria/Benoni)	R93.00	R425.00
Hydrated Lime		
Mpumalanga (Olifantsfontein)	R138.00	Not available
Pure Burnt Dolomite		
Mpumalanga (Olifantsfontein)	R700.00	Not available
Calcitic Lime		
Mpumalanga (Marble Hall)	R139.00	Not available
Mpumalanga (Marble Hall) 2-4 mm granules	R214.00	R320.00
Mpumalanga (Marble Hall) < 1mm granules	R180.00	R320.00
North West (Rustenburg/Pilanesburg)	R74.00	Not available
Calcium sludge product		
Free State (Vereeniging)	R95.00	Not available
Gypsum		
Gauteng (Midrand)	R69.00	Not available
Limpopo (Phalaborwa)	R90.00	Not available
North West (Phokeng/Rustenburg)	R90.00	R 210.00

* excluding delivery

A summary of the 2007 Gypsum Market in South Africa is depicted in Figure 3 below.

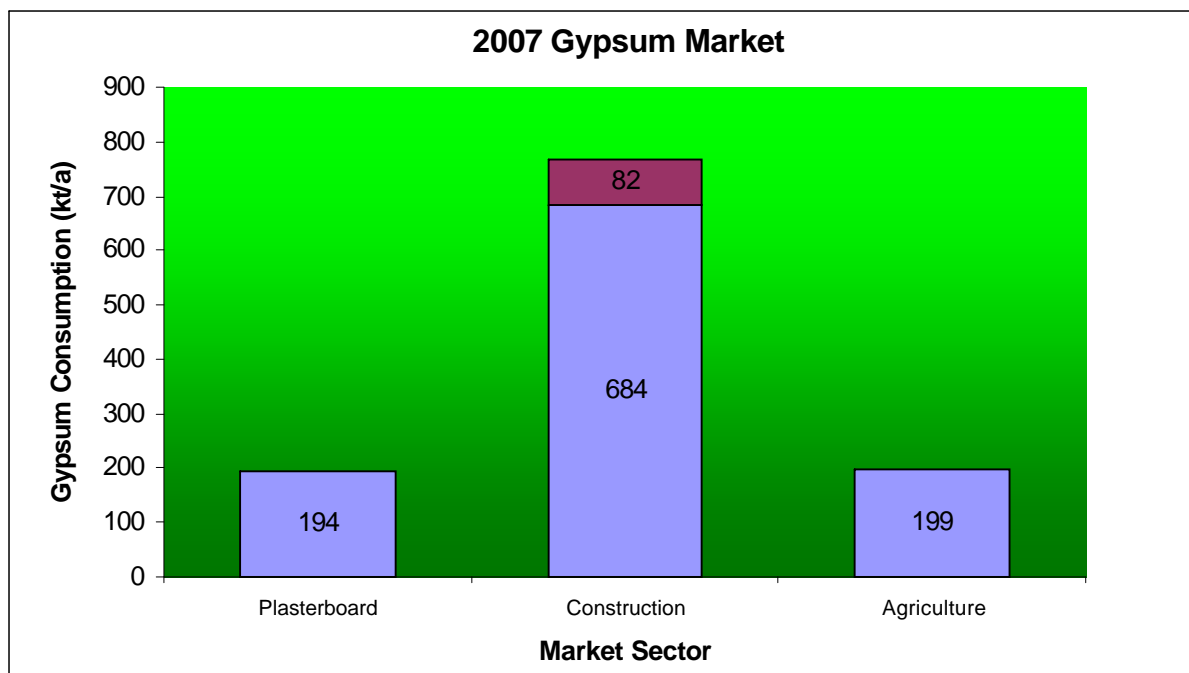


Figure 3: The 2007 Gypsum Market in South Africa based on actual sales figures. ‘Building-related applications’ is a combined estimate from Gyproc and Lafarge Gypsum. ‘Construction’ includes cement (684 kt/a) and plasters (82 kt/a)

The predominant markets for gypsum are in the construction and building related applications industries, as well as in agriculture. As mentioned above, the sector split is:

4.2.1 Construction

i. Cement (Portland cement):

The cement industry, currently the largest consumer of gypsum in South Africa, uses gypsum as an additive to Portland cement clinker to retard the setting time of the cement⁴. Portland cement is simply the most common type of cement used globally and forms the basis of all other cement based products such as concrete, mortar, grouts and stucco.

In 2008, South Africa produced 14,719 kt of cement (Source: <http://www.cnci.org.za/inf/genstats.html>). Using the industry norm of 5% gypsum as a set retarder in cement⁴, the total South African cement sector gypsum requirement was approximately 736 kt for 2008. Figure 3 reflects the 2007 growth spurt in the construction industry with 766 kt being used. On average, the Gauteng market requirement is between 500 kt per annum to 600 kt per annum⁴.

It is unlikely that FGD gypsum from Witbank can be landed at the De Hoek and Riebeeck West factories in the Western Cape at a price comparable to that obtained from van Rhynsdorp², its current source. The same applies to Natal Portland Cement (NPC) who obtain their supply from the tioxide waste stream². The De Hoek, Riebeeck West and NPC factories account for 16% of the South African cement market⁴.

Although not ideal, phosphogypsum from mined phosphogypsum dumps has been used to feed into the cement industry when natural gypsum was/is not available. This process requires additional washing to be able to meet the cement sectors' specifications which increase operational costs.

Table 2 below lists a summary comparison of natural gypsum to phosphogypsum with respect to supplying the cement industry.

Table 2: Relative comparison between natural gypsum and phosphogypsum²

Natural gypsum:	Phosphogypsum:
<ul style="list-style-type: none"> • Usually contains silica & clay • Average purity - circa 88% to 92% • Requires milling to reduce the rock to usable particle size • Requires drying to reduce free moisture circa 10% • Deposits located far from markets • May require beneficiation through a washing process • Usually associated in South Africa with high soluble salts • Soluble salts are highly undesirable for plasterboard manufacture 	<ul style="list-style-type: none"> • A waste product containing various discards from the fertilizer process • Higher purity - circa 93% to 95% • Very fine particle size • Requires drying due to relatively high free moisture content circa 15% • Some deposits are close to markets • Can be neutralized and cleaned by washing (as at Phokeng and Potchefstroom) • P₂O₅ content is problematic as it is locked into the crystal • P₂O₅ is a major concern for the cement industry - all phosphogypsum used in cement is washed and neutralised to remove soluble P₂O₅ • Highly acidic as received - pH of 2 to 3 • Highly corrosive to process plant

ii. Plasters, floor screeds and self-levelling flooring:

Gypsum plasters can either be for building work or industrial applications e.g. casting of figurines, ornamental or other decorative articles. Specialised plasters used in the medical field are imported. FGD gypsum is not suitable for this class of plaster as the purity required is generally in the order of 97% or more². FGD gypsum can be purified above 97% but the cost of this process, which is probably considerable by industry norms, could not be determined⁴.

The current demand for gypsum building plasters is in the order of 48 kt per annum, used mainly as a finishing plaster over a sand cement base².

The consumption of industrial (casting) plasters is in the order of 12 kt per annum of which nearly half is imported plasters². These plasters require highly specialised processing and are purpose made for specific applications. The current low volumes of casting plaster application cannot justify investment in local manufacture. Furthermore, casting plasters require gypsum of 97% purity to achieve a satisfactory product².

4.2.2 Building-related applications

This refers to plasterboards (ceiling and wallboards), as well as moulded products such as cornices. Plasterboard is the lowest cost flat sheet product produced in South Africa². It is used in the South African building industry and worldwide for ceilings; drywall partitioning in offices and homes; fire resistant assemblies and many other specialised applications. Apart from fibre cement which is more expensive and does not provide the same performance or construction versatility, all other gypsum based building-related products are imported at considerably higher cost¹.

Approximately 90% of all ceilings in offices and housing in South Africa are made of gypsum plasterboard and the same applies to office partitioning². In addition gypsum plasterboard is 100% recyclable.

In the United Kingdom, gypsum recycled from waste plasterboard is used in the new plasterboard, cement and agricultural sectors and new Publicly Available Specifications (PAS), developed by Waste & Resources Action Programme (WRAP) in conjunction with the British Standards Institution (BSI), PAS109:2008, provide the standard for the recycling of plasterboard into quality assured gypsum (Source: http://www.wrap.org.uk/construction_plasterboard/pas109.html).

4.2.3 Agriculture

Figure 4 is a graphical representation of gypsum sales for agricultural use in South Africa from 2002 to 2008. The graph shows a consumption of just under 200 kt per annum (i.e. 198,468 tonnes per annum) for 2007 and 208,267 tonnes per annum for 2008. The seasonality of demand for agricultural quality gypsum relative to the period in the year is also depicted.

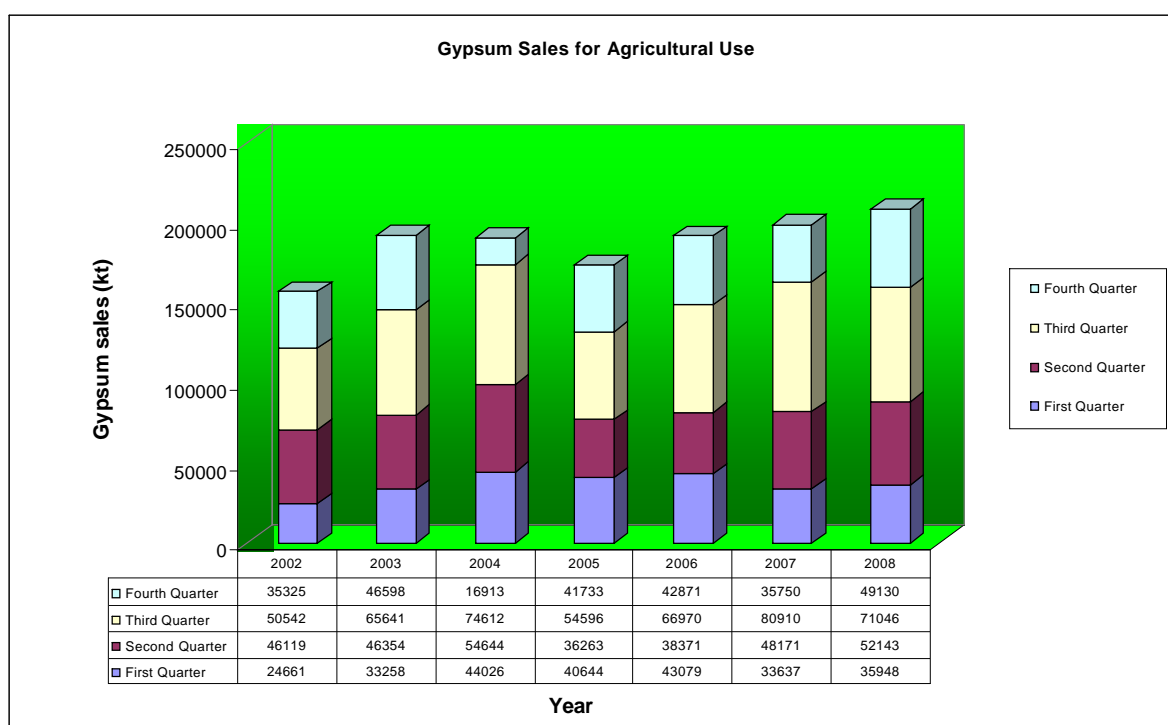


Figure 4: Graphical representation of gypsum sales for agricultural use in South Africa

(Source: Fertiliser Society of South Africa website at <http://www.fssa.org.za/>)

The potential for the agricultural use of gypsum is huge as most South African soils are sulphur deficient and require nutrient addition and conditioning⁴. The greatest demand for agricultural use gypsum is from the inland regions of the country. This is favourable, in terms of Eskom's new build power stations such as Kusile, Medupi and Project Golf, since all these stations are closer to the inland agricultural regions of the country than the current main supplies of agriculturally used gypsum.

The demand for FGD gypsum in the agricultural sector is such that a ready market for the product exists and it is doubtful if gypsum regeneration technologies (refer to Section 5) are viable in South Africa at present⁴. Economics, in terms of transport, is a key factor in any gypsum supply. Current natural gypsum supplies for agricultural use are often processed to achieve correct crystal size and to add required nutrients such as phosphates, thereby creating phosphogypsum. The sources of these gypsum supplies which besides being located considerable distances away from processing plants, are running out of reserves^{3&4}.

This being said, it must be noted that there is a seasonal demand for agricultural quality gypsum whether natural or synthetic. This will require longer term, pre-sales storage (and probable disposal due to insufficient sales) from any synthetic gypsum producer. In addition, several logistical challenges may arise with respect to transportation of the gypsum from source when supplying the agricultural sector directly.

Although ‘mined’ phosphogypsum waste dumps are used to supply the agricultural sector, issues arise with respect to the crystal particle size since the ‘mined’ phosphogypsum contains a larger crystal size than synthetic gypsum. Larger crystal particle sizes are difficult to put through the mechanical sprayers used in agriculture³. The agricultural sector requires a fine gypsum powder. While the chemical analysis of agricultural gypsum is not that critical with regards to percentage purity, consistency (in terms of growing a consistent crystal size) is important.

4.3 Potential future market status

In Europe and North America, the primary source of synthetic gypsum is from forced oxidised (refer to Section 5.1.1) FGD plants (Berland et al., 2003). The acceptance of synthetic gypsum as a viable raw material in cement and wallboard production is rapidly increasing. These two markets account for virtually all synthetic gypsum (and more than 80% of natural gypsum) consumption in both Europe and North America⁶ (Berland et al., 2003). In Europe, mining of natural gypsum hardly occurs since mine reserves are virtually depleted³.

Although FGD gypsum is currently primarily produced in North America, Europe and Japan, the Roskill Consulting Group states that production is spreading to less developed countries where synthetic gypsum will be an increasingly important future source of material (Source: <http://www.roskill.com/report/gypsum>). It is also noteworthy that in regions where more power plants are producing FGD gypsum, there are also increasingly frequent reports of shortages of the by-product into the market (Berland et al., 2003) due to the plasterboard market's preference for the more consistent quality FGD gypsum, rather than natural gypsum⁴. These shortages are due to fluctuations in FGD gypsum production.

The FGD gypsum supply from Kusile alone, as communicated to OTM by Eskom¹, will meet the South African cement industry's demand of 600 kt per annum (in the Gauteng Province) and therefore, does not guarantee future long term growth in this particular market sector. However, the 2008 country-wide projected growth in the cement sector is approximately 20% over the next seven to eight years i.e. demand is projected to increase to approximately one million tonnes per annum in this period¹⁰.

Lafarge Gypsum, who currently hold 20% of the South African market share, have projected that their future growth in the plasterboard market alone, is expected to average 5% per annum. This projection, based on the company's internal targets and sales trends, was provided to OTM in October 2008 and

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remained unchanged (despite the global economic recession) when verified in January 2009⁸. Lafarge Gypsum's raw gypsum requirements will amount to approximately 287 kt for 2009 and the company expects to have a 35% to 40% share in the plasterboard market by 2013^{7&8}.

Gyproc, who hold 80% of the South African gypsum market, initially projected their future plasterboard market growth at 7% per annum for 2009 and 2010, 6% for 2011, 5% for 2012 and 4.4% for 2013. When requested to verify these projections early in 2009, Gyproc's market growth figures as of March 2009, reflected a negative growth of -10.61% for 2009, 19.8% for 2010 and approximately 4.7% growth per annum for 2011 to 2013.

Despite several attempts to obtain physical trends/analyses of the American and European gypsum markets prior to and post synthetic gypsum introduction, no data in this regard could be sourced.

However, all the major role players in the current South African gypsum market indicated that any immediate future growth in the market would be based on growth in the plasterboard sector. This is significant considering that this implies a demand for good (>95% purity) gypsum, Gauteng is the biggest market for plasterboard in the country and FGD gypsum from the new build power stations can be made available at competitive prices (when compared to current raw gypsum prices) due to the reduction in the distance the material will need to be transported.

Should Eskom decide to produce FGD gypsum which has a purity of <95%, the gypsum could be made available to the cement and agricultural sectors. These sectors do not have as great a growth potential as plasterboard and in addition to selling it into these two sectors, Eskom will have to dispose of the bulk of the FGD gypsum due to excess production.

5. PHYSICAL AND CHEMICAL PROPERTIES OF GYPSUM PRODUCED BY VARIOUS FGD PROCESSES

FGD systems make use of an alkaline slurry to absorb SO₂ in flue gases, thereby forming calcium-sulphur compounds, or sodium-sulphur compounds as is the case in the lime dual alkali wet FGD process (Berland et al., 2003). Commercially available FGD technologies can be categorised as either once-through or regenerable, depending on what treatment the sorbent undergoes after it has sorbed the SO₂ (Srivastava, 2001).

In once-through technologies, the SO₂ is permanently bound or fixed by the sorbent, whereas in regenerable technologies, the SO₂ is freed or released from the sorbent during the regeneration step so that it may be processed to create sulphuric acid, liquid sulphur or elemental sulphur (Berland et al., 2003).

The once-through and regenerable technologies can be further categorised as either wet or dry, depending on whether the reagent is wet or dry when it leaves the absorber. Figure 5 depicts the contribution (with respect to usage) of regenerable FGD systems (combined figure for wet and dry technologies), non-regenerable wet FGD systems and non-regenerable dry FGD systems, to global FGD capacity.

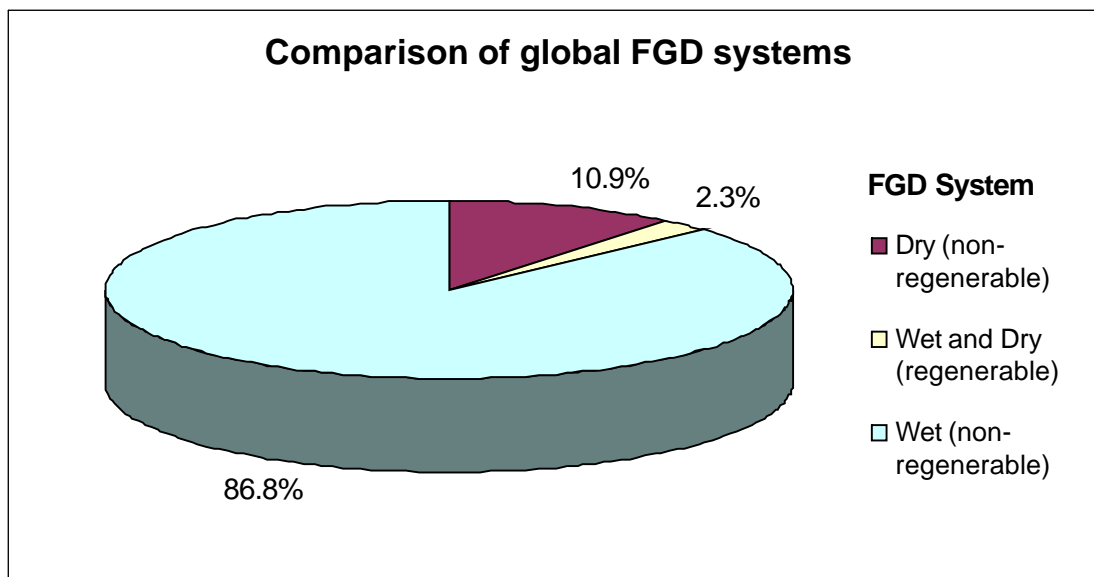


Figure 5: Proportional comparison of global regenerable (wet and dry) and non-regenerable FGD systems
(Source: Berland et al., 2003)

New FGD technologies, especially those combining SO₂ and NO_x or even SO₂, NO_x and mercury removal, are continually being developed (Berland et al., 2003). These combined pollutant removal systems may provide an opportunity for strategic capital expenditure depending on legislative requirements governing Eskom in the future.

5.1 FGD Processes

The differences between dry and wet FGD processes are critical with respect to the quality of the synthetic gypsum produced. Suffice to say, only good quality gypsum (>95% purity) has long term commercial value which is not dependant on seasonality (as is the case for lower quality gypsum used in the agricultural sector).

The European gypsum or Eurogypsum guideline specification is widely accepted by major raw gypsum utilisers (refer to Section 7 for Eurogypsum specifications), however, it is important to note that the purity of the sorbent is critical and largely dictates final gypsum purity.

Although not part of the scope of this study, limestone purity, availability and supply should be investigated since South Africa already has several large limestone consumers e.g. a large platinum group metal refinery in the Rustenburg area consumes about 140 t of limestone per day².

With respect to purity, Table 3 lists typical limestone specifications for limestone currently available in the country. Ideally, the current South African gypsum industry requires producers to use a sorbent (limestone) with purities in excess of 93% to 95% with no soluble salts and other insoluble matter. Generally, limestone sorbent with a 92% purity will result in a 90% pure gypsum by-product, provided all oxidation steps are undertaken². Calcium carbonate (CaCO₃) content is directly proportional to the purity of the sorbent and the availability of high purity limestone in South Africa needs to be studied further. It is futile to try to achieve a Eurogypsum standard if the required grade of limestone is not readily available.

Table 3: Typical constituent chemicals percentage of limestone available in South Africa as supplied by Pretoria Portland Cement (PPC) and Idwala¹

Limestone Supplier & Type	CaCO ₃	MgCO ₃	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO ₂	Mn ₂ O ₃	SO ₃	P ₂ O ₅
PPC									
% Crushed	93.5	2.2	2.5	0.3	0.5	-	0.8	<0.05	<0.005
% Graded	96.0	2.2	0.8	0.2	0.2	-	0.7	<0.05	<0.005
Idwala	96.0	1.5	0.7	-	-	0.8	-	-	-

During 2008, Eskom issued an expression of interest for limestone of 82% purity for the FGD process¹. This will not produce a gypsum marketable in the plasterboard sector².

Phase B of a 2007 research study done for Eskom by E.On Engineering with regards to retrofitting FGD at various power stations, listed sorbent i.e. limestone (CaCO₃) and lime (CaO), costs at R230.00 per tonne for CaCO₃ (Crushed limestone – Free On Board to jobsite i.e. including delivery) for wet FGD; R540.00 per tonne for CaO (Pebble lime – ex-works i.e. excluding delivery) and R650.00 per tonne (Pebble lime – Free On Board to jobsite) for dry and in-duct FGD (E.ON Engineering, 2007).

Gypsum with a high level of soluble salts is unsuitable for the plasterboard industry and will only find application in cement and agriculture². A poor quality gypsum will result in additional costs for disposal (whether on or off the power station site), and/or the ongoing maintenance and monitoring of a dump.

5.1.1 Wet FGD processes

According to the International Energy Agency's (IEA) Coal Research section, wet scrubbers, using calcium based sorbents, are the preferred FGD control technology, making up more than 80% of the total global FGD capacity (IEA, 2000). Although these systems initially produced a residue that was not usable, the trend is now towards utilising systems which produce a more marketable by-product.

Worldwide, in the larger electricity utilities, wet FGD systems are more popular due to the use of a widely available and relatively inexpensive sorbent i.e. limestone; the production of a saleable by-product *viz.* gypsum or calcium sulphate dehydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$); plant reliability, availability and most importantly, SO_2 removal efficiency achievements which can be as high as 99% (Berland et al., 2003). Worldwide, wet FGD systems are very cost effective since, although capital expenditure is higher, operating expenditure is lower and the production of a valuable gypsum by-product (which is increasingly becoming the global norm) further reduces operating costs.

Wet limestone scrubbers which produce a fly ash and calcium sulphate/sulphite mixture, hold a smaller portion of the FGD market compared to gypsum producing plants. In the United States, such plants are increasingly converting to gypsum producing facilities (Soud, 2000). Wet FGD is required to produce a gypsum product that has a market and application in the existing South African plasterboard industry².

i. Limestone-Forced Oxidation:

This technology entails re-circulating a calcium sulphate/sulphite (limestone) and water slurry through absorbers where it absorbs SO_2 in the flue gas. Air is bubbled through the slurry to form gypsum. The resultant by-product can be dewatered which results in less wet waste volume and meets market transportation requirements. This process is a proven technology and can achieve near complete (99%) oxidation (Berland et al., 2003). Best plant performance is achieved when this technology is used with medium to high sulphur coals. The process does not respond quickly to load changes; uses a low cost reagent and consumes approximately 1.6% to 1.8% of gross power produced (Miller, 2002). Worldwide, this process is also the preferred FGD technology because it reduces scaling problems in the absorber (Berland et al., 2003).

ii. Limestone-Forced Oxidation/Organic Acid:

This process is identical to the limestone-forced oxidation technology described above except that an organic acid is added to the slurry to increase the dissolution rate of the limestone thereby enabling greater SO₂ removal (Miller, 2002).

iii. Lime Dual Alkali Process:

This process involves the re-circulation of a sodium sulphate solution (the absorbing agent) through a spray tower to remove SO₂. The spent solution is then combined with lime in a separate process so that it simultaneously forms calcium sulphite sludge whilst regenerating the spent sodium sulphite solution (Berland et al., 2003). This process lowers plant corrosion, erosion, scaling and plugging but involves high costs for the lime and soda ash reagents (Miller, 2002).

iv. Magnesium-Promoted Lime:

This technology utilises either a magnesium enhanced lime (usually 5% to 8% magnesium oxide), or a dolomitic lime (usually 20% magnesium oxide) to create a more reactive but more expensive slurry (Srivastava, 2000). The lime slurry is fed to the spray tower and forms a calcium sulphite sludge containing small amounts of magnesium sulphite (Berland et al., 2003). Forced oxidation, external to the absorbers may be used to improve the quality of the gypsum produced. The commercial-grade gypsum produced from this process has a higher commercial value than gypsum produced by other wet FGD systems since it is brighter in appearance (Srivastava, 2000). This process reduces plant scaling and plugging and results in a lower liquid to gas ratio (Miller, 2002).

v. Seawater Processes:

This process, which has achieved limited application, makes use of the natural alkalinity of seawater to neutralise SO₂. From a chemistry point of view, the process is similar to the limestone-forced oxidation process but the limestone becomes completely dissolved in seawater and the process does not require any dissolution or precipitation of solids (Berland et al., 2003). Since the sulphate is completely dissolved in seawater, there is no waste product to dispose of (Srivastava, 2000).

vi. Sodium Scrubbing:

This process involves the re-circulation of a sodium sulphate solution (the primary absorbing material) through a spray tower to remove SO₂. Sodium carbonate is used as the reagent (Berland et al., 2003). This process also lowers plant corrosion, erosion, scaling and plugging but involves high costs for the lime and soda ash reagents.

vii. Ammonia Scrubbing:

This process is similar to other wet FGD systems except that highly reactive ammonia is used as the reagent. Ammonium hydroxide reacts with SO₂ to form ammonium sulphite which is then oxidised to form ammonium sulphate (Berland et al., 2003). The technology can remove more than 95% of the SO₂ and is also capable of removing other acidic gases such as hydrogen chloride and sulphur trioxide (Srivastava, 2000).

5.1.2 Dry FGD processes

Dry FGD technologies require lower capital expenditure than wet FGD systems and are considered efficient and reliable (Berland et al., 2003) although not as reliable as wet FGD systems¹¹. The operating expenditure for dry FGD systems is higher, though, due to the use of more expensive sorbents.

It must be noted that most by-products from dry FGD processes cannot be used¹¹ in the plasterboard industry and needs to be disposed of since they comprise a mixture of calcium sulphite, calcium sulphate and fly ash (Soud, 2002).

i. Lime Spray Drying:

This technology entails mixing hot flue gas in a spray dryer vessel with a mist of finely atomised fresh lime. The SO₂ in the flue gas reacts with the sorbent as the water in the slurry evaporates. Dried solids are collected in the bottom of the vessel in a particulate control device (Berland et al., 2003). This technology is most often used for power plants that are 550 MW or larger and that burn low to medium sulphur coal i.e. between 0.4% to 2% sulphur content. Approximately 90% SO₂ remove can be achieved (EPA, 2002). The resulting material is calcium sulphite rich (Berland et al., 2003).

ii. Duct Sorbent Injection:

This process allows SO₂ control directly in the flue gas duct between the air pre-heater and the particulate abatement plant. Hydrated lime is usually used as a sorbent although sodium bicarbonate is sometimes used (Srivastava, 2000). Eskom has indicated that from previous studies regarding the retrofitting of FGD in existing power stations, it is unlikely to utilise in-duct FGD injection since the units are too big for the application¹.

iii. Furnace Sorbent Injection:

This technology involves a dry sorbent being injected directly into the furnace at the optimum temperature region above the flame (Berland et al., 2003). Due to the relatively high temperatures (around 1000°C), sorbent particles decompose and become porous solids with high surface areas (Srivastava, 2000).

iv. Circulating Fluidised Bed:

This process involves circulating a dry sorbent, usually hydrated lime or Ca(OH)_2 with humidified flue gas in a fluidised bed (Berland et al., 2003). The circulating fluidised bed facilitates a long contact time between the flue gas and the sorbent since the sorbent passes through the bed several times (Srivastava, 2000). The solids are collected in an electrostatic precipitator or bag house. This application has been used successfully in smaller units when compared to most of Eskom's power stations i.e. it is mainly used in Germany for units ranging in capacity from 50 MW to 250 MW (Srivastava, 2000).

5.2 FGD Gypsum properties

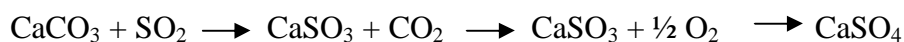
Variations between the physical, mineralogical and chemical characteristics of FGD material, whether from similar or different technologies, can be attributed to a combination of the following factors (Clarke, 1993):

- Composition of coal feedstock
- Composition of sorbents
- Combustion conditions
- Reagent ratios
- Composition and mineralogy of the fly ash
- Relative amounts of fly ash, unreacted sorbent and desulphurisation products

5.2.1 Chemical and mineralogical properties of FGD gypsum

i. By-product from wet FGD systems:

Wet FGD systems commonly use calcium-based sorbents to produce a wet FGD material. Depending on the technology used this material may be unoxidised wet FGD material, sulphite-rich wet FGD material or FGD gypsum from forced-oxidation systems (Berland et al., 2003). Although these materials have similar bulk chemical compositions, they differ in their mineralogical composition. In most wet FGD processes, FGD residues are collected as a separate by-product stream (Clarke, 1993). Sulphur is found in flue gas primarily as SO₂. Hence, the initial FGD material formed is calcium sulphite (CaSO₃). To produce calcium sulphate (CaSO₄) the material needs to undergo further oxidation. This process may be undertaken in the scrubber system through a process called in situ forced oxidation where excess air is added to the system to oxidise the CaSO₃ to CaSO₄ through the following reaction:



In some instances, it may be required or more beneficial to oxidise the FGD material as a slurry outside of the scrubber. This can be achieved by pumping either air or oxygen through a slurry acidified to a pH of approximately 4.5. The pH adjustment is required since the oxidation process is via bisulphite (Ca[H₂SO₃]₂) formation (Berland et al., 2003). Bisulphite formation through acidification is necessary due to the low solubility of calcium sulphite. Calcium bisulphite is much more soluble and since the ex situ oxidation occurs in solution, the higher bisulphite solubility increases the rate of reaction (Berland et al., 2003).

FGD gypsum and wet FGD material are both mainly crystalline in morphology. FGD gypsum is composed of finely divided cube or rod shaped crystals ranging from 1 to 250 µm in length. Wet sulphite-rich FGD material

is composed mainly of calcium sulphite hemihydrate ($\text{CaSO}_3 \cdot \frac{1}{2}\text{H}_2\text{O}$), also known as hannebachite.

Occasionally, high-calcium fly ash is used as part of the sorbent but it has been reported to be more abrasive than limestone (Berland, et al., 2003) and plant maintenance issues arise. Suffice to say, when fly ash is used as part of the sorbent, the mineralogy and bulk chemistry of the FGD material will proportionally reflect the qualities of the fly ash.

For comparative purposes, Table 4 lists the main constituents of wet FGD scrubber material prior to dewatering, for bituminous and sub-bituminous coal. The percentage ranges of calcium sulphite (CaSO_3), calcium sulphate (CaSO_4) and calcium carbonate (CaCO_3) for some of the FGD processes mentioned in Section 5.1.1 above, are indicated.

The typical bulk chemical composition for trace and major element constituents of several FGD samples of wet, sulphite-rich FGD material and FGD gypsum in which fly ash is removed before the scrubber, is listed in Table 5 below.

Wet sulphite-rich FGD material has a similar bulk chemical composition to that of FGD gypsum but is not completely oxidised and therefore, has a different mineralogical composition. The chemical constituents of wet FGD material are determined mainly by the sorbent used and the portion of fly ash collected with the FGD material. The data listed in Table 5 are for wet FGD material taken from systems where the fly ash is removed before the scrubber. The percentages of calcium oxide (CaO) and sulphites (SO_3^{2-}) present provide a proportional indication of potential CaSO_4 formation. The theoretical chemical relation of $\text{CaO}/\text{SO}_3^{2-}$ for gypsum formation is 0.70 (Kostic-Pulek et al., 2008).

Due to the non-existence of South African information, Table 6 lists the trace and major element compositions of several FGD material samples from other countries where data could be sourced. (Berland, et al., 2003).

Table 4: The percentage ranges of calcium sulphite (CaSO₃), calcium sulphate (CaSO₄) and calcium carbonate (CaCO₃) in wet FGD scrubber material prior to dewatering, for bituminous and sub-bituminous coal.

(Source: <http://www.tfhr.gov/hnr20/recycle/waste/fgd1.htm>)

Type of Coal	Sulphur Content	Type of Process/Sorbent	CaSO ₃ (% by mass)	CaSO ₄ (% by mass)	CaCO ₃ (% by mass)
Bituminous	2.9 – 4.0	Lime	50 – 94	2 – 6	0 – 3
Bituminous	2.9	Limestone	19 – 23	15 – 32	4 – 42
Bituminous	1.0 – 4.0	Dual Alkali	65 – 90	5 – 25	2 – 10
Bituminous	2.0 – 3.0	Lime (forced oxidation)	0 – 3	52 – 65	2 – 5
Sub-bituminous	0.5 – 1.0	Limestone	0 – 20	10 – 30	20 – 40

Table 5: Typical bulk chemical composition (as oxides) for wet FGD material and FGD gypsum

(Source: Smith, 1992)

Major Element	Wet, sulphite-rich FGD material (% by mass)	FGD Gypsum (% by mass)
SiO ₂	0.1 – 7.4	0.1 – 6.3
Al ₂ O ₃	0.1 – 6.0	0.1 – 5.1
Fe ₂ O ₃	0.1 – 6.0	0.1 – 5.7
CaO	38 – 52	27 – 32
MgO	1.3 – 6.1	1.0 – 4.9
Na ₂ O	0.1 – 0.9	0.0 – 0.6
K ₂ O	0.0 – 0.6	0.0 – 0.6
SO ₃ ²⁻	54 – 63	44 – 46
Typical solids content	5 – 10	5 – 10

Most major and trace elements leave the FGD system in the wet sulphite-rich FGD material or in the FGD gypsum. The elements which are primarily left in FGD gypsum are Al, As, Ca, Fe, Pb, Sb, Si and Ti (Berland et al., 2003).

Between 10% to 40% of Al, As, Cr, Cu, F, Fe, Ni, Sb, Sc, Si, Sm, Ti, U, V and W, leave the FGD system in wet, sulphite-rich FGD material (Berland et al., 2003).

The quantities of major, minor and trace elements included in the FGD material depend on the amount of fly ash also included. If fly ash is excluded, then the contribution of trace elements to the FGD material composition is restricted to those elements that are found in the flue gas stream either as extremely fine particulates, or as vapours. These elements are known as air toxic constituents (Berland et al., 2003). Some of these elements, particularly the more volatile ones, are removed largely by the wastewater stream (Meij, 1989).

Table 6: Trace element compositions of several samples from various countries using differing wet FGD systems*

(Source: Coal Research Establishment, 1992)

Element (ppm)	A	B	C	D	E	F	G	H	I	J	K	L	M	Nat.
As	<1	1	1	1	1	1	1	1	1	2	1	1	1	<1
B	<5	<5	11	10	100	10	11	4	29	<5	21	11	24	9
Ba	12	9	7	6	6	<1	<1	<1	<100	13	<1	6400	200	4
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	1	<1
Cr	4	5	10	3	4	4	4	6	4	5	9	24	3	1
Cu	64	9	12	3	5	3	<1	<1	5	7	<3	3	3	7
Hg	<3	<3	1	1	<1	<1	<1	<1	<1	<3	<1	<1	<1	<3
Mn	10	11	28	49	32	15	3	17	8	94	10	35	15	4
Mo	<1	<1	<1	<2	<1	<3	<3	<3	<2	<1	<3	<3	<2	<1
Ni	19	4	6	4	7	<3	<3	<3	5	17	<3	<3	3	2
Pb	1	2	7	3	<2	4	1	12	2	3	1	47	28	<1
Se	3	2	15	10	11	8	9	12	3	<1	4	6	<1	<1
V	8	16	12	12	12	10	10	10	10	21	12	10	10	27
Zn	10	8	3	<1	7	5	3	5	8	16	5	20	8	5

* A-I: Germany; J: Japan; K-L: USA; M: UK; Nat.: Natural mineral gypsum sample

Observations of the presence of certain trace elements in measurable quantities in FGD gypsum formed as a product of pilot-scale ex situ wet FGD material oxidation plants, have been made (Hassett et al., 1997). These potentially problematic trace elements were mercury, chromium and chlorine and although measurable in FGD gypsum, were present in very low amounts of

which a small percentage of the total quantity of trace elements was released to leachate during leaching experiments (Berland et al., 2003).

The degree of dewatering that can be achieved will account for concentrations of trace elements in the produced FGD gypsum that are inversely proportional to the effectiveness of the dewatering process, due to the partitioning of these elements into the liquid phase during the oxidation process (Berland et al., 2003).

ii. By-product from dry FGD systems:

As for wet FGD systems, the chemistry of spray dryer material by-products is dependent on the sorbent used for FGD and the proportion of fly ash collected with the FGD residues (Berland et al., 2003). Spray dryer FGD material is made up of fly ash entrained with reacted and unreacted sorbent and is unsuitable for the plasterboard and cement industries².

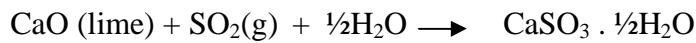
According to Gyproc², a process similar to the dry FGD system was installed at a mine in Rustenburg and at Sasolburg. Both plants' FGD residues are now pure waste products which are stockpiled on a dump with no application in industry. In both instances, an atmospheric pollutant has merely been converted into a solid waste (landfill) pollutant which will have to be addressed in the future.

CaSO₃ also has limited beneficial use in agriculture as it slowly converts to CaSO₄ through natural oxidation. If ploughed into the soil, this process robs the roots of natural absorption of oxygen resulting in crop failures².

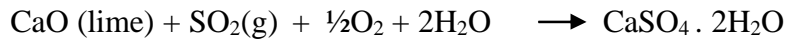
Dry FGD materials have an average particle size of 20 to 40 µm and a lower bulk density to that of normal fly ash (Berland et al., 2003).

FGD gypsum is not produced as part of the dry FGD process since the

principal reaction produces hannebachite or calcium sulphite hemihydrate (Solem-Tishmack, 1993):



However, under more oxidising conditions, gypsum may also form:



5.2.2 Physical properties of FGD gypsum

i. By-product from wet FGD systems:

Wet FGD residues can vary significantly with respect to their physical properties, depending on the relative proportions of sulphite and sulphate in the product (Clarke, 1993).

The average bulk density of gypsum is dependent on the particle shape with about 1200 kg/m³ for 'block-like' crystals and about 600 kg/m³ for 'needle-like' crystals (Berland et al., 2003).

Wet, sulphite-rich FGD material used to be known as 'scrubbing' or 'FGD sludge' due to its thixotropic properties. Thixotropic properties allow the material to stiffen in a short period of time upon standing but once agitated or manipulated, to change to a soft consistency or to a fluid with high viscosity i.e. the hardening process is completely reversible.

Wet, sulphite-rich FGD material is difficult to dewater, although its physical characteristics may be changed by 'fixation' or 'stabilisation' with additives such as fly ash or Portland cement (Berland et al., 2003).

ii. By-product from dry FGD systems:

Generally, the physical and handling characteristics of FGD material from dry systems is similar to that of fly ash. The bulk density of spray dry system residues which contain only a small proportion of fly ash, is about 600 kg/m³ but more commonly ranges from 780 kg/m³ to 1250 kg/m³ (Perri et al., 1988).

Particle size distribution for most dry FGD system material can be classified as in the 'silt-size' range.

6. POTENTIAL DEMAND FOR SYNTHETIC GYPSUM IN SOUTH AFRICA

FGD by-product utilisation (whether the by-product is FGD gypsum, wet FGD material, or dry FGD material) has various applications and has been successfully used in other countries. A non-exhaustive list of the potentially commercial areas in which these applications are used (Berland et al., 2003) follows:

- Wallboard
- Portland cement (mainly used as a grinding agent and set retarder)
- Plaster
- Concrete and grout
- Structural fills
- Floor underlayment
- Mining/mine rehabilitation applications
 - Encapsulation/neutralisation of acid generating material
 - Acid-mine drainage formation/transport buffer or barrier (including mine void filling)
 - Alkaline amendment to neutralise acid-producing rock
 - Control of subsidence in underground mines
 - Pit filling to achieve approximate original contour in surface mines
 - Soil amendment
 - Synthetic soil component
- Glass making
- Agricultural applications
 - Acid soil neutralisation clay breakdown
 - Source of calcium and sulphur for soil enrichment
 - Carbon sinks in forestry
 - Crop storage pads
 - Feedlot surface stabilisation
- Pigments/fillers in plastics, papers, foods, pharmaceuticals, fertilisers, pesticides and herbicides
- Products based mainly on a-hemihydrate gypsum

- Floor screeds (self levelling) - used mainly for heat and sound insulation
- Double/cavity floor systems
- Tunnel mortars
- Mining mortars - consolidation, rock and embankment stabilisers
- Moulding plasters
- Construction products - adhesives, toppings and thin-layer systems
- Pyrite coal spoil combined with gypsum sludge can form a potentially valuable product *viz.* 'sponge iron' and lime
- Magnesium hydroxide markets
 - Feedstock for the chemical, magnesium metal and refractory industries
 - Fuel additives
 - Acid neutralisation

The above uses are listed as **potential** since several of these applications are not commercially available in the South African context, as yet.

Although the potential market growth for dry FGD systems is significantly less than FGD gypsum produced from wet FGD systems, the potential uses of FGD gypsum from dry FGD systems (Berland et al., 2003) are listed below. It should be noted that the applications are dependant on the $\text{SO}_4^{2-}/\text{SO}_3^{2-}$ ion ratios.

- Very low potential (significant beneficiation would be required after FGD material removal)
 - Gypsum plasterboard (not domestic/white plasterboards)
 - Metal extraction

- Medium potential (further beneficiation would be required after FGD material removal)
 - Cement production and replacement
 - Soil stabilisation
 - Sludge stabilisation
 - Mineral filler
 - Ceramics
 - Liner material

- High potential
 - Agricultural use (conditioning/amelioration)
 - Structural fill
 - Stabilised road base
 - Mine backfill
 - Mineral wool
 - Synthetic/lightweight aggregate
 - Brick production

New products and systems for the use of FGD gypsum in house building, mining and road construction need to be researched further and where necessary, South African National Standards (SANS) or relevant agreement approvals will have to be obtained².

7. QUALITY OF GYPSUM REQUIRED BY DIFFERENT USERS

The overall rule for saleable gypsum is high purity with low soluble salts. If this is achieved then all industrial users will be satisfied. Purities below 86% are unsuitable for plasterboard (even with additional beneficiation) but may find application in cement although their addition rate will have to increase. Agriculture is the most likely end use for this purity.

If the combined soluble salts are higher than 0.01%, synthetic gypsum becomes unsuitable for the plasterboard industry. The gypsum plaster business can use a marginally higher level of salts but any efflorescence on the plasterboard surface is unacceptable².

Higher salts (impurities) may be acceptable for cement as long as critical components such as P₂O₅, MgO and K₂O are within limits. Higher salt content will be acceptable as long as the final cement conforms to European Norm 197 (EN 197)⁴.

Any gypsum supplied into the agriculture sector would be considered a fertiliser and must be tested (and appropriately classified) to conform to the South African Department of Agriculture specifications. All fertilisers, including bagged natural organic fertilisers, must be registered in terms of the Agricultural Farm Feeds and Fertilisers Act, No. 36 of 1947 (the Act). It should be noted that registration commits the producer to the specified composition of the fertiliser even if the gypsum is considered a 'waste' or by-product. The Act is administered by the South African Department of Agriculture with the quality and composition of manufactured products falling under the control of the Registrar of Fertilisers.

Although unlikely to be an issue in the South African context², FGD gypsum must comply with radioactivity levels as specified by the South African Nuclear Regulator (SANR). The current SANR requirement is 200 Becquerel per gram² which is a measure of the radioactivity strength from a source. Mined gypsum (natural and dumped) must have a radioactivity of less than 0.5 Roentgen per second (R/s) which is a measure of the exposure of an organism to a radioactive source.

For comparative purposes, the following three tables list the quality requirements by the main gypsum users in South Africa i.e. Gyproc and Lafarge Gypsum. All specifications are said to conform to Eurogypsum standards, however, Table 9, as supplied by Gyproc², did not contain the detail or quality of information of that supplied by the other two sources viz. (Table 7)³ and (Table 8)^{7&8}. Despite specific requests for clarification and more detail regarding the information in Table 9, much of the data could not be verified to the satisfaction of OTM but is nonetheless, presented in this report as such, for comparative purposes. It should be noted that the beneficiation and plasterboard manufacturing process employed in South Africa drives some of the local specifications for FGD gypsum to differ from the Eurogypsum standards⁸.

It may be prudent to note that raw gypsum end users voluntarily mentioned that the quality of plasterboard products received from Gyproc has declined in the last few years with much product loss due to breakages. This could explain OTM's observation of customers' preference for the Lafarge Gypsum product which has been (according to end users) of a consistently higher quality for the three to four years in which this company has been in the South African market. Lafarge Gypsum has indicated that their market share had grown to just under 20% since they have been in South Africa but that this growth, rather than being new growth, is in fact lateral movement of the market⁶. Lafarge and Gypoc have indicated eagerness to facilitate new growth in the market which becomes more possible with the potential consistency of a product such as supplied by FGD gypsum.

According to Gyproc², in reality, all gypsum above 94% purity can be used provided that, of the remaining 6%, no more than 0.1% should contain soluble salts since insoluble inclusions act as inert fillers and result in a lower compressive strength of the gypsum when calcined for plasterboard. It must be noted that to achieve this level of purity the sorbent limestone must contain 94% to 96% CaCO₃, depending on the conversion efficiency of the plant².

Table 7: General European Specifications for Synthetic Gypsum (e.g. from FGD and orimulsion) used in Plasterboard Manufacture³

NO.	MAIN SPECIFICATIONS	FIGURES	RISKS (for plasterboard manufacturers)
1	Humidity	< 10% (max. 12%)	Drying cost
2	Purity	> 95%	Strength and lighter board
3	pH	5<pH<9 (if possible, 6<pH<8)	Risk of interaction with silicates
4	Particle size	30µm<d50<80µm	Water demand
5	No needle (crystalline molecular structure)	L/I>3	High water demand
6	Density	non tapped : >1000g/l	Powder flow control
	Soluble Salts:		
7	Na ₂ O	<500ppm	Bond quality
8	MgO	<1000ppm	Flowering, Bond quality
9	Chloride	<100ppm	Calcination, Bond quality
	Impurities:		
10	Non soluble salts	<2,5%	Purity
11	Quartz	<1%	Wear of material
12	Al ₂ O ₃	<0.3%	
13	Fe ₂ O ₃	<0.15%	Colour
14	CaCO ₃ +MgCO ₃	<2.5%	Purity
15	Sulphites	<0.5%	
	Other Specifications:		
16	Heavy metals		Environment
	As	0-3ppm	
	Cu	1-10ppm	
	Zn	0-50ppm	
	Pb	0-33ppm	
	Cd	0-3ppm	
	Ni	0-3ppm	
	V	1-4ppm	
	Cr	1-7ppm	
	Mn	8-13ppm	
	Ti	100-400ppm	
17	Free carbon	<0.05%	Foam stability
18	Colour	Cream or white	
19	Odour	Neutral	
20	Organic matter	No additives which could affect the plaster behaviour	
	Radioactivity:		
21	Europe Radioactivity Index I<0.5	This is the radioactivity of plasterboards	

Table 8: Lafarge Gypsum Specifications (and statistics) for FGD Gypsum Worldwide as at October 2008^{7&8}

NO.	CHARACTERISTIC	LAFARGE SPECIFICATIONS	Actual values observed		
			Ave.	Min.	Max.
1	Humidity	< 10%	9.2	6.0	13.0
2	Purity	> 95%	95.0	89.0	99.0
3	pH	5<pH<9	8.1	6.3	9.6
4	Particle size	30µm<d50<80µm	56	16	134
5	No needle	L/I>3	80% of measures compliant		
6	Density	non tapped : >950 g/l	1.04	0.49	1.26
	Soluble Salts:				
7	Na ₂ O	<500ppm	46	4	275
8	MgO	<600ppm	305	8	2866
9	Chloride	<100ppm	110	80	200
10	K ₂ O	<600ppm	25	4	180
	Impurities:				
11	Sulphites	<0.5%	100% of measures compliant		
12	Metals				
	As	<10ppm	Test method being developed		
	Cu	<100ppm	42	5	107
	Zn	<200ppm	15	3	65
	Pb	<50ppm	13	3	23
	Cd	<5ppm	100% of measures compliant		
	Ni	<100ppm	17	6	33
	V	<100ppm	21	3	77
	Cr	<500ppm	16	10	23
	Mn	<500ppm	48	8	224
	Hg	<5ppm	100% of measures compliant		
13	Colour	White	Occasional pigmentation issues		
14	Odour	Neutral	Experienced an exceptional NH ₄ issue in a specific plant		
15	Gypsum must be non toxic				

Table 9: Typical European FGD Specifications for Plasterboard as supplied by Gyproc²

SPECIFICATION	UNIT	VALUE	THRESHOLD	ACCEPTABLE ERROR
Free moisture	%	10	Maximum	± 0.25
Purity as CaSO ₄ .2H ₂ O	%	95	Maximum	± 0.50
CaCO ₃	%	5	Maximum	± 0.50
CaSO ₄	%	0.5	Maximum	± 0.50
Chloride	ppm	100	Maximum	± 10
K ₂ O+MgO+Na ₂ O with Na ₂ O % = 0.05 maximum	%	0.1	Maximum	± 0.01
Fe ₂ O ₃	%	0.4	Maximum	± 0.04
pH		6 to 8		± 0.10
Crystal size	µm	75%>16		

Please refer to References (Section 9) for footnote details as denoted by numeric superscript

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8. COSTS AND BENEFITS OF ESTABLISHING AN FGD GYPSUM MARKET IN SOUTH AFRICA

The gypsum market in South Africa (whether for synthetic or natural gypsum) already exists. However, as seen internationally, establishing successful relationships between producers and consumers of synthetic gypsum, while possible, remains a significant challenge.

Ultimately, the economic considerations such as capital expenditure and long term return on investments as compared to disposal/dump maintenance costs, will determine the level to which synthetic gypsum is utilised. It should be noted that synthetic gypsum which is less expensive than the natural raw material does not automatically imply it will be sought after for commercial use. The main factors which govern the commercial viability of synthetic gypsum are material consistency and reliability of supply. FGD gypsum must consistently meet strict quality parameters to be utilised in the plasterboard and other manufacturing industries (the largest potential market growth area for FGD gypsum).

Initial capital outlay by an FGD gypsum producer may be relatively large to facilitate the production of the correct, commercially viable gypsum but it will probably ensure long term viability in terms of market growth and will reduce the potential environmental impact associated with off-site disposal, or on-site FGD gypsum dump maintenance.

The supply of FGD gypsum presents Eskom with several opportunities and potential challenges with respect to sales and distribution. Despite the fact that the FGD gypsum is a waste product for Eskom, it is recommended that synthetic gypsum is not given but rather sold to raw gypsum consumers to allow the purchaser a degree of input into the quality assurance required to grow a sustainable synthetic gypsum market in the country. Internationally, FGD gypsum is sold rather than disposed of on a dump.

There are three main approaches to the future sale of synthetic gypsum by Eskom *viz.*

Eskom may decide to establish its own sales department (this option will not be dealt with further since FGD by-product sales are not core to Eskom's business interests); outsource the sales to an independent business entity; or undertake period contractual agreements in a tender process open to all raw gypsum purchaser role players (from the cement and plasterboard sectors), for limited periods e.g. one year to three year supply contracts. All role players concur that for Eskom to outsource sales to a single large business entity would result in a monopoly of the market which could jeopardise future market growth. However, the possibility of a partnering black economic empowered entity acting as an intermediary between Eskom and raw gypsum purchasers, exists.

The four main prospective (existing) customers in the current South African gypsum market are Lafarge (Gypsum & Cement Divisions), PPC, Afrisam and Gyproc. All these companies are well established and any purchase of FGD gypsum by these companies should be large continuous orders thus reducing the need to provide large storage facilities for the raw gypsum on Eskom property² (there are several potential environmental and production issues which could arise from excessive storage of FGD gypsum on site).

Plasterboard and insulation go hand in hand with energy efficient buildings and as Eskom and Government are committed to 12% energy saving by 2014, the availability of lower cost FGD gypsum for plasterboard will satisfy that need.

Lightweight structures are efficient and quick to build and require plasterboard. This new method of building will speed up delivery of low cost, Government funded housing.

Users such as Gyproc, Lafarge and the cement producers will all benefit provided their delivered cost is competitive to the current supply. In addition, the shorter transport routes from Kusile (and other inland coal fired new build projects) to Gauteng will mean a reduction in vehicle emissions and less traffic on South African roads.

Although, it has been said that there is no shortage of gypsum in the country², end use suppliers of gypsum ceiling and wallboards products have stated that both Lafarge Gypsum and Gyproc occasionally ‘run out’ of gypsum containing products and Gyproc has, in the past, substituted the use of their gypsum containing ‘Rhinolite’ plastering product with that of cretestone⁵. Whether these shortages are due to plant or transportation related issues, could not be determined.

The main drawback in availability of the product by both major suppliers is the cost of transport between the source and the market. In the case of natural gypsum the ex-mine price varies from R48.00 to R90.00 per tonne whereas, natural agricultural gypsum sells for between R168.00 and R198.00 per tonne². Phosphogypsum from the dump i.e. unwashed material, sells for R62.00 to R82.00 per tonne and washed material sells for R80.00 to R120.00 per tonne².

The transport component of the delivered price is critical and typically, transport will range from 3 to 7.5 times the ex-mine cost depending on distance travelled and whether road or rail is used².

8.1 Handling of FGD Gypsum by Producer

As indicated by Eskom¹, gypsum is considered a waste product. It is assumed that, once produced, ‘disposing’ of the FGD gypsum is Eskom’s main concern and that no further downstream or value added processing is envisaged. However, there are several issues to be considered (Meadows, 2006) by the FGD gypsum producer, as well as the potential purchaser or on-site material handler. These items are listed in Table 10 below:

Table 10: Factors to be considered by FGD gypsum role players on a power plant site

Electric Utility	Potential raw FGD Gypsum purchaser	On-site FGD Gypsum /FGD material handler*
Sorbent/reagent quality		
Dust abatement mechanism and particulate emissions control in plant/on dump site	Dust abatement mechanism and particulate emissions control for loading of gypsum from supplier/in site beneficiation or processing plant	During transportation of gypsum to dump site/on dump site
FGD technology and system design		
Gypsum dewatering system and design	Gypsum dewatering system and design if plant shared with FGD gypsum producer	
Effluent water management	Effluent water management	Effluent water management
Gypsum handling and storage	Temporary gypsum handling and storage	
Chloride bleed system for FGD plant (potential requirement)		
Operating and maintenance procedures	Operating and maintenance procedures	Operating and maintenance procedures
Management of off-specification gypsum	Management of off-specification gypsum	
Off-site transport disruptions	Off-site transport disruptions	On-site transport issues
Contractual issues	Contractual issues	Contractual issues

* could be Eskom or a contracted-out function

Lafarge Gypsum and Gyproc have several international associations with power utilities. Gyproc indicated that they have plants at 30 power stations world wide⁹ and Lafarge Gypsum, at 150 power station associations, worldwide⁶.

When initially approached by OTM in 2008, Gyproc and Lafarge Gypsum mentioned that while the trend overseas is for the development of an on-site plant to process the raw gypsum further e.g. into plasterboard, the finished product (plasterboard) does not transport well⁹ and in South Africa, with larger capacity stations, both companies

prefer to transport raw gypsum away from any supplying utility, to their existing processing plants located in Gauteng.

At this stage, both Lafarge Gypsum and Gyproc indicated a willingness to finance the building of basic on site facilities (for loading and storage) at a power station whilst Gyproc stated that this would be significantly cheaper than the proposed new mine they are planning in the Kimberly area which would cost at least R40,000,000.00 to establish⁹.

When OTM contacted Lafarge Gypsum to verify this information in February 2009 (due to conflicting information discussed directly between Lafarge Gypsum and Eskom towards the end of 2008/early 2009)¹, Lafarge Gypsum stated that they had revised their strategic approach to potential synthetic gypsum supply from Eskom, considering the time frames of Kusile's construction and commissioning, and were now prepared to establish on-site facilities should that be required⁸.

From Eskom's perspective, an on site plant will require land appropriately situated in the vicinity of the FGD plant with a surface area allocation in the order of 10,000 m² to 15,000 m². In addition, the power station would need to supply typical infrastructural and utility needs (water and electricity) which, dependent on the type of contractual agreement reached, the raw gypsum processor may purchase.

A point to note is that a plasterboard manufacturing plant requires gas supply to generate the 2 GJ needed for the burners used in the drying and calcining process⁷. The burner (oven) cannot be fired with coal or oil since this causes discolouration of the final product⁷ which reduces its market potential. The total power supply for a plasterboard manufacturing plant is approximately 1 MW⁸.

Lafarge Gypsum has indicated that often, power utilities have synthetic gypsum storage issues. Lafarge Gypsum has several types of joint ventures with power stations in other countries where they either have an on-site plaster board plant; remove the raw gypsum to their off-site processing plants; supply the limestone required by the FGD system (in a 'trade-off' for the gypsum or utilities required) or

manage the FGD gypsum stockpiles and other logistical issues associated with raw gypsum supply, for the power station^{7&8}.

In addition, the Lafarge Gypsum and Gyproc plants in Gauteng are currently under-utilised. Gyproc's Brakpan plant presently runs at 60% to 70% capacity and has additional storage capacity for 12 kt of raw gypsum⁹. 40% of the company's sales occur in the first six months of the year with the remaining 60% in the second half of the year⁹.

Gyproc has also initiated the required environmental impact assessment processes for the proposed expansion of their Brackpan plasterboard plant, to enable the receipt and processing of phosphogypsum for the production of plasterboard. It is estimated that approximately 500 to 900 tonnes of phosphogypsum will be received and processed per day (Environmental Science Associates, 2008).

Lafarge Gypsum's Roodekop plant in Rondebult, Germiston also has excess capacity and operates with a one month 'safety' stock in its on-site storage bunker which is always kept to maximum holding capacity, so that assurance of supply can be given to customers. According to Lafarge Gypsum^{7&8}, demand for gypsum is relatively constant throughout the year except in October and November where demand increases by about 15% above the average. Lafarge Gypsum generally works their budget based on an 11 month supply of gypsum since December is a characteristically quiet month with respect to the construction industry.

Although this report is intended to assess the gypsum market with respect to the demand for synthetic gypsum, should Eskom consider disposing FGD gypsum on an on-site dump or co-disposing the FGD gypsum with ash sent to existing ash dams/dumps, cognisance should be taken of the following:

Gypsum is a sparingly soluble substance and gypsum waste dumps are a significant source of sulphate ions in groundwater and soil, as well as in surface water runoff (Kostic-Pulek et al., 2008). Effluent water from a gypsum dump is very acidic water (pH of approximately 1.5)².

Trace elements (heavy metals) present in all ash dumps, migrate in acidic environments. Despite the very alkaline nature of Eskom's ash dams/dumps, the addition of acidic media or increased sulphate ions from FGD gypsum, together with natural rainfall which tends to be slightly acidic, increases the risk of heavy metal migration through the ash dam/dump and into the natural environment.

The on-site handling of FGD gypsum bears with it similar fugitive emission impacts as a dry ash dump. Gypsum plant related dust collectors wear quickly². In addition, the relatively simplistic dust suppression methods employed for dry ash dumps may not be appropriate in all instances of FGD gypsum disposal. Any pure gypsum dump will require similar environmental monitoring and control mechanisms as an ash dump.

The potential problems for pure gypsum (calcium sulphate) or calcium sulphite disposal may not be applicable for co-disposal of FGD gypsum with fly ash. Ash will affect the binding properties of the gypsum. The potential for co-disposal of FGD gypsum with ash on existing ash dams/dumps must be thoroughly investigated particularly in terms of the integrity of wall stability, heavy metal migration through the dump, sulphite ion leaching and in the case of wet ash dams, toe drains scaling/blockages.

8.2 Potential Impact of FGD Gypsum on Current Gypsum Mines

Phosphogypsum has already taken a market share from natural gypsum in the agricultural sector and to a lesser extent, in the cement industry where Lafarge cement is the only producer using phosphogypsum in place of natural gypsum, after some beneficiation.

The introduction of FGD gypsum will impact on the operation of Gyproc's 'Bushmanland' mine, assuming that some of the cement factories supplied from this mine convert to FGD gypsum². Similarly, Lafarge's Geelvloer mine would also be affected².

Since the mines are owned by the suppliers, closure does not involve contractual issues with a third party mining house. Also, because gypsum is so close to the surface, less than 3 m overburden is removed to extract the mineral. Therefore, with respect to potential job losses due to mine closure, the staff compliment at mines is very low (less than 50 people)².

It is unlikely that PPC's De Hoek and Riebeeck West plants and Gyproc's Parow plant will convert to FGD gypsum due the cost of transport from Witbank to the Cape, as there are natural deposits within 300 km of these plants².

8.3 FGD Gypsum Market Projection

Part of the brief of this study is a 30 year market projection for gypsum produced during the FGD process in South Africa. Based on market trends up to the third quarter of 2008, a ten year projection was made with a reasonable degree of confidence, although, projections of market growth beyond that period were educated estimates based on overseas trends, current market initiatives and assumptions concerning social mindsets regarding plasterboard use.

To project the FGD market growth in ten year increments up to the year 2038, certain factors have been taken into consideration and assumptions made *viz.*:

- A steady population growth of 2% per annum
- Wherever low cost FGD material is available, building industry use has expanded
- FGD availability has resulted in more manufacturers establishing plants in the region thus promoting more exposure to the product
- The per capita usage of plasterboard in South Africa is low compared to current world consumption figures, indicating a high potential for market growth.
- The advent and progress made by the South African Steel Frame Association (SASFA) in promoting steel framed housing has been remarkable and the

assumption is made that this method of building captures 20% of the market in 30 years time.

- The publication of South African National Standards (SANS) 204 addressing energy efficiency in housing will drive the promotion of plasterboard and insulation in construction
- The social acceptance of plasterboard internal walls in residential housing and not just in office space, is slowly gaining market share against brickwork
- Government's commitment to build more low cost, energy efficient houses to reduce the backlog of some four million low cost housing units
- All existing and inherited low cost Government houses have no ceilings. A retrofit of ceilings in these houses will be required to meet the energy savings envisaged. It is estimated that approximately 5 million such houses already exist and that 50% of these households could afford to install a ceiling. The average gypsum requirement for 1 m² of ceiling is 5.7 kg.
- Gypsum will replace lime in road building and coal mining
- It is assumed that only good quality, saleable FGD gypsum will be produced, therefore, the manufacture of calcium sulphite is not considered for long term projections.

For purposes of this report, the cement market projections (Figure 6 and Figure 7), exclude the Cape Province and Kwa-Zulu Natal plants due to their distance from future Eskom FGD gypsum sources. The same exclusion applies to Gyproc's Cape Province based plant but not to Lafarge Gypsum's plants, which are located in Gauteng.

From Figure 6, it is evident that both the plasterboard and construction industries will benefit from an increase in gypsum availability, however, agricultural usage will also increase as South African soils generally require conditioning (such as with gypsum) for increased crop yields.

The marked growth in plasterboard and plasters concurs with Government's commitment to low cost housing over the next ten years, large construction (infrastructural) projects being undertaken in Gauteng, as well as the other

assumptions mentioned above which are linked to a growing acceptance of plasterboard products.

It is assumed, from discussions with industry representatives, that the new (i.e. not yet established) market sector with a largest potential for growth in the next 30 years (from all the potential FGD applications listed in Section 5 of this report), is mining. This sector has not yet been developed and needs to be researched further.

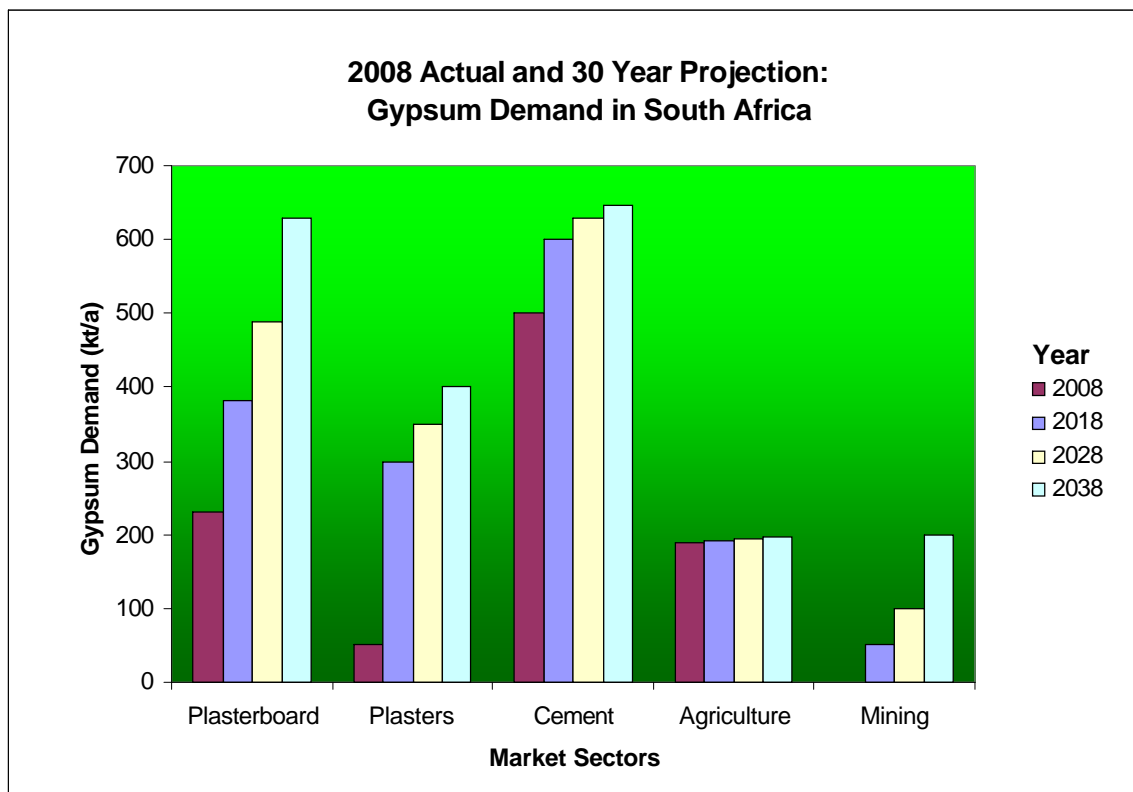


Figure 6: Projected gypsum demand in South Africa over the next 30 years for major current and future (mining) market sectors as of November 2008

Since the global economic recession towards the end of 2008, the ten year market growth projection initially made, although included, may be optimistic. Gyproc and Lafarge Gypsum are currently operating on five year projection plans.

Figure 7 has been included as a revised ten year projection from 2008 to 2018, in an attempt to factor current economic trends into the original projections of potential gypsum market growth.

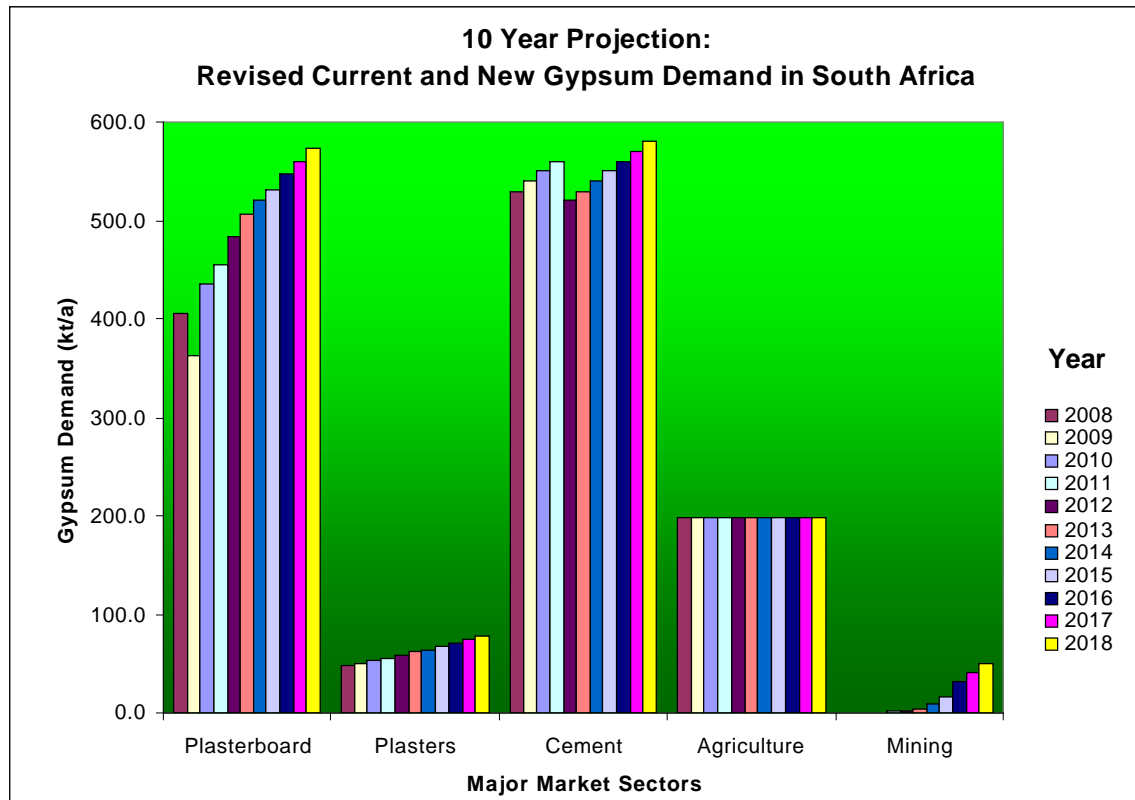


Figure 7: Projected gypsum demand in South Africa over the next 10 years for major current and future (mining) market sectors as of March 2009

The decrease in the plasterboard sector growth for 2009, is due to Gyproc’s negative projection for the year (refer to Section 5.3). Cement growth indicates the 20% growth expected in the next 7 to 8 years with an average 5% growth in subsequent years. It should be noted that growth in the mining sector could be more marked if focus was given to marketing gypsum use in the sector.

9. CONCLUSIONS

The FGD technology employed by Eskom and the quality of the gypsum produced are critical to the effective growth of the gypsum market in Southern Africa, particularly the plasterboard sector of the market which shows the most potential for sustained growth. The introduction of commercially viable FGD gypsum for the plasterboard sector will increase the potential for sustainable FGD gypsum market growth in South Africa. Most of the technical difficulties in producing commercially viable FGD gypsum have been addressed internationally and the operating changes required to utilise the material in commercial applications are becoming quite well established (Berland et al., 2003).

The introduction of FGD gypsum, of the correct quality, into this growing sector would facilitate further optimisation of FGD gypsum usage and provide Eskom with opportunities to meet other corporate responsibilities with respect to waste minimisation, energy efficient housing and demand side management, as well as 'green building' contributions.

Raw gypsum suppliers in South Africa are keen to utilise FGD gypsum due to the high transportation costs incurred as a result of the location of current sources of the material. However, structuring successful relationships between FGD gypsum producers and purchasers remains a significant challenge¹². Market projections presented in this report would be similar for any of Eskom's current coal-fired new build projects (i.e. Kusile, Medupi or Project Golf) since the travelling distance still remains less than from current gypsum sources.

While legislative requirements guide the need for industries to implement FGD to meet more stringent SO₂ emission standards, environmental and economic best practice guide that implementation towards producing commercially viable gypsum instead of opting for long term disposal. Gypsum waste dumps, whether the disposal is directly onto a dump or co-disposed with ash, form significant ecological risk factors and the global trend is towards dump avoidance or recycling (Kostic-Pulek et al., 2008).

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