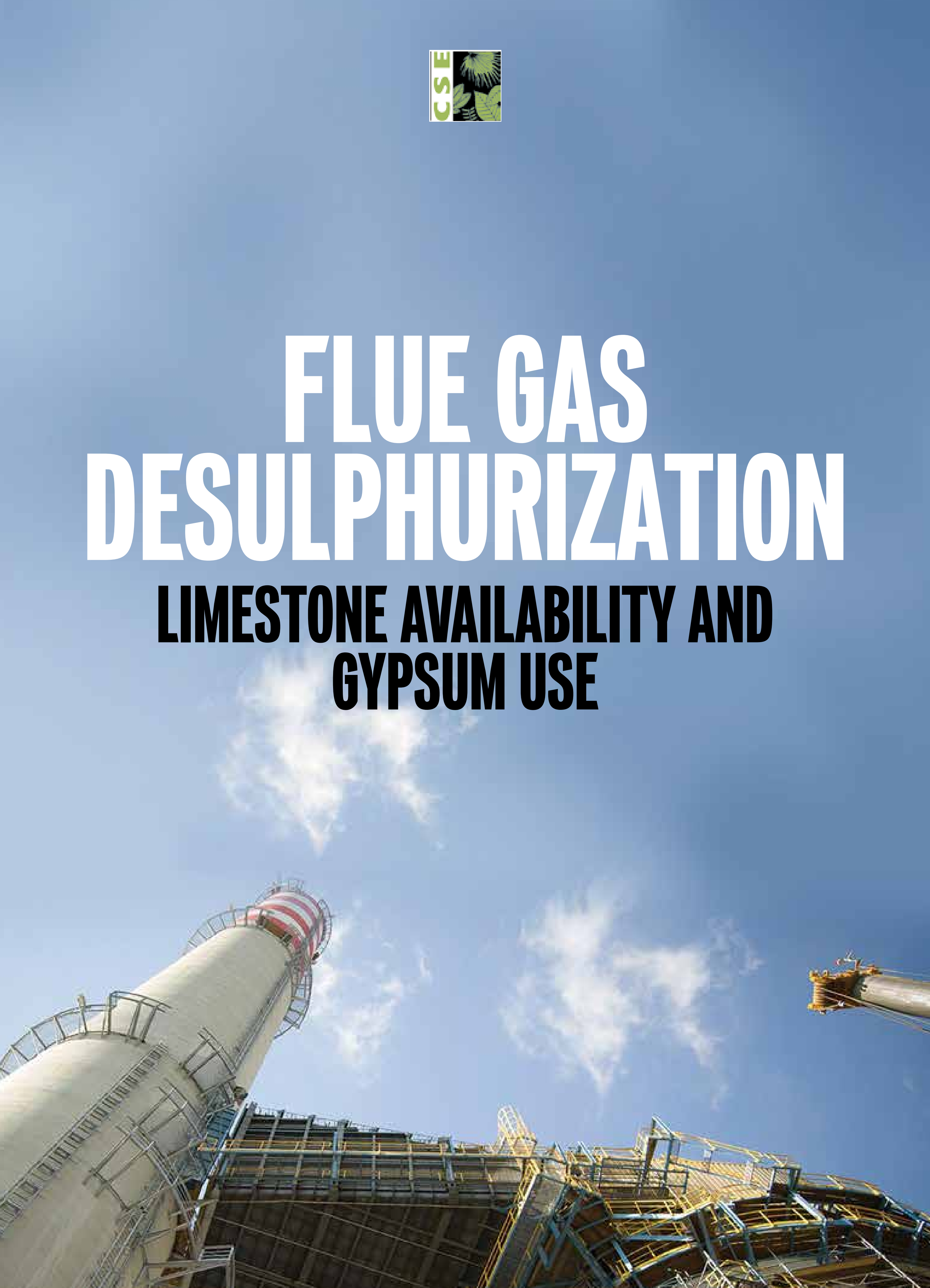
FLUE GAS DESULPHURIZATION

LIMESTONE AVAILABILITY AND GYPSUM USE



FLUE GAS DESULPHURIZATION

LIMESTONE AVAILABILITY AND GYPSUM USE

CENTRE FOR SCIENCE AND ENVIRONMENT

Research director: Sunita Narain

Author: Vinay Trivedi

Editor: Akshat Jain

Design and cover: Ajit Bajaj

Layout: Kirpal Singh

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Phone: 91-11-40616000
Fax: 91-11-29955879
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1. EXECUTIVE SUMMARY

A large number of India's coal-based thermal power plants are set to install flue gas desulphurisation (FGD) systems by 2022 in order to meet new emission norms announced by the government in 2015. Limestone is a key raw material in most FGD systems installed to control sulphur dioxide (SO_2) emissions. This report attempts to address the availability of limestone for FGD and also the use of its by-product, FGD gypsum.

Limestone is an abundant resource in India with total reserves of 200 billion tonnes. India's limestone production has been growing steadily and it is among the world's largest producers with 338 million tonnes of limestone produced in 2017–18. The cement industry consumes a major share of limestone, followed by the steel and chemical industries. CSE estimates that the coal-based power sector would require only seven to ten million tonnes of limestone annually for operating FGD systems. This is less than three per cent of India's present limestone consumption. Moreover, regional distribution of limestone reserves shows that access will not be a problem as a majority of power plants are located within 200 km of a limestone mine.

For FGD, high quality limestone ($CaCO_3$ > 90 per cent) with minimum impurities is desirable. High quality limestone is already being produced for use by the steel and chemical industries. Industry experts believe that producing additional high quality limestone would not be a challenge given our large reserves. As per CSE's estimation, the cost of limestone will not be significant. A 500 MW plant will require about 32,000–40,000 tonnes of limestone annually, costing around three to four crore rupees with an impact of less than one paisa per unit of electricity. Ensuring the use of high quality limestone will offer multiple benefits: high removal rates of SO_2, generation of valuable gypsum that can be used by the cement and other industries, and eliminating the need for dumping gypsum thus attenuating related environmental impacts. Additionally, a power plant can offset the cost of limestone by selling FGD gypsum.

Gypsum is a scarce resource in India. India's gypsum consumption in 2014–15 was around ten million tonnes, out of which it only produced 2.5 million tonnes while importing the rest.[1] The quality of FGD gypsum is at par or even better than mineral gypsum and it has become a substitute for mineral gypsum across the world. China is able to utilize more than 70 per cent of its FGD gypsum, largely in cement and construction. In India as well, gypsum is an integral component of cement production and the sector has to rely on costly imports or poor quality synthetic gypsum. By adopting FGD, India's power plants would produce around 12–17 million tonnes of gypsum which can thus meet domestic shortfall and reduce the import burden.

A number of steps need to be taken to ensure limestone availability and gypsum utilization. The Ministry of Environment, Forest and Climate Change (MoEF & CC) should release guidelines for appropriate safeguards in handling, storage and transport of limestone and gypsum. Captive limestone miners should be allowed to sell high quality limestone to their nearest power plant.

In the long term, power plants should be directed to utilize all the FGD gypsum produced; however, for the short term disposal guidelines can be issued. While the use of FGD gypsum in the cement industry should be encouraged, it is also necessary to provide incentives to the manufacturers of high-end gypsum products like wall boards and plaster boards. The agriculture sector can also become a valuable consumer of FGD gypsum; however, certain quality checks and field trials are essential to ensure its use in agriculture is safe.

2. BACKGROUND

In December 2015, the standards set by the MoEF & CC for coal-based thermal power plants came into force.[2] The new standards aim to drastically cut emissions of particulate matter (PM), SO_2, mercury and oxides of nitrogen (NO_x) (see *Table 1: New emission norms for thermal power stations*). To arrest pollution and to meet the norms, power plants will need to upgrade their electrostatic precipitators (ESP), install FGD systems, and fine-tune boiler operations.

Table 1: New emission norms for thermal power stations

Emission norms for plants installed after 1 January 2017 are very stringent

Pollutant (mg/Nm^3)	Unit size	Installed before 31 December 2003	Installed between 2004 and 2016	Installed 1 January 2017 onwards
PM	All	100	50	30
SO_2	<500 MW	600	600	100
	>=500 MW	200	200	100
NO_X	All	600	300	100
Hg	All	0.03 (>500 MW)	0.03	0.03

Source: MoEF&CC, 2015

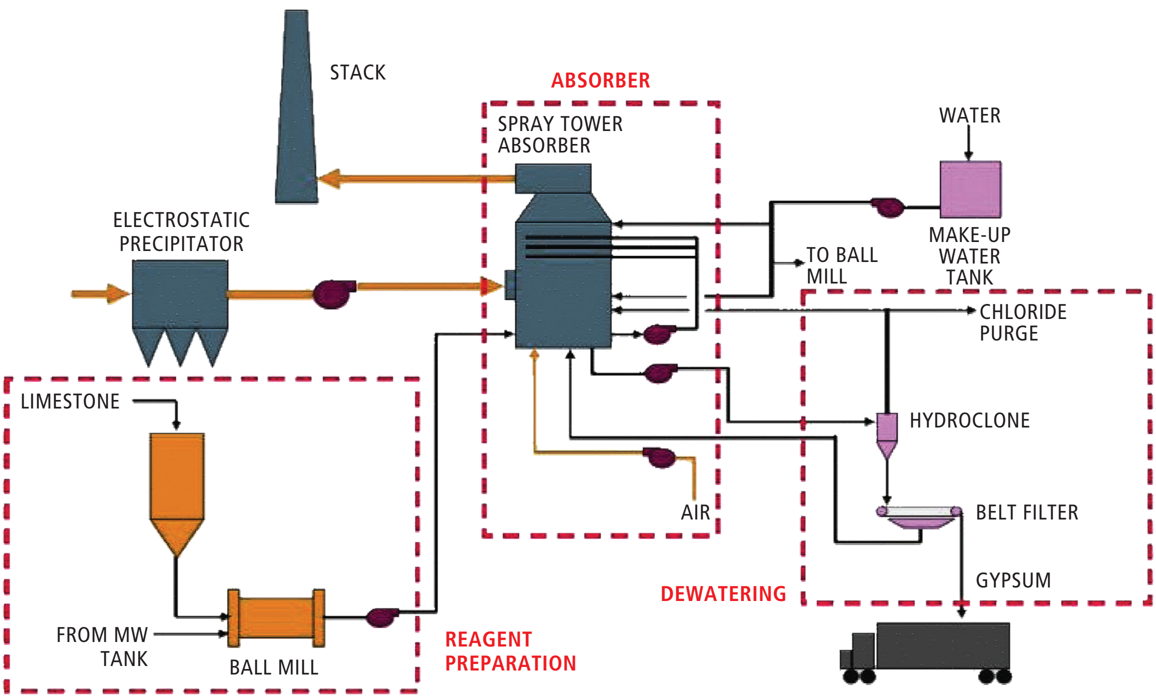
Of all the thermal power plant emissions, SO_2 is a particularly harmful pollutant. Epidemiological studies have reported links between exposure to SO_2 and health problems such as chronic obstructive pulmonary disease (COPD)[3], asthma and respiratory disease, and increased mortality.[4] Another study plotted a 0.34 per cent increase in non-accidental mortality for every one part per billion (ppb) increase in SO_2.[5] Sulphur dioxide also behaves as a secondary pollutant since it reacts with compounds in the atmosphere to form small particles, increasing particulate matter concentration. Small particles penetrate deeply into the lungs and contribute to health problems.[6] Acid rain, leading to damage of soil, vegetation and property, is another serious hazard.

India is the largest emitter of SO_2 in the world, contributing more than 15 per cent of global anthropogenic emissions.[7] Controlling these emissions would require the installation of FGD systems in power stations.[8] Until recently, the industry claimed that FGD systems were not appropriate for Indian plants for a number of reasons: technology was not proven for Indian coal which has high ash content; many plants claimed to have insufficient space to install FGD systems; controlling SO_2 would result in a significant increase in power tariff. Over the last two years, CSE published a series of reports that addressed these issues/myths. This report addresses two remaining persistent queries from power plants and regulators: availability of sufficient quantity of limestone for plants that are scattered across India and the use of gypsum, the main by-product of FGD.

3. FLUE GAS DESULPHURIZATION (FGD) SYSTEMS

FGD systems are installed in power plants to remove SO_2 from flue gas[9] (see *Figure 1: Schematics of a wet FGD system*).[10] Flue gas is sprayed with a reagent (wet limestone is commonly used), which reacts with the SO_2 in the flue gas producing calcium sulphate di-hydrate [$CaSO_4 \bullet 2H_2O$], also known as gypsum. The process limits the amount of SO_2 that can escape into the atmosphere.

Figure 1: Schematics of a wet FGD system
Wet limestone reacts with the SO_2 in flue gas to produce gypsum



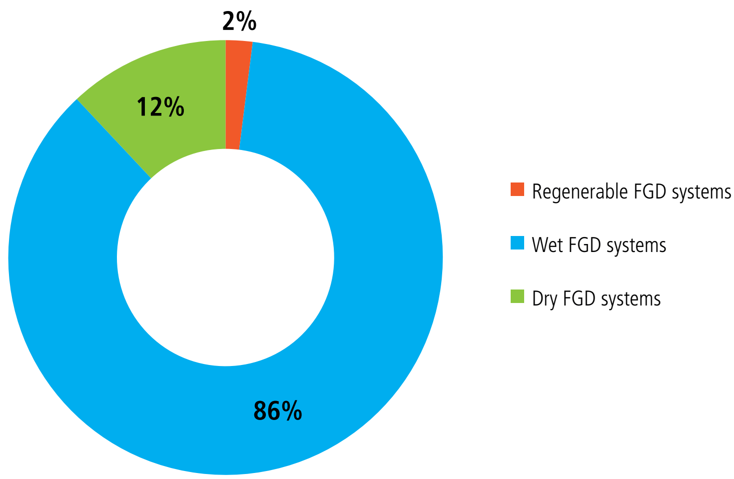
Source: Northeast States for Coordinated Air Use Management, 2011

FGD systems are categorized according to the reagent and the quantum of water used in the process. Commonly used reagents include lime, limestone, sodium hydroxide, ammonia, seawater, magnesium oxide and magnesium hydroxide. Limestone-based wet FGD systems which can remove 90–99 per cent of SO_2 are the dominant choice for thermal power stations globally[11] (see *Graph 1: FGD technology global population*).

While no survey on FGD installations has been carried out in recent years, Transparent Technologies Pvt. Ltd, a domestic supplier of FGD systems, estimates wet FGD systems still have a dominant share of the global market. In China and Germany, wet FGD systems have over 90 per cent share of the installed base.[12] Approximately 85 per cent of the FGDs installed in the US are wet systems, 12 per cent are spray dry and three per cent are dry systems.[13] India's FGD installation is expected to follow the same trend.

Graph 1: FGD technology—global population

Wet FGD technology dominates the global market



Source: USEPA, 2003

Another popular FGD system is the seawater-based FGD system which is favoured in coastal areas. The natural alkalinity of seawater can remove up to 99 per cent of SO_2, thus eliminating the cost of the reagent.[14] In the case of the dry scrubbing process, atomized lime slurry is sprayed into the flue gas in the absorber vessel. The resulting calcium sulphate is collected downstream. The removal efficiency of dry scrubbers is up to 60 per cent.[15] Since smaller units need to meet looser norms, these systems may be suitable for them. A variant of this, known as dry sorbent injection (DSI) system, is a relatively inexpensive process—scrubbing material in DSI is usually trona or sodium bicarbonate.

3.1 FGD SYSTEMS IN INDIA

So far only seven gigawatt of coal-power capacity goes through FGD systems in India (see *Annexure 1: FGD footprint in India*). Till 2015, there were no national regulatory standards for SO_2 emissions in the thermal power sector. Certain states such as Gujarat had enacted state-wide norms for SO_2 emissions but they were not enforced.

In December 2015, MoEF & CC announced new norms for emissions from coal-based power plants. The original notification required the plants to meet the new norms by December 2017. However, the Central Pollution Control Board (CPCB) extended the timelines to meet SO_2 norms over the 2017–22 time period. As per Central Electricity Authority's (CEA) FGD implementation plan, out of 196 GW of total capacity FGD installation is feasible in about 170 GW. Out of this, FGD has been planned for 161 GW of capacity (see *Table 2: Plan for FGD implementation in India*).

Table 2: Plan for FGD implementation in India

Almost 90 per cent of capacity in India would install FGD

S.No.	Description	Capacity (MW)	Units (No.)
1	Total capacity considered	196,667	650
2	Capacity retired/identified for retirement	8,967	82
3	Capacity already having FGD	6,130	15
4	Capacity with CFBC boilers	5,524	48
5	Capacity claims to SOx complaint	5,115	23
6	Balance capacity	170,931	482
7	Capacity where FGD has been planned	161,552	415
8	FGD possibility being explored	690	
9	Space not available	8,689	

Source: CEA, 2019

A significant share of India's thermal power capacity is likely to opt for wet limestone FGD due to its well proven operational and technological track record across the world. Accordingly, India's power plants will also require limestone for the operation of their FGD systems. Our estimates show the country's reserves and production capacity will easily be able to meet this incremental demand for limestone.

Table 3: Capacity vs Age distribution of the plant

Only 108–130 GW of the capacity out of 195 GW should ideally opt for wet limestone FGD

Capacity	Age distribution			
	0–15	16–25	26–35	>35
=>500 MW and above	101.74	7.2	7	0.5
250–500 MW	16.15	0.6	0	0
Upto 250 MW	21.42	12.26	17.23	10.84

We believe that units which are 500 MW or larger and less than 25 years old should opt for wet limestone FGD. Units between 250–500 MW but less than 15 years old may also consider wet limestone FGD depending on their emissions and especially if they are located in polluted or densely populated areas. The plants that are situated near the coast may be better off installing seawater-based FGD.

Units that are smaller than 250 MW and are less than 25 years old should opt for a combination of DSI, coal washing, fuel switching or other inexpensive measures. Many of the units that are more than 25 years old should be phased out within a short time frame.

4. LIMESTONE

A large number of coal-based power plants will need relatively high quality limestone to operate their FGD systems. This makes it necessary to assess the quantity and quality of limestone available for this purpose.

4.1 LIMESTONE RESERVES AND PRODUCTION IN INDIA

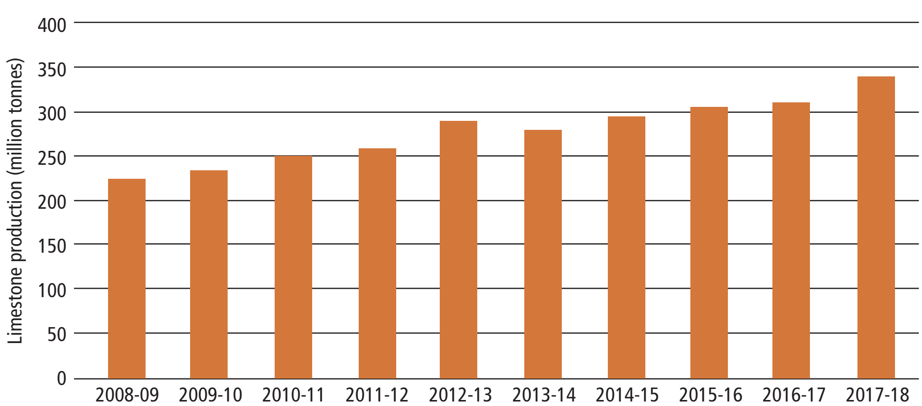
Limestone is a sedimentary rock composed mainly of calcium carbonate ($CaCO_3$) in the form of the mineral calcite. According to the estimates of the Indian Bureau of Mines (IBM), the total reserves/resources of limestone of all categories and grades stands at over 200 billion tonnes, of which 16 billion tonnes (eight per cent) are placed under the Reserves category and 184 billion tonnes (92 per cent) under Remaining Resources category. Of the Reserves category, proved reserves are around 9.4 billion tonnes and the rest is included under Probable Reserves.[16]

Limestone is available across different states (see *Figure 2: Limestone reserves in India*). Karnataka is the leading state with 27 per cent of the total resources followed by Andhra Pradesh and Rajasthan (12 per cent each), Gujarat (ten per cent), Meghalaya (nine per cent), Telangana (eight per cent), and Chhattisgarh and Madhya Pradesh (five per cent each).[17] Since the cement industry is the main consumer of limestone, most of the mines are owned directly by the cement companies.

In 2017–18, 338 million tonnes of limestone was produced. Limestone production has steadily increased in India in the past decade (see *Graph 2: Production of limestone*). It is being produced across most states of India, with Rajasthan being the leading producer accounting for 22 per cent of total production, followed by Madhya Pradesh (13 per cent), Andhra Pradesh and Chhattisgarh (11 per cent each), Karnataka (nine per cent), Telangana (eight per cent), Gujarat (seven per cent) and Tamil Nadu (six per cent). Cement is the largest limestone consuming industry accounting for 94 per cent share followed by Iron and Steel (four per cent), and Chemicals (two per cent). [18]

Graph 2: Production of limestone

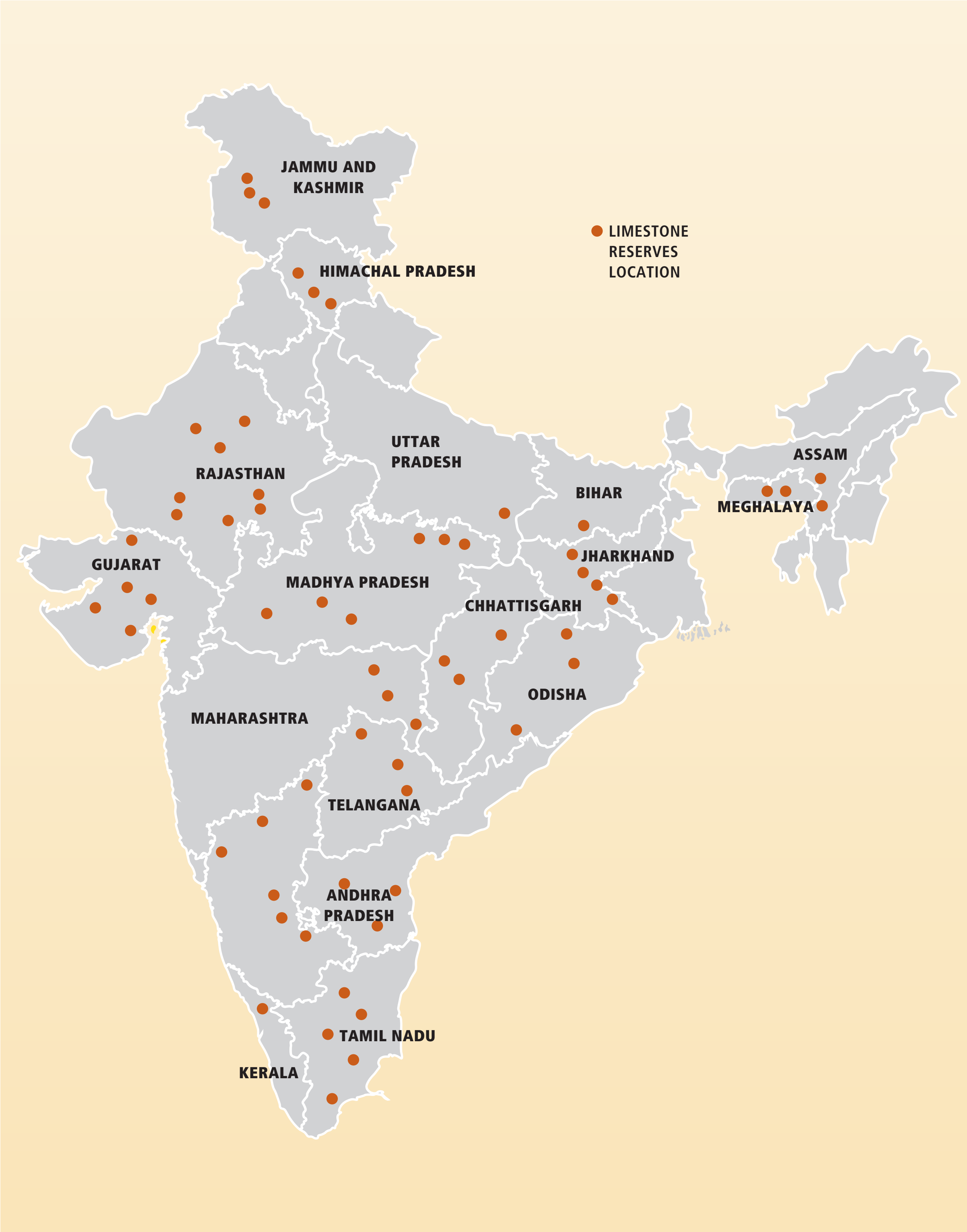
Production of limestone has been steadily increasing in India



Source: India Mineral Yearbook, 2018

Figure 2: Limestone reserves in India

Availability of limestone is spread across the country



Source: Indian Bureau of Mines, 2018

4.2 LIMESTONE REQUIREMENT FOR FGD

As per CEA's National Electricity Plan, 2018, coal-based thermal power plants will generate 1,018 billion units in 2021–22 and 1,246 billion units in 2026–27. Based on the projected electricity generation and general coal quality (in terms of sulphur content), we have estimated potential SO_2 generation if no emission controls are put in place. SO_2 reduction potential is calculated based on the following parameters: potential fleet distribution (in terms of unit size and age), relevant norms, and emissions in line with norms. Although plants will use a range of reagents or alternative measures such as DSI, we have assumed that the cumulative SO_2 reduction will be achieved using only limestone—this assumption will therefore give us the upper limit of limestone needed by India's coal-based power sector. Under this scenario, 9–10 million tonnes of limestone will be needed annually by 2026–27, which is only about three per cent of the current limestone consumption.

Table 5: Limestone requirement of coal-based power plant

Thermal power plants will require 7–10 million tonnes of limestone by 2026–27

Year	Capacity (GW)	Electricity Generation (billion units)	Category	SO_2 (million tonnes)	SO_2 reduction (million tonnes)	Limestone requirement (million tonnes)
2015	188	895	Uncontrolled	4.30		
2022	248	1018	Uncontrolled	4.75		7–8
			With abatement	1.02	3.73	
2027	248	1246	Uncontrolled	5.81		9–10
			With abatement	1.25	4.56	

Source: CSE estimations based on CEA coal generation projection (see Annexure 2: Assumptions for SO_2 estimations)

While the limestone requirement for FGD is a small fraction of overall supply, an important factor is the distance of the source of limestone from the power station. Given the weight of limestone, transportation adds significantly to costs. To assess the ease of access to limestone, we identified large power generation clusters across the country totalling 134 GW. Next, we identified the limestone-mining areas that are nearest to these power-generating clusters (see *Annexure 5: Key power station/clusters and nearby limestone deposits*).

The results have been summarized (see *Table 6: Proximity of power generation capacity to limestone mining districts*) and they show that almost 60 per cent of the power generation capacity (~80 GW) falls within 200 km of a limestone-mining district. Another 20 per cent lies between 200–300 km of the mining district. Many states house both power plants as well as limestone mining regions (Madhya Pradesh and Rajasthan). In certain cases, power stations are close to limestone-mining districts in the neighbouring states—power stations in Punjab and Haryana are close to limestone deposits in Himachal Pradesh and Rajasthan.

Table 6: Proximity of power generation capacity to limestone mining districts

Most plants are located within 200 km of a limestone mining district

Distance (Km)	Capacity (MW)
0–100	30,170
101–200	49,174
201–300	27,760
301–400	15,230
>400	14,170

Source: CSE, 2019

Thermal power plants will have to make arrangements for procurement and transportation of limestone and its storage within the plant premises. Limestone storage yards with a capacity of at least two to three months would be typically needed by power stations to ensure that FGD operations run uninterrupted. NTPC's Vindhyachal power station in Madhya Pradesh (MP) commissioned FGD systems recently. It procures limestone from the Katni district in MP, about 200 km away, instead of sourcing it from the nearby Sonbhadra district of Uttar Pradesh. The limestone, in the form of boulders, is transported by trucks and stored within the plant premises close to the FGD unit. The storage facility can accommodate stock for two to three months. A crusher has been installed with a cyclone precipitator for converting the boulders to powder or slurry. Similarly, CLP India Pvt. Ltd procures limestone from Rajasthan and has a storage capacity of five to six months in the plant premises. Limestone needs of two to three days are stored near the FGD system for processing.

Wet FGD systems use limestone as an absorbent. The SO_2 in flue gas reacts with $CaCO_3$ and produces calcium sulphate ($CaSO_4$) and a small amount of $CaSO_3$ in a certain temperature and humidity. Magnesium Oxide (MgO) in the limestone can also produce a desulphurization effect. Other chemicals present in natural limestone such as SiO_2, Al_2O_3, Fe_2O_3 can't produce a desulphurization effect and are hence considered as impurities in limestone.

Typically, the content of $CaCO_3$ in limestone should be higher than 90 per cent (CaO > 45–50 per cent) for good performance of wet FGD.[19][20] Poor quality limestone increases requirement of limestone. Impurities also have an impact on the stable operation of wet FGD systems as well as on their efficiency in reducing SO_2 concentration in flue gas. Furthermore, they can affect the quality of gypsum produced.[21] Apart from quality, mechanical factors such as grind size (grindability index) and chemical factors such as SO_2 loading also affect the FGD's SO_2 removal efficiency.

Bureau of Indian Standards (BIS) has detailed broad requirements for different industries. For example, cement can use limestone of a wide variety (CaO varying from 44–52 per cent) while steel and glass require very high quality limestone ($CaCO_3$ > 90 per cent) for some processes (see *Annexure 3: Grades of Limestone*). Secondly, while some industries (building, cement, iron and steel) can accommodate materials such as iron, alumina and silica in limestone, others (glass and chemical) require limestone to be as free from impurities as possible.[22] Similarly, BIS may also need to specify requirements of limestone being used in FGDs to ensure good quality FGD gypsum.

4.3 COST OF LIMESTONE

The quality of limestone determines its selling price. Depending on the grade of limestone the price varies between ₹273–1007 per tonne. Industry experts told CSE that the average selling price for limestone for FGDs would be around ₹500–600 per tonne. However, NTPC has procured limestone at ₹900 per tonne for the Vindhyachal power station's FGD system—possibly, this is a higher quality limestone (see *Table 7: Limestone prices in India*).

Table 7: Limestone prices in India

Price varies with quality of limestone. The best quality limestone goes to the steel industry

	User industry	Price range (in ₹)	Average selling price (in ₹)
1	LD (steel process)	473—863	737
2	Steel Melting Shop (SMS)	289	289
3	Blast Furnace (BF)	300—1007	524
4	Chemical	273	419
5	Cement	427—630	427

Source: IBM, Average Sale Price of Limestone for the month of January 2016

To develop some understanding of the cost of limestone for FGD in one power plant, we take the case of a 500 MW unit:

Table 8: Annual limestone requirement and cost for a 500 MW plant

The per unit cost of limestone is very low

Total coal consumption (million tonnes)	SO_2 generated (tonnes)	Limestone requirement (tonnes)	Per unit (₹/Kwh)
2.25	18,049	32,000	0.00859

Note: High quality limestone delivery price at plant is taken as ₹900/tonne.
Assumptions: Plant operates at plant load factor (PLF) of 85 per cent; sulphur content in coal (0.4 per cent); removal efficiency (90 per cent)
Source: CSE estimations

Based on our analysis, a 500 MW plant will require 32,000–40,000 tonnes of limestone annually. The annual cost of limestone will be in the range of ₹3–4 crore. The cost of limestone can be more than offset by selling gypsum, which sells for over ₹1,000 per tonne, produced from the process.

Limestone requirement for coal-based power plants is miniscule compared to the present demand and consumption of limestone. However, it is essential that good quality limestone be allocated to power plants. Most power plants do have a mine near them from which limestone can be sourced but the problem is that many of those mines are captive mines. Captive mines are those mines which are not allowed to sell limestone to any company other than the one that owns them. It is essential that these mines be opened up for use by the power plants in order to facilitate the availability of good quality limestone for FGD. This will ensure that there is enough supply of good quality limestone at low cost. Further, MoEF & CC should release guidelines for handling and storage of limestone and gypsum in power plants. Proper transportation, handling and storage practices need to be put in place to avoid fugitive emission like fly ash.

5. GYPSUM

Gypsum ($CaSO_4.2H_2O$) is a hydrated calcium sulphate used widely in industries due to its property of losing three-quarters of its water when moderately heated/calcined. This calcined gypsum can be moulded in various shapes during cooling. Gypsum is classified into three major categories based on its production method: a) natural, also called mineral gypsum; b) synthetic gypsum, a by-product of industrial processes; and c) marine gypsum.

Natural or mineral gypsum is extracted through mining. Marine gypsum is recovered from salt pans during the production of common salt. Synthetic gypsum is a by-product obtained through chemical process such as production of fertilizers. FGD gypsum is a unique synthetic by-product derived from FGD systems.

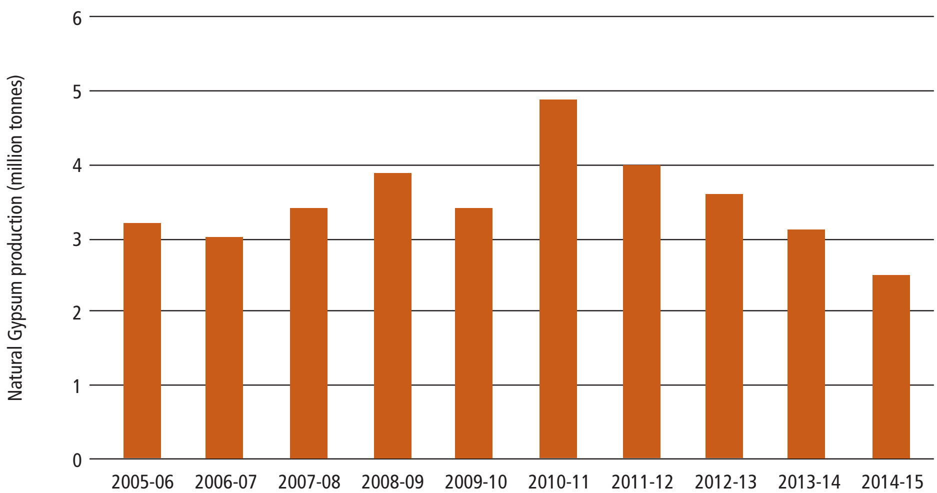
The cement industry is the dominant consumer of both mineral and synthetic gypsum. The chemical composition of the three categories of gypsum varies slightly, which in turn determines its use in various sectors (see *Annexure 4: Gypsum classification standards*).

5.1 PRODUCTION AND CONSUMPTION OF GYPSUM

The total global production of mineral gypsum in 2015 was about 268 million tonnes. China, the global leader, produced half of the world's gypsum (129 million tonnes). Most of the other major producers had shares of less than six per cent each. India's gypsum production in 2014–15 was 2.5 million tonnes, which was less than one per cent of the global total.[23]

Graph 3: India's gypsum production

Gypsum production has been decreasing, a worrying trend for the cement industry



Note: As per Government of India Notification S.O. 423 (E), dated 10 February 2015, 'gypsum' has been declared as 'Minor Mineral', hence the producers report the production data directly to the respective states and not to IBM.
Source: IBM, 2017

India is among the largest importers of gypsum in the world with annual imports of 3–5 million tonnes. Gypsum is mainly imported from Oman, Pakistan, Iran and Thailand. The other major sources to meet the demand include domestic mines, and synthetic and marine gypsum.

Rajasthan accounts for 82 per cent of the national gypsum deposit and Jammu and Kashmir accounts for 14 per cent; the rest is distributed among Tamil Nadu, Gujarat, Himachal Pradesh, Karnataka, Uttarakhand, Andhra Pradesh and Madhya Pradesh.[24] Rajasthan is the leading producer, contributing about 99 per cent of the total output. The remaining one per cent is contributed by Jammu and Kashmir.

IBM tracks only industrial sector consumption of gypsum. Hence, data is available only for that segment. About 10.3 million tonnes of gypsum in all forms was consumed in the organised sector in 2014–15. The respective share of natural gypsum, by-product gypsum and marine gypsum in total consumption during 2015–16 was about 58 per cent, 37 per cent, and five per cent. The cement industry was the largest consumer (99 per cent), using nearly all of the mineral gypsum and reported by-product gypsum. The balance was consumed by a variety of industries such as plaster of Paris, asbestos products, ceramics, fertilizers, refractories, textile, pharmaceutical, paint and chemicals. A portion of by-product gypsum generated from chemical industries is used by the agricultural sector but this consumption is not tracked by the IBM.

Table 9: Break-up of gypsum consumption in India

Cement sector is the dominant consumer of gypsum

Type of gypsum	Quantity (million tonnes)	Source	Consumed in
Mineral gypsum	5.9	From Rajasthan mines, imported from Oman, Pakistan, Iran and Thailand	Largely in cement and some in steel sector
Synthetic gypsum or by-product gypsum	3.8	From chemical plants such as fertilizer	Largely cement
Marine gypsum	0.5	Salt pans of Gujarat and Tamil Nadu	Largely cement
Total	10.31		99 per cent is consumed in cement sector

Note: Nearly 3–4 million tonnes of gypsum is imported. However, it is not clear whether it is mineral gypsum or synthetic gypsum.

Source: IBM, 2015

5.2 FGD GYPSUM

FGD gypsum is a by-product of the wet limestone FGD system, a result of the reaction of limestone with SO_2 in flue gases. It is important to note that the chemical composition of natural and FGD gypsum is quite similar (see *Table 10: Comparison of mineral gypsum vs FGD gypsum*). In fact, FGD gypsum has an even higher content of $CaSO_4.2H_2O$ than natural gypsum, particularly if higher quality limestone is used and the process parameters are maintained. Its quality makes FGD gypsum a valuable substitute of natural gypsum with large scale uses. Production of FGD gypsum can therefore reduce the need for mining gypsum and its related environmental impact.

Table 10: Comparison of mineral gypsum vs FGD gypsum

Due to comparable quality, FGD gypsum is substituting mineral gypsum across the world[24]

Parameter	Natural gypsum	FGD gypsum
Colour	White or colourless transparent	Yellow, nearly white or greyish black
Size	~140 um	30–60 um
Impurities	Clay, sand	Ash, calcium, carbonate, calcium sulphate and Mg, K, Na, Al etc.
SiO_2	1.34	1.5~6
Al_2O_3	0.14	0.1~2.2
Fe_2O_3	0.18	0.1~1.2
MgO	0.98	0.2~0
H_2O	19.69	15~21
$CaSO_4.2H_2O$	82.56	>=90

Source: Wang and Deng, 2015

With the implementation of FGD systems, India will produce around 12–17 million tonnes of FGD gypsum annually. Around 10 million tonnes of gypsum was consumed by the industrial sector in 2015–16, of which almost half was imported. The cement industry needs a large amount of gypsum (16–20 million tonnes of gypsum based on 330 million tonnes of cement produced in 2018–19) in its manufacturing and it is actually facing a gypsum shortage. Apart from imports, the sector is using inferior quality synthetic gypsum from the fertilizer industry. FGD gypsum can thus fulfil this shortfall both in quantity and quality.

Utilization of gypsum

Cement gypsum: Gypsum plays a crucial role in cement. It makes mortar or concrete more workable by keeping the cement in a plastic state at early stages of hydration. Gypsum also contributes to strength acceleration in early stages of hydration.[25] Synthetic gypsum has gained popularity in cement production across the world. China is utilizing a significant portion of its FGD gypsum in the cement and construction sectors.

Agricultural gypsum: Gypsum is a soluble source of essential plant nutrients like calcium and sulphur and can improve overall plant growth. Gypsum amendments improve the physical properties of some soils (especially heavy clay soils). It helps reduce erosion losses of soils and nutrients, and the concentrations of soluble phosphorus in surface water runoff.[26] FGD gypsum is being used in agriculture in US and China.

Gypsum boards: Gypsum board or drywall is essentially a board with a gypsum core and a paper facing. Being fire resistant, it is used as building material for wall, ceiling and partition systems in residential, institutional and commercial structures. Manufacturers are globally shifting towards FGD gypsum as an effective alternative to natural gypsum ore.

Utilization of FGD gypsum has been increasing across the world. It has replaced the use of mineral gypsum in many applications and comprises a significant share of total gypsum consumption. FGD gypsum's share is over 50 per cent in the US, where it is mainly utilized in wall board manufacturing. In China, FGD gypsum is mainly used by the cement sector and to improve alkaline soils. The growth of FGD gypsum generation and utilization has been extraordinary in China. China is able to utilize more than 70 per cent of its FGD gypsum.

5.3 REVENUE GENERATION FROM FGD GYPSUM

The revenue generated from FGD gypsum is dependent on the price of gypsum. Since a large quantity of domestic gypsum supply remains under the government, it also controls its pricing. Rajasthan State Minerals and Mines Limited (RSMML), a public sector enterprise of the state of Rajasthan, fixes prices regularly and these prices usually become the market price drivers. Prices of gypsum have remained stagnant over the years, ranging from ₹450–1,100 per metric tonne (see *Table 11: Basic sale price of gypsum to various industries from India's lone producer*).

Table 11: Basic sale price of gypsum to various industries from India's lone producer

RSMML largely controls the domestic mineral gypsum prices as it contributes 99 per cent of total production

From all mines/dispatch points	Basic sale price (₹)
Gypsum RoM for cement industry	515
Gypsum RoM for PoP industry	715
Gypsum RoM for gypsum board manufacturing industries	1,065
Gypsum board (loose)	775
Gypsum power (packed)	1,075

Source: RSMML, 2019

Since the supply of gypsum from RSMML is quite limited, the cement industry located across the country has to rely on other sources. Import pricing depends on the source of gypsum and the port of arrival; however, that is also aligned with RSMML selling price. Plants located near the sea can economically import gypsum. For plants located far away from the port transport costs can be high, which is why some cement plants use somewhat inferior quality chemical gypsum (phosphogypsum) from nearby fertilizer plants. As coal-based power plants are located across the country, transportation costs for FGD gypsum to the cement plants can be significantly lower if sourced from the nearest power plant.

Only a handful of units in India are currently operating limestone-based wet FGD. Therefore, FGD gypsum prices are not well established. However, one can safely assume that they would be in line with RSMML's mineral gypsum prices. Another proxy is the price of synthetic gypsum—various vendors are selling phosphogypsum online at ₹500–1,000 per tonne, based on the quality. Gypsum of 99 per cent purity is being sold at 1800/MT and Gypsum of 55–60 per cent purity is being sold at 750/MT.

Table 12: Annual revenue from gypsum sale for 500 MW unit

FGD gypsum can give significant revenue if proper market linkages are set up beforehand

	Limestone consumed (tonnes p.a.)	Gypsum generated (tonnes p.a.)	Sold to cement	Sold for gypsum board manufacturing	Sold to other industries / agriculture	Disposal (25 per cent)	Revenues (₹)
Conservative estimates*	32,000	54,400	(40 per cent of total) 21,760	(20 per cent of the total) 10,880	8,160 (15 per cent of the total)	136,000	2.61 cr.
Optimistic estimates**	32,000	54,400		(100 per cent) 544,000			5.44 cr.

**Based on price from RSMML mines*

*** Considering 100 per cent is sold to wall board and plaster board manufacturers*

Source: CSE, 2019

Based on the domestic demand scenarios and international end uses, we can estimate the potential revenue from the sale of FGD gypsum. We start from the analysis presented above (see *Table 8: Annual limestone requirement and cost for a 500 MW plant*) which estimated a 500 MW unit would use 32,000 tonnes of limestone annually. Under this scenario, the unit would produce 54–60,000 tonnes of gypsum per annum (see *Table 12: Annual revenue from gypsum sale for 500 MW unit*). This revenue model is based on China's experience of FGD gypsum utilization, which is around 75 per cent of their total FGD gypsum generation.

As per the IBM Working Group report, 'augmentation of infrastructural activities will engender growth of the cement industry, which will raise the consumption of gypsum and thereby its demand leading to increased dependence on imports and synthetic gypsum. FGD gypsum can play a crucial role in reducing imports.' Accordingly, we have projected that a major share of FGD gypsum will be sold to the cement industry.

Gypsum board manufacturing industry, which is presently in its nascent stage, could grow with appropriate encouragement, similar to its growth in developed countries. Gypsum is an excellent partition material because of its light weight and other characteristics and is a useful construction material for high-rise buildings. Gypsum is sold for wall board/plaster board manufacturing at much higher prices compared to the cement industry. Thus, earning can be much higher if those industures grow as projected in optimistic estimates (see *Table 11: Basic Sale price of gypsum to various industries from India's lone producer*).

Our analysis shows that a 500 MW coal-based generating unit could earn around ₹2–5 crore annually by selling FGD gypsum. This earning can offset the cost of limestone incurred in operating the FGD. Looking at wide applications and scarcity in India, full utilization of FGD gypsum can be achieved with proper market linkages. This will also eliminate environmental impact of gypsum disposal. Thus, MoEF & CC should direct power plants to utilize 100 per cent of FGD gypsum. Disposal guidelines may be given only for a short period of time.

6. RECOMMENDATIONS

Apart from providing cleaner air for all of us to breathe, FGD installations in India can be beneficial in other significant ways as well. Gypsum is a scare resource in India. India's mineral gypsum production has been decreasing and the country's reliance on imported gypsum has increased. FGD gypsum can significantly reduce this import burden. However, the following issues need to be addressed to achieve this:

1. BIS has specified broad specification guidelines for gypsum being used in the cement sector. In turn, BIS may also need to specify the quality of limestone being used in FGDs to ensure good quality FGD gypsum.

2. MoEF & CC should release guidelines for handling and storage of limestone and gypsum in power plants. Proper transportation, handling and storage practices need to put in place to avoid fugitive emission like fly ash.

3. MoEF & CC should direct power plants to utilize 100 per cent of FGD gypsum. Disposal guidelines should be given only for a short period of time.

4. The agriculture sector can also be a potential consumer of FGD gypsum in India. Gypsum is commonly used in non-nitrogen-based fertilizers. FGD gypsum has been determined safe for agricultural use through many studies. However, it is always prudent to set strict quality standards. Agricultural research organisations such as Indian Council of Agricultural Research should carry out field testing to ensure applicability of gypsum produced from Indian power plants.

ANNEXURES

ANNEXURE 1: FGD footprint in India

Power station	Capacity of the plant connected to FGD (MW)	Type of FGD	Technology supplier	Area of construction (sq. m)	Water consumption (cu. m/year)	Auxiliary power consumption (per cent)	Reagent used	Reagent consumption (kg/hr)
Tata Trombay	750	Seawater	Alstom	7,200	147,73,000	1–1.5	Seawater	–
Reliance Dahanu	500	Seawater	Ducon	Data not available	87,600,000–105,120,000	1.25	Seawater	–
Udupi TPP	1,200	Seawater	Ducon	10,000	306,600–350,400	0.5	Limestone	–
Adani Mundra	1,980	Seawater	Alstom	1,500	125,000–140,000	1.5	Seawater	–
JSW Ratnagiri	1,200	Seawater	Alstom	1,500 (scrubber alone)	Data not available	Data not available	Seawater	–
NTPC Vindhyachal stage V	500	Limestone	Alstom	10,000–20,000	613,200–876,000	1.1	Limestone	6,250
CLP India	1,200	Limestone	GE-Alstom				Limestone	
IL&FS Cuddalore	1,200	Limestone	Datong		36,500,000	1.9	Limestone	3,800
NTPC Bongaigaon	750	Limestone	BHEL/ Ducon	Data not available	Data not available	3.1	Limestone	Data not available

**FGD systems have been installed in NTPC's Bongaigaon unit in Assam and the IL&FS power station in Cuddalore, Tamil Nadu, however, they are yet to be commissioned and stabilized*

Source: Centre for Science and Environment, 2019

ANNEXURE 2: Assumptions for SO_2 estimations

Sulphur dioxide emissions were calculated based on vintage, size, coal consumption and sulphur content in the coal. Final emission were calculated based on units which will meet their respective standards by installing SO_2 control technology based on the reduction required. Ten per cent sulphur assumed to be trapped in ash based on CSE findings.

ANNEXURE 3: Grades of Limestone

Industry/grade	Standards
Cement	CaO (42 per cent) minimum, Phosphorous (<1 per cent) max, MgO (4 per cent) max.
Blast Furnace	CaO (44–46 per cent), MgO (4–8 per cent), SiO_2 (5–7 per cent) max.
Steel melting shop (SMS)	CaO (48–53 per cent), MgO (4 per cent) max.
Chemical	CaO (95 per cent)/ (50 per cent) min,
Sugar	CaO (80 per cent)
Glass	$CaCO_3$ (94.4 per cent), Total $CaCO_3$+$MgCO_3$ (97.5 per cent), SiO_2 (2.5 per cent)
Fertilizer	$CaCO_3$+$MgCO_3$ (85 per cent), SiO_2 (5 per cent)
Building	CaO (40 per cent) max, SiO_2 (10–20 per cent) min.

Source: http://geologydata.info/non_mettalic/limestone.htm

ANNEXURE 4: Gypsum classification standards

Characteristic	Type I	Type II	Type III	Type IV
Free water (maximum per cent)	1.0	-	1.0	-
Carbon dioxide (max mass per cent)	1.0	-	3.0	-
Silica, insoluble matter (max. mass per cent)	0.7	6.0	6.0	-
Iron and aluminium (max. mass per cent)	0.1	1.5	1.0	-
Magnesium oxide (max mass per cent)	0.5	1.0	1.5	3.0
Calcium sulphate dihydrate (mass per cent)	96.0 (min)	85.0–90.0	85.0 (min)	70.0–75.0
Chlorides (max. mass per cent)	0.01	0.003	0.1	0.5
Industry usage	Surgical plaster	Fertilizers	Pottery, building	Cement

Source: BIS, 2003

ANNEXURE 5: Key power station/clusters and nearby limestone deposits

Major limestone deposit	Limestone production (MTPA) (2014–15)	Nearest power station/cluster	Limestone state	Power station/ cluster state	Distance (km)	Capacity of thermal power (MW)
Sonebhadra	2.95	Singrauli	Uttar Pradesh	Madhya Pradesh	125	6,680
Katni	5.58	Anuppur	Madhya Pradesh	Madhya Pradesh	168	1,410
Satna	17.89	Sidhi			163	3,960
Katni	5.58	Umaria			98	1,340
		Betul			410	1,330
		Seoni			110	600
Neemuch	4.53	Khandwa			413	1,200
Renukut (Sonebhadra)	2.95	Sonebhadra	Uttar Pradesh	Uttar Pradesh	39	9,680
Chandrapur	9.25	Chandrapur	Maharashtra	Maharashtra	15	5,380
		Amravati			248	1,350
		Gondia			228	3,300
		Jalgaon			472	1,420
		Nagpur			171	7,376
		Nashik			686	1,170
Bilaspur	19.82	Korba	Chhattisgarh	Chhattisgarh	99	6,975
		Janjgir Champa			169	4,120
		Raigarh			169	4,363
		Raipur			113	1,370

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Major limestone deposit	Limestone production (MTPA) (2014–15)	Nearest power station/cluster	Limestone state	Power station/ cluster state	Distance (km)	Capacity of thermal power (MW)
Bilaspur	3.57	Bathinda	Himachal Pradesh	Punjab	296	1,360
		Tarn Taran			248	
		Rupnagar			85	1,260
		Mansa			294	1,980
		Patiala			160	1,400
		Hisar		Haryana	304	1,200
		Panipat			294	920
		Jhajjar			405	2,820
		Yamunanagar			225	600
Gulbarga	20.1	Raichur	Karnataka	Karnataka	173	3,320
		Bellary			302	2,560
Bagalkot	3.53	Mangaluru			474	1,200
Kutchh	8.67	Kutchh	Gujarat	Gujarat		9,160
		Jamnagar			324	1,940
		Sabarmati			415	
Amreli	5.57	Sabarmati			252	1,270
		Bhavnagar			118	500
		Kheda			238	1,470
Junagadh	7.24	Bhavnagar			209	
		Jamnagar			157	1,940
		Surat			550	600
		Tapi			575	1,350
Nalgonda	14.79	Warangal	Telangana	Telangana	144	750
		Paloncha			223	1,200
		Karimnagar			216	1,760
		Khammam			133	3,040
		Mancheriyal			297	1,050
		Vijaywada		Andhra Pradesh	213	3,820
		Vizag			557	1,320
Cudappah	10.28	Cuddapah	Andhra Pradesh	Andhra Pradesh		2,370
		Nellore	Andhra Pradesh	Andhra Pradesh	178	3,500
		Krishnapatnam	Andhra Pradesh	Andhra Pradesh	187	1,440
Ariyalur	10.94	Cuddalore	Tamil Nadu	Tamil Nadu	126	2,070
		Tiruvallur			298	3,550
		Salem			207	1,080
		Neyveli			90	2,320
		Tuticorin			360	1,200

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Major limestone deposit	Limestone production (MTPA) (2014–15)	Nearest power station/cluster	Limestone state	Power station/ cluster state	Distance (km)	Capacity of thermal power (MW)
Sirohi	12.02	Barmer	Rajasthan	Rajasthan	250	1,240
Chittorgarh	18.06	Baran			267	1,500
		Jhalawar			222	750
		Kota			164	1,200
Pali	17.75	Ganganagar			543	1–760
		Bikaner			300	250

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Thermal power stations must control sulphur dioxide pollution to comply with the 2015 environmental norms stipulated for them.

The discussion, however, has so far been restricted on the question of selection of suitable technology. Issues related to operations—particularly the suitability of specific technology options—sourcing of raw material, and the utilization of suitable by-products of the process have not been considered so far.

This publication attempts to address this gap by showing that procurement of limestone for wet flue gas desulphurization (FGD) will not be a major problem. It also highlights the utility of the by-product emanating from the process, called FGD gypsum, and its potential uptake in India.

Centre for Science and Environment
41, Tughlakabad Institutional Area,
New Delhi 110 062 Phones: 91-11-40616000
Fax: 91-11-29955879 E-mail: cse@cseindia.org
Website: www.cseindia.org