SO_2 CONTROL AND TIMELINE FOR FGD INSTALLATION

DECONSTRUCTING THE MYTHS

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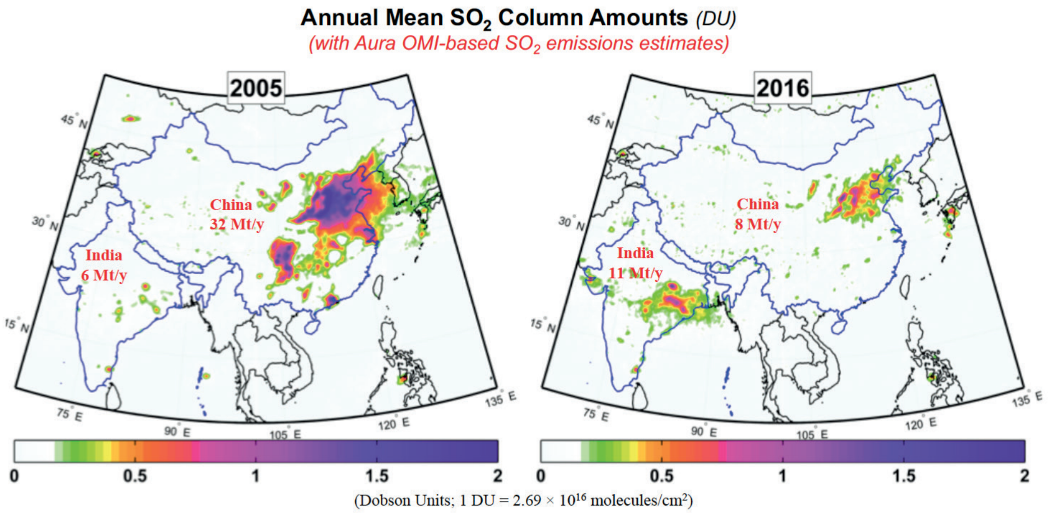
Sulphur dioxide (SO_2) is a toxic air pollutant that causes acid rain, haze and many serious health problems.

According to a University of Maryland (UoM) study, India has overtaken China as the world's largest emitter of anthropogenic SO_2 despite China's far larger industrial activity and coal use. This scenario has arisen due to a lack of effective control measures in India (see *Figure 1: Comparison of Emission between India and China*).[1]

Figure 1: Comparison of emission between India and China



Source: Scientific Reports, 2017.

The largest source of SO_2 emissions is combustion of fossil fuel at power plants (73 per cent) and other industrial facilities (20 per cent)[2]—this is also verified by satellite imagery released by the UoM study (see *Figure 2: India's SO_2 concentration between 2005 and 2016*).[3] India's installed capacity of coal-based power is 197 GW (as on 31 March 2018). The actual generation of electricity by coal-based power stations during FY 2016–17 was 910 BU.[4] Assuming an SO_2 emission factor of 8 g/kWh,[5] the SO_2 generated during the period was approximately 7.28 million tonnes.

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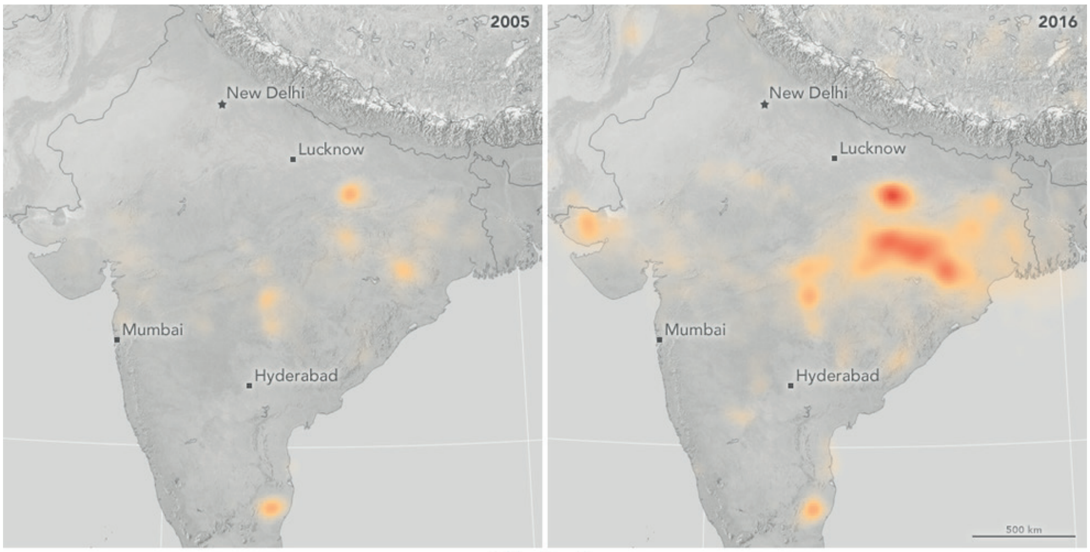
Figure 2: India's SO_2 concentration between 2005 and 2016

Concentration has increased in areas with coal-based power stations installed



Source: NASA, 2017.

Indian government emission standards

The Ministry of Environment, Forest & Climate Change (MoEF&CC) notified new emission standards for coal-based power stations on 7 December 2015 under the Environment (Protection) Act, 1986. Standards for the different types of power plants were laid out based on their age and unit sizes for three key pollutants—PM, SO_2 and NO_x (see *Table 1: SO_2-emission standards*)

Table 1: SO_2-emission standards

Parameter (mg/Nm³)	Unit size (MW)	Installed before 31 December 2003	Installed between 2004 and 2016	Installed 1 January 2017 onwards
SO_2	< 500	600	600	100
	>= 500	200	200	100

Source: MoEF&CC

With the rising economic growth in India, energy needs have increased exponentially. This has resulted in additional demand for power, fulfilled mostly by coal-based thermal power-generating units. The resultant increasing pollution burden on the environment makes implementation of the standards crucial.

Emission-control technology

Indian coal contains sulphur in the range of 0.2–0.7 per cent by weight. With this sulphur content, it is estimated that coal-based power plants in India emit SO_2 in the range of 800–1,600 mg/Nm³.[6]

SO_2 emission can be controlled at three stages:

I. **Pre-combustion**: Sulphur content in the coal can be reduced through coal washing;

II. **During combustion**: Injecting sorbents in the boiler (CFBC); or

III. **Post-combustion**: Flue gas desulphurization (FGD) system or dry sorbent injection (DSI) technology can be used for flue gas treatment.

Flue gas desulphurization (FGD) system is a control device used by coal-fired power plants across the world to remove SO_2 from exhaust gases from the boiler using an alkaline reagent. After the SO_2 is removed, the flue gas is released into the atmosphere. The first FGD system was installed at Battersea

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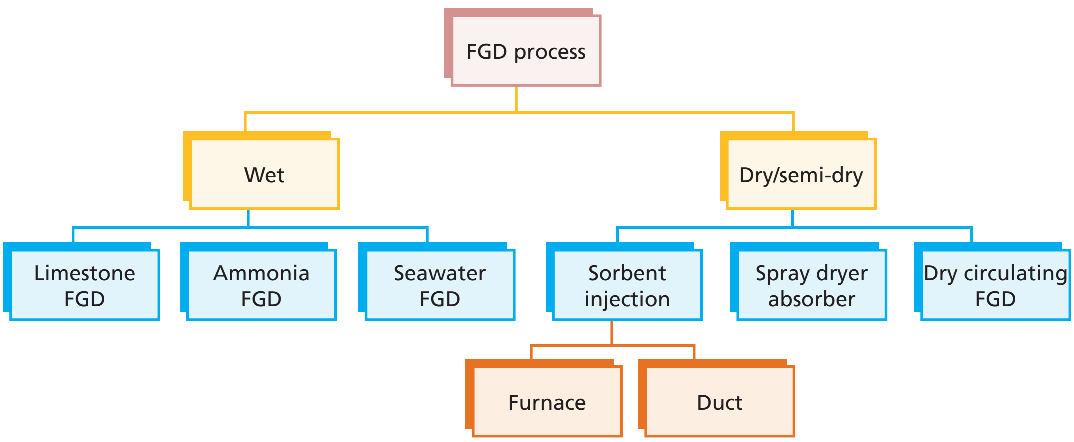
Power Station of London Power Company in the 1930s.[7] FGD is a mature technology with a large number of installations across USA, Europe and China.

There are two main types of FGD systems (see *Figure 3: Different FGD processes*):

a) **Wet FGD process:** Most FGDs installed across the world are of this type, with an SO_2 removal efficiency of more than 90 per cent. Based on the reagent, wet FGD process is further divided into three subcategories:
   i. Seawater-based FGD
   ii. Ammonia-based FGD
   iii. Limestone-based FGD

b) **Dry and semi-dry FGD process:** This includes sorbent injection in the furnace or duct using sodium/calcium bases reagent, and spray drier absorber (SDA) technology using slaked lime or limestone as reagent.

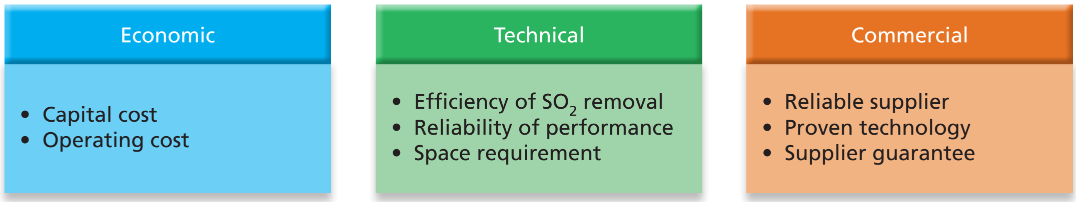
Figure 3: Different FGD processes for coal-based power stations



Selection of SO_2-control technology

Selection of a suitable SO_2-control technology is important for power stations and should be based on three aspects—economic, technical and commercial (see *Figure 4: Aspects of FGD selection*). In India, 4.6 GW of 8.7 GW capacity of FGD installed opted for wet limestone-based FGD (WLFGD), while the balance (i.e. coastal plants) opted for seawater-based FGD.

Figure 4: Aspects of FGD selection



WLFGD is techno-economically feasible for inland power stations, while ammonia-based FGDs are not very popular because the reagent (ammonia) is considerably more expensive and hazardous than limestone. There is a risk of ammonia slip, i.e. ammonia releasing into the atmosphere without any reaction taking place in the FGD system, which is a major environmental concern. Hence limestone-based wet FGD is a preferred option because the reagent is easily available, inexpensive and can be easily handled (see *Table 2: Comparison between various SO_2 removal systems*).

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DSI system

For small power-generation units (<= 250 MW), a removal efficiency of 50–60 per cent is sufficient to meet the norms especially when SO_2 emissions are in the range of 800–1,000 mg/Nm^3. In such a case, dry sorbent injection (DSI) systems can suffice. DSI uses calcium-based (calcium hydroxide) or sodium-based (sodium bicarbonate) sorbent to remove SO_2. DSI provides a feasible alternative for units that would not find it cost-effective to invest in a wet or dry FGD system. Also, erection and commissioning period is around one year. Sorbent injection generates extra dust loads on electrostatic precipitators (ESPs), thus necessitating some level of retrofits. Appropriate action for ESP should therefore be undertaken simultaneously (see *Figure 5: DSI system*).

Figure 5: DSI system

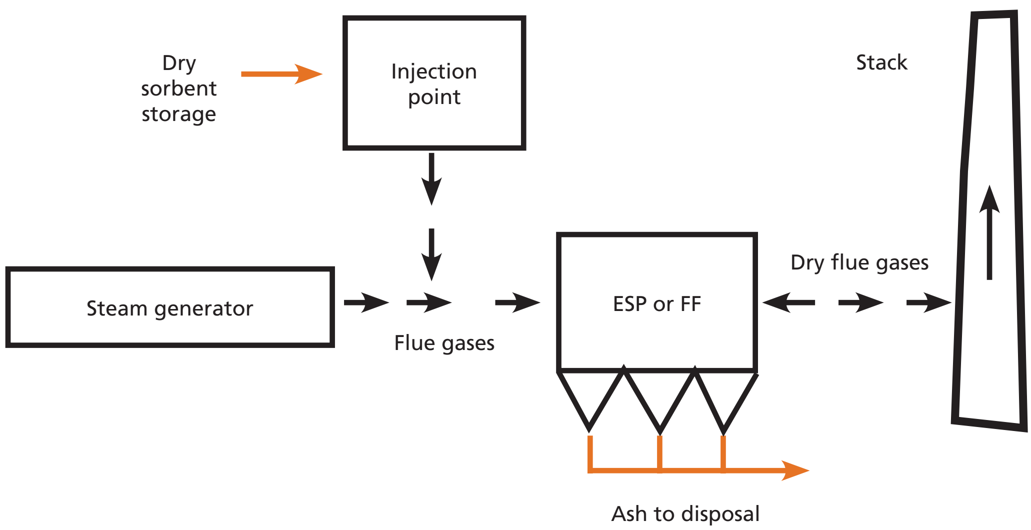

Table 2: Comparison between various SO_2 removal systems

Description	Limestone—wet FGD	Ammonium—wet FGD	Seawater—wet FGD	Direct sorbent injection (DSI)
Reagent used	Limestone	Ammonia	Seawater	Sodium bicarbonate, calcium hydroxide
SO_2 removal efficiency	>95%	>99%	90–98%	50–60%
Byproduct	Gypsum	Ammonium sulphate (fertilizer)	None	Non–saleable product
CO_2 production	Yes	No	No	Depends on reagent
Wastewater	Yes	Negligible	Yes	Nil
Hazardous material	No	Yes (Ammonia)	No	No

Wet limestone FGD system operation

Wet limestone-based FGD plants consist of the following four main process systems:

I. Flue gas handling system
II. Reagent (limestone) handling and preparation system
III. Absorber and oxidation system
IV. Secondary-water and gypsum-handling system

The most important part of any FGD system is a tank, the absorber, where flue gas coming out of coal-fired boiler mixes with limestone slurry. Flue gas from the ESP enters the absorber at the bottom, while limestone slurry enters the absorber from the top, and both move in the counter-flow direction. In this process, SO_2 is removed from flue gas in the form of gypsum, a byproduct (see *Figure 5: Overview of wet limestone-based FGD process*).

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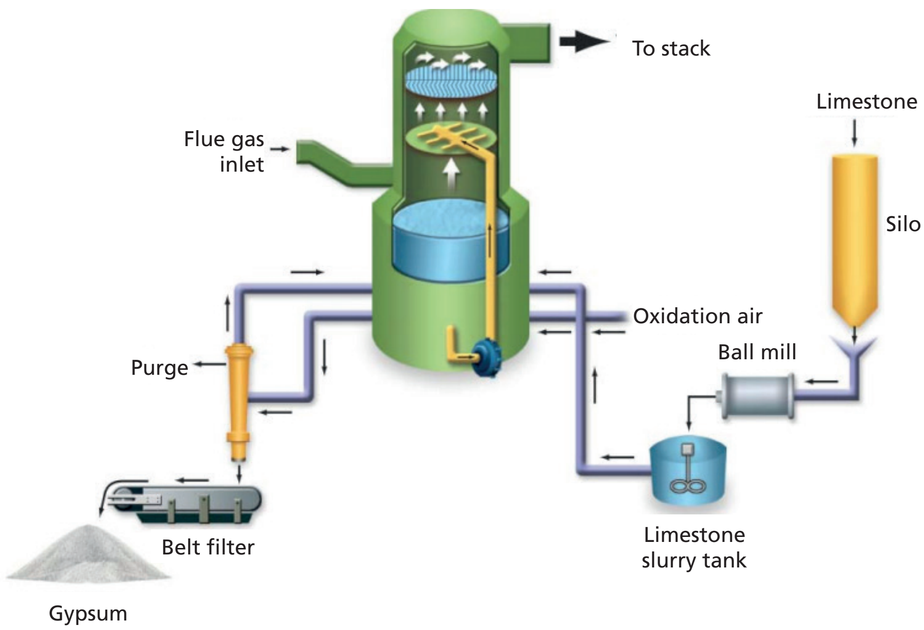
Figure 5: Overview of wet limestone-based FGD process



Source: Marsulex

The overall reaction in the absorber is:

$$SO_2 + CaCO_3 + \frac{1}{2}O_2 + H_2O \rightarrow CaSO_4.2H_2O + CO_2$$

Sulphur dioxide + Limestone + Oxygen + Water → Gypsum + Carbon dioxide

Installation stages for FGD

The FGD installation timeline varies between 18 and 24 months with major steel works fabricated at the installation site. A typical timeline for installation of WLFGD, right from civil foundation works to its operation, is shown in *Annexure I: Milestone report for method of SO_2 control*. The critical parameters for operation and, consequently, design of WLFGD system include density of limestone slurry, pH, SO_2 removal efficiency and flue gas temperature.

Commissioning of FGD can be divided into six broad stages:

I. Trial of electrical motors at no load

II. Commissioning of the following equipment:
- Absorber recirculation pump
- Ball mills for limestone crushing
- Vacuum belt filter and hydro-cyclone
- Oxidation blower
- Gas-to-gas heater (GGH)
- Mist eliminator
- Agitator

III. Cold commissioning—System trial with water

IV. Commissioning of FGD inlet, outlet and bypass damper

V. Checking of interface between boiler and FGD

VI. Hot commissioning—System trial with limestone slurry

Contrary to popular perception, there are several FGD suppliers present in India. There were more than thirty bidders to NTPC's recent tender. Most of them are foreign entities or Indian companies collaborating with foreign entities (see *Annexure 2: Timelines for installation of major WFGD systems*). Necessary building material and raw material are also available domestically. Competition among multiple bidders can be useful to bring the costs of FGD systems down further. Capital cost for installation of limestone-based FGD has reduced to around Rs 20 lakh/MW in auction processes (see *Table 3: Facts about limestone-based FGD*).

Table 3 : Facts about wet limestone-based FGD for a 500 MW unit

Description	Unit	Reality
Capital cost	lakh/MW	20*– 40 lakh/MW
Construction period	Months	18–24 months
Auxiliary power consumption	%	1–2 %
SO_2 removal efficiency	%	>95%
Water consumption	m^3/MWh	0.08–0.2
Sp. area requirement	m^2/MW	21–28
Shutdown time	Months	0.5–1
PM reduction	mg/Nm^3	10–15

**GE awarded bid for NTPC-Telangana STPS (2 × 800 MW)*

Limestone demand and gypsum utilization

Limestone is the major raw material for FGD. The $CaCO_3$ content in limestone has to be at least 90 per cent by weight. Its quality affects the efficiency of SO_2 removal as well as quality of gypsum-FGD system byproduct. The requirement of limestone depends on the sulphur content in coal, efficiency of SO_2 removal and quality of limestone used. The quantity of gypsum produced in the FGD system is usually 2–2.5 times of limestone used. The cement industry requires gypsum's purity to be a minimum of 70 per cent by weight and to have a pH of 5–7.

Availability of limestone is not an issue in India. The production of limestone stood at 313 million tonnes during FY 2016–17, an increase of 2 per cent over the previous year.[8] Rajasthan was the leading producer (21 per cent), followed by Madhya Pradesh and Andhra Pradesh (11 per cent each), Chhattisgarh and Karnataka (10 per cent each), Gujarat, Tamil Nadu and Telangana (8 per cent each). The total limestone reserves (proved and probable) in India are 16,335 million tonnes.

Gypsum produced from the FGD process, depending upon its quality, has great utility across several sectors. Its uses include:

i. **Cement industry:** India is the second largest producer of cement in the world. In 2016–17, total installed capacity was 502 million tonnes and production was estimated to be 153 million tones.[9] Cement plants utilize gypsum of around 4–5 per cent by weight of quantity of cement produced.

ii. **Ash-brick manufacturing:** Gypsum (5 per cent) is used along with fly ash (70 per cent), lime (10 per cent) and sand (15 per cent) in the manufacturing of fly ash bricks.[10] Gypsum use purity should be 80 per cent. However, in case of variation in purity, percentage of gypsum in the mix can be adjusted to obtain the desired quality of bricks.

iii. **Gypsum board:** Gypsum board is a premier building material for wall, ceiling and partition systems in residential, institutional and commercial buildings and is designed to provide a uniform surface. One principal advantage of gypsum board over plywood, hardboard and fibreboard is its strong fire resistance.

iv. **Agricultural land improvement:** Gypsum (sometimes called land plaster) can be used as a soil additive to improve soil's workability and receptivity to moisture and to overcome the corrosive effect of alkalinity.

Data on FGD gypsum use from other countries indicates significant demand from several industries. According to a 2016 American Coal Ash Association (ACAA) survey, FGD gypsum use in the United States was around 17 million tonnes. The gypsum board industry was the largest consumer of this gypsum, using 34 per cent of the total annual production (9 million tonnes). This amounted to

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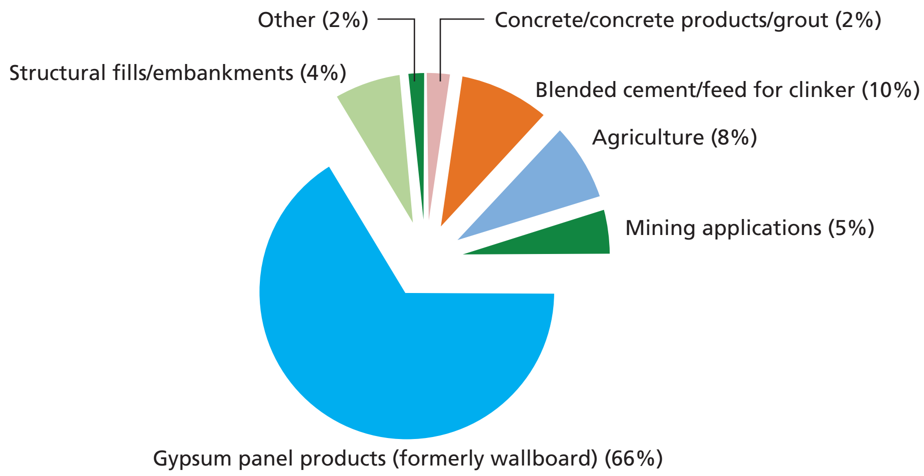
approximately 25 per cent of the wallboard industry's demand. Another 10 per cent was utilized by the cement and clinker industry (3 million tonnes), which amounted to 45 per cent of the cement industry's gypsum demand (see *Figure 6: Major uses of FGD gypsum in the US*). Europe also is a major consumer of FGD gypsum—its utilization by their construction industry totalled 8.3 million tonnes in 2013.[11]

Figure 6: Major uses of FGD gypsum in the US

Gypsum is largely used for wallboard manufacture



Source: ACAA, 2017.

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Annexure 1—Milestone report for method of SO_2 control

Table 1.1: Wet limestone-based documentation and procurement

S. no.	Major milestone	Start month	Stop month	Months taken	Remarks
1	Letter of Award (LoA)	1	1	0	Documentation
2	Basic and detail engineering	1	5	5	
3	Procurement	5	7	3	Equipment mobilization to site

Table 1.2: Wet limestone-based FGD construction

S. no.	Major milestone	Start month	Stop month	Months taken	Remarks
1	Civil foundation	1	7	7	Construction period
2	Electrical and C&I work	4	15	12	
3	Equipment erection	2	17	16	
4	Trial operation	18	23	6	
5	Performance guarantee test	23	24	2	

Table 2.1: Direct sorbent injection (DSI) method

S. no.	Major milestone	Start month	Stop month	Months
1	Letter of Award (LoA)	1	1	0
2	Planning and detail engineering	1	3	3
3	Civil foundation	4	6	3
4	Equipment erection	6	11	6
5	Trial operation and PG test	11	12	1

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Annexure 2: Timelines for installation of major WFGD systems

Timelines for 500 MW	Erection sequences																							
	Year 1												Year 2											
Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Activities																								
Start and completion of Construction	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Civil foundation		■	■	■	■	■	■	■																
Temporary power supply								■	■	■														
Absorber foundation		■	■	■	■																			
Unloading hoppers			■	■	■																			
Limestone handling system						■	■	■	■															
Limestone silo								■	■															
Duct foundation				■	■																			
Gypsum De-watering house			■	■	■	■	■	■	■	■	■	■	■											
FGD control room										■	■	■	■	■	■	■	■							
GGH erection					■	■	■																	
Cable tray								■	■	■	■	■												
RC pump house								■	■	■	■	■												
SO_2 analyser room					■	■	■	■																
Duct support and installation				■	■	■	■	■	■															
Slurry piping installation										■	■	■	■	■	■									
Other piping													■	■	■									
Steam piping															■									
Instrument air																■	■							
Valves installation													■	■	■	■								

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Timelines for 500 MW	Erection sequences																							
	Year 1												Year 2											
Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Power supply											■	■	■	■	■	■	■							
Equipments installation								■	■	■	■	■	■	■	■	■	■							
Booster fan							■	■	■	■	■	■	■											
Construction of tanks					■	■	■	■	■	■	■	■	■											
Absorber erection				■	■	■	■	■	■	■	■	■	■											
Absorber internals installation														■	■									
Flake/rubber lining																■	■							
Electrical work and panels installation					■	■	■	■	■	■	■	■	■											
Instrumentation												■	■	■	■									
Painting and insulation														■	■	■	■							
Internal inspection															■	■	■							
Dismantling of temporary supports and scaffolding																■	■							
Individual trial run of equipments																		■	■					
Flue gas in and check																				■	■	■	■	
Total trial run and tuning of parameters																								■
Start operation and synchronization																								■
Handover																								■

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