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Impact of coal mining on vegetation

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Abstract
Coal, for the previous few decades has been the most important source of energy and shall continue to be in the near predictable future. With an overwhelming dependence of almost all major industries on coal, coal mining, extraction is predicted to expand manifolds in the years to come. Coal mining and its allied activities like its transportation, washing etc have numerous prejudicious effects on the environment but the greatest brunt is borne by the vegetation in the adjoining areas, the first and foremost being the clearance of vast forest tracts to set up mining infrastructure resulting in significant losses to vegetation cover and disturbance of the biodiversity. The plants growing in and around the mining areas exhibit a general poor health with visible injury as well as loss of foliage, stunted growth, reduced leaf area. In physiological terms they exhibit higher phenol concentration in their leaves, higher rate of transpiration and reduced photosynthetic rate. The local flora is also threatened by exotic species invasion, which with their numerous competitive advantages often disturb the local floristic composition. Although these adverse effects on vegetation are a matter of serious concern, exhaustive studies have not been conducted in this regard.

Keywords: coal mining, deforestation, cover, morphology, anatomy, physiology, biodiversity

Introduction

With a contribution of 38 % to the world's total electricity, Coal is a reliable and affordable source of energy in several countries. Its varied usage in several industries ranging from iron and steel industry, cement industry as well as the chemical industry coupled with its abundant reserves and high rates of production make it a reliable and affordable source of energy. Coal mining has fed many industries resulting in economic growth, upward financial mobilization of the people employed directly in those industries as well in the neighboring areas and a better living condition in terms of the material comforts but it impacts on the environment such as Acid Mine Drainage, air pollutants containing sulfur dioxide, nitrogen oxides, particulate matter and heavy metals are severely damaging. The extraction of coal at the mining site, its processing and its transportation to a power station distresses the environment [2].

Unplanned mining activities result in a myriad of problems ranging from soil erosion, pollution, surface subsidence, formation of sinkholes, soil degradation, loss of soil nutrients, ecosystem degradation, landscape damage, loss of biodiversity, heavy metal and organic contamination of water and soil. Coal dust and Coal Combustion Waste which is the nation's second largest waste stream after municipal solid waste, is dumped in pits and leads to leaching out of the toxic substances and polluting the water and soil in the surrounding areas. Thus coal mining very adversely affects the biological communities thriving in the nearby areas.

Vegetation refers to the plant cover of the Earth, displays patterns that reflect a wide variety of environmental characteristics as well as temporal aspects operating on it (Kumi- Boateng and Issaka, 2012). Despite being of great biological and environmental importance, 0.618 million acres of vegetation in India, is under tremendous threat in mining areas where surface mining and illegal small mining activities are rampant. The aforementioned impacts can directly or indirectly affect and harm the growth of the vegetation around mining areas. Since release of large amounts of carbon during mining operations is mitigated by vegetation around the mining areas, a damaged vegetation can result in the leakage of substantial carbon to the atmosphere which further weakens the overall carbon sink effect of the vegetation and aggravates the harmful environmental impacts of mining.

Vegetation is therefore a key factor to be considered during the analysis and evaluation of the ecological and environmental studies in the mining area and is also crucial for maintaining the environmental stability and carbon sequestration ability of the mining area. The effects mining has on vegetation are complex, depending on the type and intensity of mining as well as via indirect impacts on other local environmental factors, such as groundwater and soil. Usually the construction of the coal field and the landscape changes that occur due owing to the new surface infrastructure inflict greater damage on the vegetation than during the actual coal production from underground mining. Construction of infrastructural facilities on surface for mining, beneficiation, housing and other activities take a heavy toll of forest wealth. Coal extraction leads to degradation of land, addition of pollutants to air and water, deforestation, and civic environment.

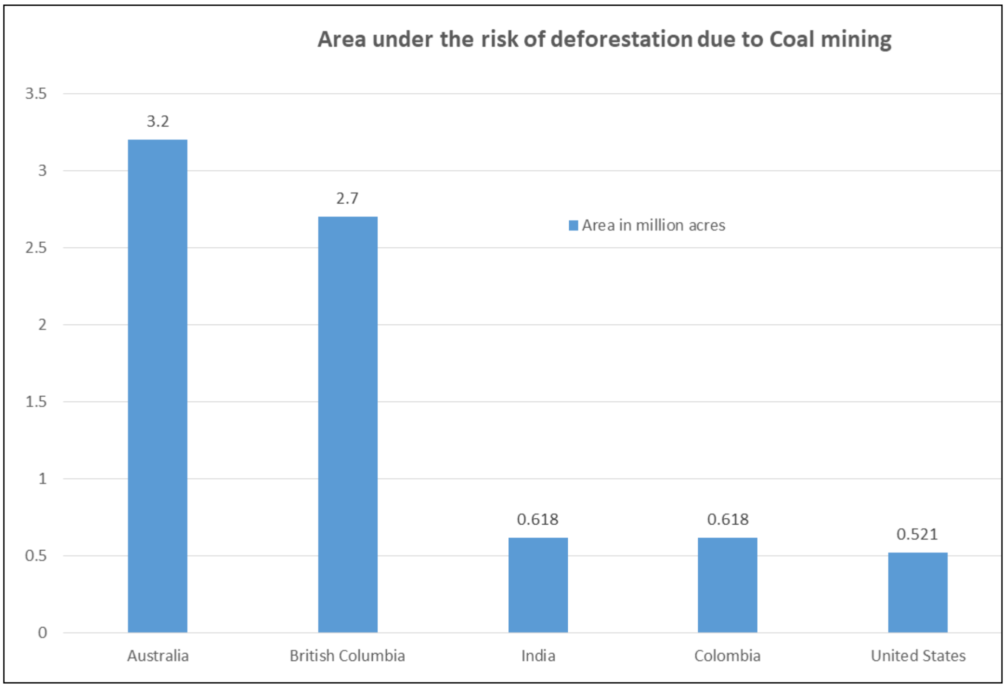

Fig 1: Area under the risk of Deforestation due to Coal Mining, UNFCC's report Double Jeopardy: Coal's threat to Forests, 2015

The first and most remarkably visible impact of mining operations in forested areas is the clearance of vast forest tracts which alters the food availabilities and wildlife habitat. Kumar and Pandey (2013) [6] studied that in some of the coal mines, the forest cover is completely lost to the mining enterprises. The settlement of coal dust on foliage which affects the growth of plants. Further, the pollutants can also affect the physiological and metabolic state of the plants by affecting stomatal structure and function, structure and activity of photosynthetic pigments, other enzymes and production of reactive oxygen species.

Right from its excavation to loading and unloading, coal produces dust and radiation which have a direct negative impact on the ecology, biodiversity, and health of the surrounding communities [3]. Activities like drilling, blasting, sizing, and transportation cause release of total suspended particulate (TSP) matter and inhalable particulate matter (PM10) which are the main players behind air pollution in and around the mining zone [1]. The habitat diversity in the coal mining areas of Bokaro, Jharkhand and came to a conclusion that while intact forests may be resistant to the impacts of mining and development, fragmented forests may find withstanding such invasions difficult [7]. Yet this aspect remains grossly under reported. Associated infrastructure developmental activities like construction of roads and new pipelines routes lead to habitat fragmentation and open up the remote areas for accessibility.

Remote sensing technology affords a viable means of analyzing the changing land use pattern at mine sites located at inaccessible places. The information generated from this technology provides reliable data which can be used for environmental compliance and evidence during litigation. With the advent of space borne remote sensing techniques it has become possible to get a synoptic coverage of a larger area, at cost effective and repetitive manner which is extremely useful.

Impact on Vegetation

Vegetation Cover

The first, foremost and the most visible impact of Coal Mining is on the vegetation cover. Setting up of a mine and the infrastructure supporting it requires clearing of vast areas of land. Among the different kinds of land cover changes, deforestation has received greatest scientific attention as it has been shown to be associated with alteration in species distribution, carbon sequestration potential, hydrological regimes, and climate change among others (Townsend *et al*. 2008). According to the Ministry of Coal (MoC), about 60% of coal resources are located in the forest areas (MoC, 2005). Most newly allocated coal blocks in the last few years have been in or near forest areas. 28% of all the coal leases acquired by Coal India lay under forest region, ie, out of which 2 00 000 ha are coal leases and 55 000 ha lay under forest cover (Greenpeace Report, 2012) [17].

As per Ministry of Coal estimates, keeping in view the rising demand the need for forestland for mining will increase from about 22 000 ha in 2005 to 75 000 ha by 2025. In Angul-Talcher region in Odisha, for instance, forest cover has reduced by 11% between 1973 and 2007 due to coal mining (Singh, 2010). Pandey and Kumar (2013) in their studies have concluded that the spatio-temporal landuse / land cover changes in South Karanpura coal mine and its surrounding areas during the period from 1992 to 2009 have witnessed substantial losses in vegetation cover. Land use/ land cover maps for the year 1992, 2004 and 2009 generated through the visual interpretation of ETM and IRS-1D LISS-III satellite images with selective field checks identified substantial changes over agricultural land, coal mining area and forests. The study revealed that area under coal mining expanded from 10.06 sq. km in 1992 to 21.29 sq. km in 2004 and reduced to 19.40 sq. km by the year 2009 due to reduction of coal reserve and decline in the coal production indicating 92.84% area increase in coal mining induced land use changes. The most significant losses were borne primarily by forests which lost around 71.85 % of their area and croplands which witnessed a loss of around 38.67%

Thus, a detailed knowledge of land use practices is essential to understand the land use pattern, its dynamics and implications for the management and planning of land, as well as policy making and infrastructure developmental initiatives

Impact on Biodiversity

Mineral resources often exist in significantly biologically diverse areas, and conservation priorities [16] and tensions between mining and conservation are expected to intensify with a growth in human populations and technological advancement [7, 8]. With this realisation, concerns regarding biodiversity in and around the mining sectors now features as a central agenda item in intra-governmental discussions for a post-2020 Strategic Plan for Biodiversity [9, 10].

Although Coal extraction has traditionally been seen as a temporary and spatially limited perturbation to ecosystems (2), even localized damage to biodiversity can have large cascade effects on ecosystem function and productivity. Although it is often assumed that legally mandated restoration after extraction (which includes drilling and all forms of mining) will return an area to close to its pre disturbance state, it seldom happens. Extraction activities have therefore been considered trivial disruptors of natural systems as compared to other human activities, such as agricultural land clearing [5].

Direct effects include local habitat destruction and fragmentation, visual and noise disturbance, and pollution (14). Indirect effects can extend many kilometers from the extraction source and include human expansion into previously wild areas, introduction of invasive species and pathogens, soil erosion, water pollution, and illegal hunting [14]. In combination, these factors lead to decline in populations and changes in community composition

Coal mining affects both the qualitative as well as the quantitative parameters of species distribution. Therefore on a large scale, the mining can change the biodiversity by influencing the species composition. Malviya *et al* (2010) studied the habitat diversity in the coal mining areas of Bokaro, Jharkhand and concluded that while intact forests may be resistant to the impacts of mining and development, fragmented forests are less likely to withstand such invasions. The associated infrastructure developmental activities like construction of roads and new pipelines routes lead to habitat fragmentation and open up the remote areas for accessibility. The areas in closer proximity to the coal fields or sites / industries / power plants generating coal dust have been observed to exhibit poorer ecological health with clear evidences of mass mortality.

FRAGSTATS is a computer software program which is designed to compute a wide variety of landscape metrics for categorical map patterns and using it, a spatial diversity map was generated for the concerned study area. The diversity metrics computed by FRAGSTATS are not affected by the spatial configuration of patches. Shannon diversity index (SHDI) can be used as a relative index for comparing landscapes over time. The Shannon diversity index is commonly used to characterize species diversity in a community. It takes into consideration both abundance and evenness of the species present.

SHDI values start from 0 which mean that the landscape is composed of only one patch or no diversity. In the studies conducted by Malviya *et al*, Shannon Diversity Index increased from 1.67 in 1972 to 1.71 in 2006 which indicates greater diversity over time or more fragmentation of landscape in time. Shannon Evenness Index (SHEI) is a measure of evenness of patch type and ranges from 0 to 1. Values closer to 0 indicate unevenness or greater diversity while 1 indicates that the landscape is highly even being dominated by one patch type. The SHEI values decreased from 0.86 in 1972 to 0.71 in 2006, thus indicating higher observed diversity in time.

Table 1: Changes in various aspects of biodiversity

S.No	Aspect	Effect	References
01.	Lichen *(Graphis, Lecanora perplexa, Hyperpphyscia adglutinata, Pyxine subcinerea)*	Decrease in quantitative parameters like Frequency, Density and Abundance of species	Charak *et al* (2009) Study site - Moghla mines, Rajouri [J&K
02.	Shannon Diversity Index [SHDI]	Shannon diversity index has increased from 1.67 in 1972 to 1.71 in 2006 - indicates greater diversity over time or more fragmentation of landscape in time	Malaviya *et al* (2009) Study site – Coalfields around Bokaro, JH
03.	Native Floristic Composition	Increased growth of non-native weeds, persistent, often competing with native species Loss of Sal forests, fragmentation of patches	Singh, Shashikant, 2007 Study Site – Kalakote Coalfields, J&K Malaviya *et al*, 2009

Impact on Morphology and Anatomy

By incorporating several generalized morphological characteristics of plants it is possible to estimate the likely effects of Coal mining on vegetation and thereby the environmental risks associated with proposed dust and other pollutant generating activities such as coal extraction, its piling, transportation and the ash generated by its burning [26]. There is often a decrease in the total number of leaves developed per plant, together with a greater degree of defoliation, indicating that coal-smoke pollutants inhibited the production of leaves and stimulated the formation of abscission layers leading to a premature leaf fall [25].

The observed reduction of leaf area may be regarded as a defensive response to the environmental pollution, in order to protect plants from injury, because the rate of gaseous flux to leaves has been reported directly proportional to leaf area [29].

Greater root biomass and root development has been observed in many cases which can be attributed to a shift in Carbon assimilation from leaf development to the growth of stems and the root system. This mode of assimilate partitioning suggests that the plants put greater priority to the growth of roots than leaves, under the stress of environmental pollution The increases of shoot/root dry weight ratio indicate that the rate of translocation of photosynthates to the roots was slowed down under the influence of air pollutants, which may have occurred because the pollutants inhibited the phloem loading system [28].

. The decreases of the area of xylem tissue and dimensions of tracheal elements in the stems of polluted plants suggest that the extent of xylem development, and the growth of vessels and fibres in length and width, suffer in polluted environments. The increased number of vessels in the xylem tissue may be regarded as an adaptive response to the stress of coal-smoke pollution. Dimensional variation in tracheal elements under pollution stress has also been observed in *Dalbergia* (Ghouse *et al*., 1984) growing in the vicinity of the power plant complex studied here.

Table 2: Impact on various aspects of Morphology as studied by different workers

S.No	Aspect	Impact	Reference
01.	Root Biomass and Development	Increases	Wang *et al*, 2016
02.	Leaf Area, Plant Height	Decreases	Singh, Shashikant,2007
03.	Stomatal Size	Increases	Singh, Shashikant, 2007
04.	Production of Leaves	Inhibited by coal smoke	Gupta & Ghouse, 1987
05.	Stomatal Frequency, Epidermal Cell Frequency	Decreases	Singh, Shashikant, 2007
06.	Stomatal Conductance	Decreases	Sharifi *et al*, 1997
07.	Premature Leaf Fall	Formation of Abcission Layers leading to premature leaf fall	Zimmerman, 1950
08.	Xylem tissue, Tracheal elements, Vessels, Fibres	Decrease in area, increase in length	Ghouse, 1987
09.	Trichomes	Increase in length and density	Ghouse, 1987
10.	Shoot/root dry weight ratio	Increases, Rate of translocation of photosynthates to the roots decreased	Teh and Swanson, 1982

Impact on Physiology

The dust generated due to mining and associated activities has a varied range of effects on a plants' physiology by affecting different parts and processes**.**

Table 3: Impact of Coal dust and pollutants on plants, studied by different workers

S. No	Aspect	Effect	Reference
01	Availability of PAR	Dust particles cause shading, occlude stomata, reducing the availability of Photosynthetically Active Radiation	Ricks and Williams, 1974, Hirano *et al*., 1995
02	Gaseous Exchange	Reduced due to dust loading and deposition	Ernst, 1982
03	Growth	General reduction, stagnancy	Van Gardingen *et al*., 1991
04	Pollen germination	Gets inhibited	Rao, 1971
05	Fruit set formation	Does not occur	Rao, 1971
06	Leaf temperature	Increases due to heat absorption by dust	Hirano *et al* 1995
07	PS II quantum yield	Decreases	Naidoo, 2004
08	Rate of photosynthesis	Reduction (21-58 %)	Sharifi *et al* (1979, 1997)
09	Shoot Length	Reduction	Sharifi *et al* (1979, 1997)
10	Proline Content	Higher in plants closer to mining areas and plants growing on Overburden dumps, as	Boruah, 2017

		compared to control site plants	
11	Anti-oxidant enzyme content	POD – Peroxidase, GR – Glutathione reductase, SOD – Superoxide Dismutase, APX – Ascorbate Peroxidase, MDAR - Monodehydro Ascorbate Reductase increases	Boruah, 2017

Coal dust may cause a decrease in light available for photosynthetic processes, an increase in leaf temperature due to changed surface optical properties, and interference with the diffusion of gases into and out of leaves (Farmer, 1993).The shading effect caused by dust layer lowers the stomatal conductance. Dust loading on leaves also impacts plant growth through its effect on leaf gas exchange [22]. Dust particles may also occlude stomata and may also cause physical injury to tree leaves and bark and a general reduction in growth [24]. Rao (1971) observed that coal dust prevented pollen germination on stigmatic surfaces, thus reducing fruit set. Dust deposits can also act as a medium for the growth of fungal diseases. In addition to this, sucking and chewing insects are not affected by dust deposits to any great extent, while their natural predators are affected (Farmer, 1993; Lovett *et al*., 2009). Effectiveness of pesticides also decreases due to reduced penetration because of surface dust.

Black coal dust particles deposited on leaf surface, increase leaf temperature by absorbing excessive radiation. [24] The increase in leaf temperature also increased the transpiration rate [24]. An increase in the canopy temperature is more pronounced. Absorption tends to be highest in areas where light intensity and metabolic rates are highest, e.g. near the top of the plant canopy. Dust coatings increased leaf temperatures 2 to 4°C, increased the number of bacteria and fungi on the leaves and increased transpiration. Water loss increased with increased concentration and decreased particle size Particles of larger dimensions block the stomatal opening thereby lowering the rate of transpiration and causing mechanical injury to the guard cells.

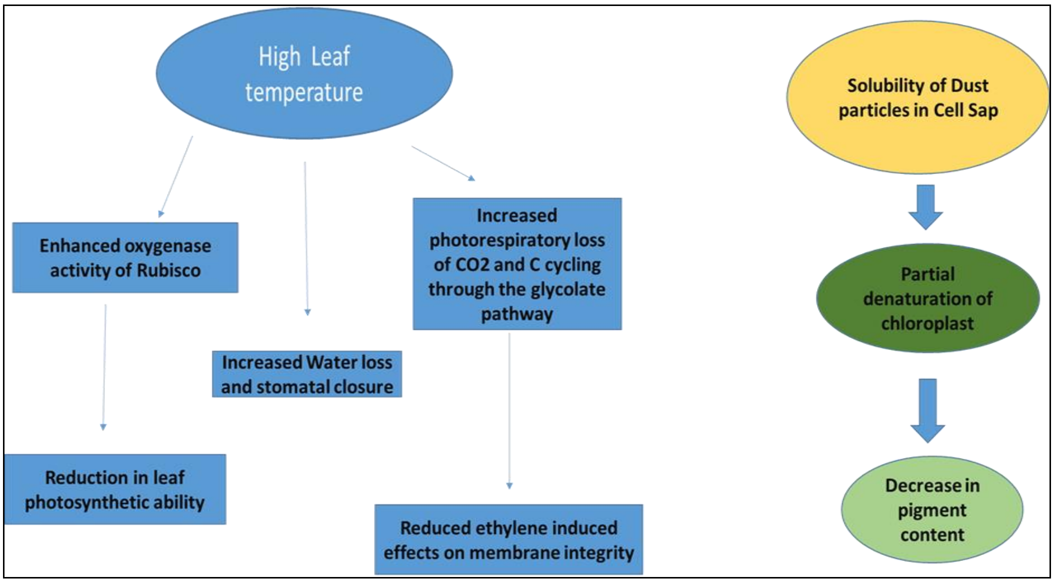

Fig 2: Impact of elevated leaf temperatures due to coal dust deposition (b) Impact of Dust solubility

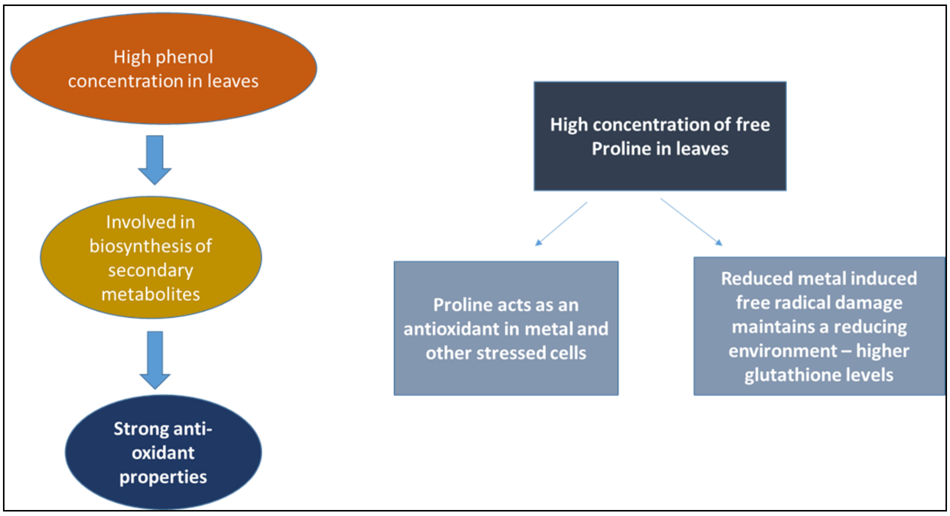

Fig 3: Reason behind High Phenol and Proline concentration in the leaves of Plants growing in the close vicinity of mining areas and on Overburden dumps. Boruah, 2017

Impact on Photosynthesis

Coating with dust may cause abrasion and radiative heating, and may reduce the photosynthetically active photon flux reaching the photosynthetic tissues (Lepedus *et al*., 2003; Lichthenthaler *et al*., 1982, 1999, 2002; Naidoo & Chirkoot, 2004; Prusty *et al*., 2005). The coal dust decreases the photosynthetic rate by shading the leaf surface. Dust of smaller particle size are known to have a greater shading effect.

A 21–58% decrease in photosynthesis and a reduction in total shoot length was observed in plants growing in the vicinity of coal mining areas. This also resulted in reduced growth rates and plant vigour which is of major concern especially in horticultural crops, through reductions in fruit setting, fruit size and sugar levels.

In addition to these damages, the pollutants retarded the growth of leaves in size and, as a result, the total photosynthetic area of the plants decreased at the 18-week stage of growth.

The pigments content of the light harvesting complex is an important aspect related to be considered when studying the impact of dust and pollutants associated with mining and allied activities (Santosh & Tripathi,2008). Chlorophyll and other pigments often get oxidised, reduced, pheophytinised and reversibly bleached thereby hindering the plant's photosynthetic ability

The ratio of chlorophyll a/b was observed to decrease in several studies with the increasing load of pollutants suggesting that the pollutants caused a rapid destruction of chlorophyll a relative to chlorophyll b, and hence a l decreases in the total chlorophyll contents of leaves.

Lower PS II quantum yield and lower electron transport rate through PS II, (Naidoo, 2004) [4] reduced quantum efficiency of PS II were also observed in plants that grew in and around areas where mining operations are in full swing. These effects were more pronounced in dwarf and isolated trees.

Conclusion

With an ever increasing demand for energy worldwide, the location, extent, and methods of extraction are evolving at a rapid rate and sadly most of these projects are operating at biologically rich regions. The effect of these changes on the vegetation and biodiversity of these changes are less extensively studied. We speculate — on the basis of the best available, but incomplete. Although these effects have serious long term impacts on the environment, so far, there has been little research into potential mitigation measures. Adoption of techniques and technologies that can help mitigating the damaging effects of the pollutants generated by coal mining and its allied activities depend less on science than on economics. Coal cleaning techniques are very expensive. A conventional coal-fired power plant can be made more efficient by injecting the CO_2 released into ammonium carbonate followed by transportation and underground deposition (preferably in soil below the sea floor). This process is by far the most expensive. Besides the cost of the equipment and the ammonium carbonate, the coal-fired power plant also needs to use 30% of its generated heat to do the injection (parasitic load). One way to reduce this parasitic load is to burn the pulverised coal with pure oxygen instead of air. SO_2 can be removed by flue-gas desulfurization and NO_2 by selective catalytic reduction (SCR) while particulates can be removed with electrostatic precipitators. Putting these techniques into application on such a large scale and a substantial shift towards cleaner sources of energy remains a tough challenge

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