INTRODUCTION

Coal was the key energy source for the industrial revolution, which has provided amenities that most of us take for granted today—including electricity, new materials (steel, plastics, cement and fertilizers), fast transportation, and advanced communications. Coal replaced wood combustion because of coal’s abundance, its higher volumetric energy density and the relative ease of transportation for coal (Ananth Chikkatur, 2008).

However, the use of coal also has many negative impacts. Coal mining historically has been a dangerous occupation, with workers toiling under often inhuman conditions. Mining has leached hazardous chemicals into water sources and destroyed forests and habitats. Even entire mountains have been lost due to strip mining. Coal use has severely degraded air quality and human health because of high particulates and sulfur dioxide (SO₂) emissions. While regulations on power-plant emissions have reduced air pollution significantly (particularly in Europe and the United States), there is now a much bigger, global threat from increased coal use. Emissions of carbon dioxide (CO₂) from coal combustion have been identified as a primary culprit in increasing atmospheric CO₂ concentrations, strongly affecting the world’s climate (IPCC, 2001a). Mitigating climate change will require deep reductions in global CO₂ emissions, especially from coal use (Freese, 2003; Reece, 2006; US OTA 1978; Ananth Chikkatur, 2008).

The problem of mine fire is as old as the history of the mine. The fires in coal mines are posing great hazard due to its in­creasing trend in the worked and much more so in our country, while mining of thick and thin seams under difficult geo-mining conditions. Due to fires in underground as well as surface mines, not only a considerable amount of resources is lost, but the entire mine environment is badly affected. So long as the fires are restricted to underground working only, these do not pose very serious threat because of their comparative ease in tackling but once these become surface tire, impacts are very severe and the control measures are very difficult. As India is planning to double the coal production by the turn of 2005 AD (present rate is 250 MT/annum) so it has become necessary to analyze
critically the fire problems in Indian coal mines (Sahu and Pal, 1998).

**TYPES OF COAL**
As geological processes apply pressure to peat over time, it is transformed successively into:

- **Lignite** - also referred to as brown coal, is the lowest rank of coal and used almost exclusively as fuel for steam-electric power generation. Jet is a compact form of lignite that is sometimes polished and has been used as an ornamental stone since the Iron Age.

- **Sub-bituminous coal** - whose properties range from those of lignite to those of bituminous coal and are used primarily as fuel for steam-electric power generation.

- **Bituminous coal** - a dense coal, usually black, sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke.

- **Anthracite** - the highest rank; a harder, glossy, black coal used primarily for residential and commercial space heating.

- **Graphite** - technically the highest rank, but difficult to ignite and is not so commonly used for ignition.

**Coal properties and burning process**
Coal, the most used fossil fuel, is a readily combustible rock containing more than 50 percent by weight of carbonaceous material, formed from compaction and indurations of variably altered plant remains. These remains were initially deposited in a swampy environment in the form of peat. Unpredictable amounts of other chemicals such as sulfur, chlorine, sodium, and various other minerals can be found in coal. The physical properties of coal, such as color, specific gravity, and hardness, vary considerably. This variance depends on the composition and the nature of preservation of the original plant material that formed the coal; the quantity of impurities in the coal derived from soil and silt being co-deposited with the coal; and the amount of time, heat and pressure that has affected the coal since it was first formed. Time, heat and pressure also determine the degree of maturation of the coal, which is classified according to the increasing amount of carbon, as lignite, sub-bituminous coal, bituminous coal, and anthracite. Rank is another index of coal quality. This is a measure of brightness of the coal as measured microscopically, and is a function of the vitrinite content – one of the micro litho types in coal (D. J. Williams, personal communication).

Oxidization of coal is a chemical process which can be defined in a simplified form as:

\[
\text{COAL} + O_2 \rightarrow \text{CO}_2 + \text{Energy}
\]

But practically it is rather more complicated and may consist of different stages, which also depend on the presence of other substances, such as water, pyrite etc. For dry coal, the simplified reaction is described by Schmal (1987), referring to Kok (1981) as:

\[
C_{100}H_{40}O_{11} + 113O_2 \rightarrow 100 \text{ CO}_2 + 37 \text{ H}_2O + 4.2 \times 10^8 J/kmol O_2
\]

The first part of the reaction, which consists of chemical absorption of oxygen from the coal surface, can be presented in following equation. However, the heat of absorption is difficult to isolate on CO₂ invariably formed in the process.

\[
C_{100}H_{40}O_{11} + 17.5 O_2 \rightarrow C_{100}H_{40}O_{16} + 2.5 \times 10^8 J/kmol O_2
\]

A number of factors are responsible for determining the overall rate of the reactions, the main ones being oxygen content of air; exposed surface area of the coal; temperature; and composition of coal.

**ORIGIN OF COAL FIRE**
Coal seam fires can be divided into near-surface fires, in which seams extend to the surface and the oxygen required for their ignition comes from the atmosphere, and fires in deep underground mines, where the oxygen comes from the ventilation.

Mine fires may begin as a result of an industrial accident, generally involving a gas explosion. Historically, some mine fires were started when bootleg mining was stopped by authorities, usually by blowing the mine up. Many recent mine fires have started from people burning trash in a landfill that was in proximity to abandoned coal mines, including the much publicized Centralia, Pennsylvania, fire, which has been burning since 1962. Of the hundreds of mine fires in the United States burning today, most are found in the state of Pennsylvania.

Some fires along coal seams are natural occurrences. Some coals may self-ignite at temperatures as low as 40 °C (104 °F) for brown coal in the right conditions of moisture and grain size. The fire usually begins a few decimeters inside the coal at a depth in which the permeability of the coal allows the inflow of air but in which the ventilation does not remove the heat which is generated.

Two basic factors determine whether spontaneous combustion occurs or not, the ambient temperature and the grain size:

- The higher the ambient temperature, the more quickly the oxidation reactions proceed.
- The grain size and structure determine its surface area. Kinetics will be limited by availability of reactant, which in this case is carbon exposed to oxygen.

Wildfires (lightning-caused or others) can ignite the coal closer to the surface or entrance, and the smouldering fire can spread through the seam, creating subsidence that may open further seams to oxygen and spawn future wildfires when the fire breaks to the surface.

Prehistoric clinker outcrops in the American West are the result of prehistoric coal fires that left a residue that resists erosion better than the matrix, leaving buttes and mesa. It is estimated that Australia's Burning Mountain, the oldest known coal fire, has burned for 6,000 years. Globally, thousands of inextinguishable mine fires are burning, especially in China, where poverty, lack of government regulations and runaway development combine to create an environmental disaster. Modern strip mining exposes smoldering coal seams to the air, revitalizeing the flames.

Rural Chinese in coal-bearing regions often dig coal for household use, abandoning the pits when they become unworkably deep, leaving highly combustible coal dust exposed to the air. Using satellite imagery to map
China's coal fires resulted in the discovery of many previously unknown fires. The oldest coal fire in China is in Bajigou and is said to have been burning since the Qing Dynasty (before 1812).

**CAUSES OF MINE FIRES**
The exact causes of mine fires are till date unknown. Researchers said there are (A) Geologic factor (Seam thickness, seam gradient, caving characteristics, faulting, coal out-bursts, friability, rider seams, depth of cover, geothermic gradient etc.), (B) Mining factors (mining methods, rate of advance, pillar conditions, roof conditions, packing, leakage, multi-seam working, coal losses, main-roads, worked-out areas; heat from machines, ventilation pressure differential, barometric pressure, changes in humidity etc.). (C) Seam factors (rank, petrographic composition, temperature, available air. particle size, moisture, sulphur, interfering minerals. physical properties, effect of previous oxidation, heat due to earth movement, bacterial effect etc.) (Morris and Atkinson, 1986). The importance of each factor is yet to be analyzed. Jharia coalfield result show that factors like shallow depth working, thick seam mining and multi-seam contiguous panel working had created very complex situations which not only initiated the start of the multi factor is yet to be analyzed. Jharia coa field result show that factors like shallow depth working, thick seam mining and multi-seam contiguous panel working had created very complex situations which not only initiated the start of the fires but also speeded up their spread. The unscientific and slaughter mining had taken a toll of the reserves particularly before nationalization of Indian coal industry (Sharma and Banjerjee, 1989; Reports of the Committee on Coal Mine Fires, Planning Commission, Govt. of India).

**STATUS OF FIRES IN INDIAN COAL MINES**
The dangerous occurrence of fires in Indian coal mines (in cause-wise and coalfield- wise), are shown in Table 1. Critical-investigations reveal that fires due to Endogenous cause (spontaneous heating) are more severe than exogenous one. Further it is observed that the occurrence of spontaneous heating in underground workings got reduced considerably till 1972, thereafter started increasing giving the peak maxima in 1977 (Table 2). Though in 1981-82, it further reduced but again increased till 1987, whereas surface fires got reduced considerably after 1976. Spontaneous heating in open-cast working, mostly remain unchanged. Cause-analysis revealed that premature collapse of pillars, extraction of shallow seams by caving and not providing the isolation/preparatory stopping at the proper place are the main reasons for these underground fires. Spontaneous heating on surface are mainly in coal stocks and washery rejects. Bord and pillar working without slowing shows much higher rate than proper slowing, though longwall retreatment shows the least. Coal sample analysis shows that high ash coals are more

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**Table 1:** Incidence of mine fires cause-wise and coalfield-wise (Annual Reports of the Chief Inspector of Mines, DGMS, Ministry of Labour, Govt. of India) (Sahu and Pal, 1998).

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Cause</th>
<th>COAL FIELDS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Premature Collapse followed by spontaneous heating</td>
<td>Jharia 10</td>
<td>Raniganj 8</td>
</tr>
<tr>
<td>2</td>
<td>a) Spontaneous heating (U/G)</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>b) Spontaneous heating (Surface)</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Bontuls Conflagration</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Illicit Distillation</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Spontaneous heating in quarry over burden containing carbonaceous matter (dumped)</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Negligent acts e.g. dumping of hot ashes soft-coke making etc.</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Spontaneous combustion in washery rejects</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Other causes</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>a) Fire crossing from neighbouring mine/ area</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>b) Miscellaneous</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>96</td>
<td>35</td>
</tr>
</tbody>
</table>
susceptible to spontaneous heating (Pal, 1994).

**COAL IN INDIA**

Exploration, development, and sale of coal and lignite resources in India are completely under the control of the Indian Government, through the Ministry of Coal. The Ministry of Coal effectively determines all matters relating to the production, supply, distribution and sale price of coal. The Ministry is in administrative control of major coal-producing companies including Coal India Limited (CIL), Singareni Colliery Company Limited (SCCL), and Neyveli Lignite Corporation (NLC). After nationalizing the coal mines between 1972 and 1973, the Government of India held the rights to nearly all coal mines in the country, and CIL was the public-sector holding company for these mines. CIL has seven coal-mining companies as its subsidiaries; the eighth subsidiary, Central Mine Planning and Design Institute Limited (CMPDIL), provides technical support in planning, exploration, mine development, and research and development in coal technologies. More than 90% of coal and lignite produced in India is from the CIL, SCCL, and NLC mines, as only a small amount of captive coal mining is allowed for private steel, power and cement companies. The Geological Survey of India (GSI), the Mineral Exploration Corporation (MEC), SCCL, and CMPDIL map India’s coal resources by undertaking prospecting surveys in areas with potential coal resources. The GSi and MEC are under the jurisdiction of the Ministry of Mines. The Coal Ministry also is in administrative control of the Coal Controller’s Organization, which, among others, gives grants for opening new seams/mines, collects and publishes data on the coal sector, collects excise duties, and monitors progress in captive mining (Ministry of Coal, 2006a).

In addition to the Ministry of Coal, the Ministry of Power plays a key role in recommending coal linkages to power projects and in recommending coal block allocations for captive mining. A similar role is played by the Ministry of Steel for the steel sector. The Planning Commission of India sets the long-term vision and priorities for the government and provides overall policy guidance and sectoral growth targets for all government ministries through its national plans. The Power and Energy Division of the Planning Commission also provides support to an Energy Coordination Committee under the chairmanship of the Prime Minister that addresses all key energy sector issues.

Among the other government entities involved in coal, the Ministry of Environment and Forests plays a key role in regulating the environmental impacts of mining and in providing clearances for mining in forest lands. The Ministry of Mines (through the GSi and MEC) also facilitates coal resource exploration. The Directorate General of Mines Safety, in the Ministry of Labor, helps protect occupational health and safety of mine workers in India through legislation, examinations, inspections and investigations (Ananth Chikkatur, 2008).

**Coal Mining in India**

Extraction of coal deposits from the Earth’s surface and from underground. Because coal was the basic energy source that fueled the Industrial Revolution, the resulting industrial growth supported the large-scale exploiting of coal deposits. In the late 20th century, open pit mines replaced underground mines as the principal source of coal in the Industrial nations. The mining of coal from surface and underground deposits today is highly productive through mechanical operation (Ibid, Vol-2, p 112).

Environmental concerns will be the key to the coal industry’s future. Relative to other fossil fuels, coal is less energy efficient and pollutes more. The primary concerns at the regional levels have to do with the environmental impacts on air, water, land, forest, biodiversity, climate and the costs of mitigating these.

Even with its major hurdles, coal will remain a future mainstay, a foundation and a fundamental of our economy. Coal has a crucial role in meeting current needs and is a resource bridge to meet future goals through the enhancement of knowledge and technology. The challenge is to apply the right technology in the most efficient and environmentally friendly way.

Coal is the most abundant fuel resource in India. It is the prime source of energy and perhaps the largest contributor to the industrial growth of the country. It is a crucial and enduring element in a modern, balanced energy portfolio, providing a bridge to the future as an important low cost and secure energy solution to sustainability challenges. Some important fact about coal industry in India is as follows. India is the third largest producer of coal in the world. Coal is one of the primary sources of energy. India has some of the largest reserves of coal in the world. Indian coal has high ash content (15-45%) and low calorific value. With the present rate of around 0.8Mt average daily coal extraction in the country, the reserves are likely to last over a 100 years. The energy derived from coal in India is about twice that of energy derived from oil, as against the world, where energy derived from coal is about 30% lower than energy derived from oil. Coal India Limited (CIL) is the largest company in the world in terms of coal production.

Coal continues to be the major source of primary commercial energy worldwide. Considering the limited reserve potentiality of petroleum and natural gas, eco-conservation restriction on Hydel projects and geo-political perception of nuclear power, coal will continue to occupy the centre stage of India’s energy scenario. Share of coal in world’s energy consumption is 27%. The importance of coal in India can be gauged by the fact that it supports about 54.5% of the commercial energy in the country. The coal production in India has increased from 73 Mt in 1972 to about 382 Mt in 2004-05. Coal demand as projected for the year 2006-07 is 448 Mt, for 2011-12 is 620 Mt and is projected to 1061 Mt by the end of 2024-25 (Ministry of Information and Broadcasting, Government of India, 2006). In India, coal production will have to be increased to meet the energy demand over the next 20-25 years at the rate of 20-25 Mt/year. To meet the energy demand and overall coal production, open cast coal mining has grown at a phenomenal rate, and in 1995-96, when the country produced 274 Mt, the open cast mines accounted for 68% of the coal production in the country (Kumar 1995). By 2000, the coal production from surface mining rose to 250 Mt,
which was about 70% of the total coal production. In underground coal mining, the miners suffer from coal dust inside the workings but, in surface mining, the air pollution problem is much more acute, particularly with respect to dust pollutants. In opening an opencast mine, massive overburden (OB) has to be removed to reach the mineral deposit (Ghose 1989). This may require excavators, loaders, dumpers, and conveyor belts, which results in massive discharge of fine particulates from OB material. Similarly, normal operation will require excavation, size reduction, waste removal, transportation, loading, and stockpiling. All will release particulate matter. Closure of the mine is similar to that of opening, but for a shorter period. It is reported (Cowherd 1979) that vehicular traffic on haul roads of mechanized opencast mines could contribute as much as 80% of the dust emitted (Ghose and Majee, 2007).

**Problems of Coal Mining Activities**

Though coal is considered as a major energy sources, mining activities are the cause of environmental concern. The mining operations like drilling, blasting, extraction, transportation, crushing and other associated activities are carried out to underground and opencast mines. Mining operations damage the environment and ecology to an unacceptable degree, unless carefully planned and controlled. There is a need for balance between mining and environmental requirements.

It is reported the various impacts of mining on environment and their mitigation measures and its impact on Air Quality, problem with greenhouse gases, acid rain and ground level ozone and Coal Mine Fires. It is found that the number of coal mines in the world is affected by fires leading to steady destruction of precious energy resource. The reason for mine fires presumably involves the phenomenon of spontaneous heating through two interrelated process viz., the oxygen coal interaction or oxidative process and the thermal process. If remains uncontrolled, the fire could spread further through interconnected pathways and fissures in the strata. It is estimated that about 10% of total coal resources are in the fire-affected areas. If proper action is not taken in time (it is already too late) most of the coal producing nations will be the major contributors for the current environmental pollution.

**Factors Causing Coal Fire**

Coal as a fossil fuel can catch fire by both natural and man-made causes. Some causes of coal fires can be found in:

- Spontaneous combustion
- Forest fires close to coal seams
- Traveling fire from one seam to the other
- Natural hazards (e.g. thunderstorms)
- Old mining techniques (e.g. insufficient ventilation of the mine shafts, old generators and lighting systems that spray sparks)
- External heat sources (e.g. illegal distillation of alcohol in Indian coal mines)
- Human induced (careless acts of mine workers)
  (Robert H. Williams and Eric D. Larson)

**IMPACT OF COALFIRE ON ENVIRONMENT**

Coal is one of the non-renewable energy sources used widely in developing countries when available locally. With time, the use of coal has increased in the power generation industries as well as in other sectors. Coal mining and its related activities not only provide the energy resource but also causes environmental hazards. Underground or opencast coal mining operations have significant negative impacts on the environment. Mining operations directly impact upon deforestation; subsidence; lowering of the groundwater table; air and noise pollution; destruction of microbes in the soil which recycle the biodegradable matters; degradation of land; and coalfires contribute to greenhouse gases and lead to local and global warming. Noxious gases such as sulfur dioxide, nitrogen oxides, carbon monoxide and carbon dioxide often affect the immediate surroundings of an active coalfire. Smoke and windblown ash can also plague the surrounding areas. Another associated problem is widespread cracking and subsidence of land surface. As the burned coal turns into ash, often the rock overburden can no longer be supported and deep cracks open up. Eventually the surface collapses causing extensive damage to agricultural land, buildings, transport network etc. It is, therefore, of utmost importance that these coalfire affected areas should be identified and regularly monitored.

Over the past two centuries anthropogenic emissions of greenhouse gases (GHG) have increased alarmingly. This steady increment of GHGs in the atmosphere acts as a blanket that retains solar radiation leads to global warming. Among all the GHG, CO₂ has a significant status in this phenomenon. Since the pre-industrial era the concentration of CO₂ has increased from 280 ppm to 380 ppm. The extent of this increment is not only influenced by human activity such as rapid industrialization and deforestation but also some geo-natural events such as coalfire. Coalfires are widespread in most of the coal producing countries that emit a significant amount of CO₂.

**Figure 1**: a) Coal Fire, Left b) Coal fire in Northern China, Right (Photo courtesy: Gangopadhyay & Lahiri Dutt, 2005)

**Greenhouse gas emissions from coal fires**

Over the past two centuries, anthropogenic emissions of greenhouse gases (GHGs) have increased to an alarming situation. This steady increment of GHGs in atmosphere act as a blanket that retains solar radiation in the atmosphere leading to global warming. Among all the GHGs, CO₂ has a significant status in this phenomenon. Since pre-industrial era the concentration of CO₂ has increased from 280 ppm to 370 ppm (2005 Mauna Loa annual average data). This rise in the concentration of CO₂ is not only influenced by human activity such as rapid industrialization and deforestation, but also by some geo-natural events such as coalfires. The greenhouse gases, emitted from all sources, have increased the global mean surface air temperature between...
approximately 0.3 and 0.6°C since the late 19th century and have caused serious consequences for low-lying coastal areas as a result of rising sea levels from both thermal expansion and melting of ground-based glacial ice (Gangopadhyay et al., 2008). Presently the impacts of coal fires on climate change and their contributions to global warming are increasingly getting expert attention. Recent coal fire studies in China, one of the major producers of coal, estimate that the country contributes 0.3% of the total world annual output of CO₂ caused by fossil fuels. Other researchers put this amount at a much higher level, 3% of the world’s total, neither of which is a negligible amount. However, the above mentioned estimations are based on indirect methods such as the total coal burnt in a certain area. Presently some hyperspectral remote sensing-based methods are being developed that use the absorption features of CO₂ in a particular part of the electromagnetic spectrum to quantify CO₂ emissions. Finally, coal emissions come from a combination of naturally and anthropogenically ignited coal fires. Any assessment of these from a GHG perspective should attempt to apportion these emissions into these two categories. If, however, it is viewed that any emission from fossil fuels is undesirable, this separation becomes unimportant (Gangopadhyay et al., 2008).

METHODS FOR COALFIRE DETECTION

The conventional method is borehole temperature measurement in coal seams to identify anomalies. This method is useful to validate the processed remote sensing data and to identify deep subsurface fires. Some geophysical methods are also being used to measure the subsurface temperature anomalies from remotely sensed data. Two of them are described below:

Radioactive method

Sedimentary rocks contain radioactive elements such as Uranium (92U235, 92U238), Thorium (90Th232). These radioactive elements emit α particles during decay. During this process they are transformed into Radon (86Rn222, 86Rn220, 86Rn219) having a half-life of 3.96 sec to 3.825 days. The concentration of α particles measured depends on weather conditions, that is if temperature is higher the transportation of α particles is higher. Factors other than temperature influencing the transportation include pressure, porosity and water content (WMA, personal communication).

Resistivity method

The resistance of rock is calculated using a few electric poles by measuring resistance in ohms (Ω) per meter and comparing these with the standard value. Under normal conditions the resistance of sedimentary rock is 600–800 Ω/m, but in burnt rock it increases to 1200–3000 Ω/m, because of high porosity, cracks and low water content (Wuda Mining Authority, 2003).

COAL FIRE IN INDIA

Jharia, along with the Raniganj Coalbelt, about 250 km northwest of Calcutta, is producing one third of the coal in India. Many researchers, such as Bhattacharya (1991), Cracknell and Mansoor (1992), Reddy et al. (1993), Saraf et al. (1995), Prakash et al. (1997) have worked on the Jharia coalfire. Using airborne predawn TIR (thermal infrared) and daytime multispectral data Bhattacharya et al. (1991) could distinguish the fires from the background. To detect the coalfire another attempt was made by Mukherjee et al. (1991) using pre-dawn airborne thermal data. They also attempted to estimate the depth of the fire using a linear heat flow equation. Cracknell and Mansoor (1992) first used Landsat-5 TM and NOAA-9 AVHRR data and found that nighttime NOAA data was quite useful to isolate the warm areas from the background. Reddy et al. (1993) used the short-wave infrared (SWIR) region of the EMR, which is covered by Landsat TM band 4,5 and 7. They stated that the hotspots found in the image corresponded well with the field measurements. In the same area, using Landsat TM band 6 and 7, Saraf et al. (1995) found that comparatively high temperature zones should correspond with surface fires, while the less warm areas should correspond with subsurface fires. Later Prakash et al. (1997) used the Landsat TM TIR and SWIR bands to identify surface and subsurface fires separately. Based on a dual band approach for TM data, Prakash and Gupta (1999) attempted a method for calculating the area of surface fires. The main problem they faced while developing this method was reflected solar energy in the SWIR region. The Raniganj Coalbelt in the state of West Bengal, adjacent to Jharia coalfield, has been affected by surface and subsurface coalfires since the beginning of mining in the region in the mid-1800s. These fires are endangering the lives of millions of people. This study is based on Landsat 5 thermal data with inputs from toposheets and census data (Gangopadhay, 2000; Gangopadhyay et al., 2005; Lahiri-Dutt et al., 2005).

Chatterjee et al (2007) was made an attempt to study the coal fire dynamics of Jharia Coalfield during the 1990s from medium resolution satellite thermal IR data such as Landsat-5 TM and Landsat-7 ETM+ data (acquired in 10.4–12.5 µm spectral region). The dynamics of coal fire was addressed on the following aspects: (i) changes in the spatial extent of fire-affected areas, and (ii) propagation of coal fire during the 1990s. A marked decrease in the spatial extent of fire-affected areas during the 1990s was observed in this study. The spatial coverage of surface and subsurface coal fires was found to change from 0.42 and 2.06 km² respectively, in 1992, to 0.33 and 1.36 km² respectively, in 1996 and 0.08 and 1.60 km² respectively, in 2001. Using the three available satellite thermal datasets acquired in 1992, 1996 and 2001, an attempt was made to find the net lateral propagation during 1992–96 and 1996–2001. The propagation of coal fire was found to be more erratic than regular in nature. During 1992–96, the net lateral propagation was in general towards south and at places towards west, whereas during 1996–2001 it was in general towards north.

Ghose and Majee (2007) studied the characteristics of the airborne dust created by surface coal mining in the Jharia Coalfield. Work zone air quality monitoring was conducted at six locations, and ambient air quality monitoring was conducted at five locations, for a period of 1 year. Total suspended particulate matter (TPM) concentration was found to be as high as 3,723 µg/m³, respirable particulate matter (PM10) 780 µg/m³, and benzene soluble matter was...
up to 32% in TSP in work zone air. In ambient air, the average maximum level of TSP was 837 μg/m³, PM10 170 μg/m³ and benzene soluble matter was up to 30%. Particle size analysis of TSP revealed that they were more respirable in nature and the median diameter was around 20 μm. Work zone air was found to have higher levels of TSP, PM10 and benzene soluble materials than ambient air. Variations in weight percentages for different size particles are discussed on the basis of mining activities. Anionic concentration in TSP was also determined. Their report concludes that more stringent air quality standards should be adopted for coal mining areas and due consideration should be given on particle size distribution of the air-borne dust while designing control equipment.

**Jharia and Raniganj coal fire**

The Jharia coalfield in Bihar is an exclusive storehouse of prime coking coal in the country, consisting of 23 large underground and nine large open cast mines. The mining activities in these coalfields started in 1894 and had really intensified in 1925. The history of coal-mine fire in Jharia coalfield can be traced back to 1916 when the first fire was detected. At present, more than 70 mine fires are reported from this region.

Coal, a non-renewable source of energy, is found in several parts of the world. The coal layers are mined by two methods: open cast mining and underground mining. Coal is formed from organic matter with high carbon content, which when exposed to certain conditions (temperature, moisture, oxygen etc.) tends to ignite/burn spontaneously at rather low temperatures. This may occur naturally or the combustion process may be triggered by other causes. However, once a coal seam catches fire, and efforts to stop it an early stage fail, it may continue to burn for tens to hundreds of years, depending primarily on the availability of coal and oxygen. Coal fires have occurred in nearly all parts of the world like India, the US, Indonesia, South Africa, Australia, China, Germany and many other countries. However, the nature and magnitude of the problem differs from country to country. In India, the fire in the Jharia coalfield has mainly been due to unscientific mining and extraction of coal in the past.

Fires may occur in coal layers that are exposed to the surface of the earth or areas close to it. These are visible to the naked eye. Also, fires erupt in the underground seams, which have large cracks that serve as channels for oxygen to the burning coal. The main cause of natural coal fires are lightening, forest fires, bush fires, etc. Among human causes are accidents, negligent acts, domestic fires, lighting fires in abandoned underground mines for heating or distilling alcohol etc. Besides, burning away of an important energy resource, it creates problems for exploitation of coal, poses danger to humankind, raises the temperature of the area, and when present underground, can cause land to subside.

The pollution caused by these fires affects air, water, and land. Smoke, from these fires contains poisonous gases such as oxides and dioxides of carbon, nitrogen and sulphur, which along with particulate matter are the causes of several lung and skin diseases. High levels of suspended particulate matter increase respiratory diseases such as chronic bronchitis and asthma, while the gases contribute to global warming besides causing health hazards to the exposed population. Methane emission from coal mining depends on the mining methods, depth of coal mining, coal quality and entrapped gas content in the coal seams. These fires also pollute water by contaminating it and increasing its acidity, which is due to a certain percentage of sulphur that is present in coal. This fire leads to degradation of land and does not allow any vegetation to grow in the area.

The measures for controlling coal mine fires, in the case of Jharia coalfields, include bull dozing, leveling and covering with soil to prevent the entry of oxygen and to stabilize the land for vegetation. Fire fighting in this area requires relocation of a large population, which poses to be a bigger problem than the actual fire fighting operations.

Gangopadhyay et al (2005) makes an attempt to identify temperature anomalies of the Raniganj coalbelt to locate the spatial distribution of coalfires. Landsat Thematic Mapper (TM) thermal band data was used to calculate surface temperature along with NDVI (normalized vegetation index) derived emissivity. Raniganj and Jharia regions together have been for long the single largest coal supplier in India, now contributing about a quarter of the total output in the country. Numerous reasons such as improper mining techniques and policy, as well as unauthorized mining caused surface and subsurface coalfires in these areas. These coalfires burn millions of tonnes of valuable coal resources, creating severe environmental problems and posing enormous operational difficulties of mining. After first use of remote sensing as a tool to identify coalfires in 1960s, with the time, the efficiency of remote sensing to identify and monitoring coalfires has been well established by several researchers. With the knowledge of local geological setting and density sliced surface temperature image the spatial distribution of coalfires can be revealed.

**R & D in Clean Coal Technologies**

**Clean Coal Technologies (CCT)**

Coal is India’s most abundantly and widely used fossil fuel. There will be an increase of 100% in the usage of coal from 2006 to 2030. Clean Coal Technology is new generation processes in which generation of electricity with increased energy efficiency & reduced environmental effects and fuels from coal. CCTs reduce air emissions, waste products and other pollutants compared to older coal based systems and increase the amount of energy gained from each ton of coal used. CCTs also address Grean House Gas (GHG) emission.

**BHEL’s Vision on Clean Coal Technology**

The CCT Vision of BHEL to cover the following.

1. Coal Beneficiation, in which ash content in the coal is reduced so that particulate emission from the power station chimneys is reduced.
3. Integrated Gasification Combined Cycle in which the cycle efficiency is improved and thus less coal input in addition to hydrogen conversion is enhanced & PFBC.
4. Underground Coal Gasification from which we can obtain fuel without contaminating the surface as well as utilization of un-mine-able coal seams

5. Zero Emission Technologies
- In Furnace / Post Combustion NOx / Sox
- SPM 2.5 & SPM 10 Reduction.
- Mercury Capture, 5.4. CO2 Capture and Sequestration.
- Oxy fuel combustion which reduces the NOx emission level and also enables CO2 Capture easier.

6. Conversion to different energy forms
- Coal Gas to Hydrogen,
- Coal Gas to SNG

7. Hot gas filtration & Hydrogen sulphide removal system,
8. Ash utilization,
9. Co-firing of biomass and
10. CFD modeling for technologies out lined above for simulation of processes and scale up purposes.

Figure 2: BHEL Road Map (Selva Kumaran et al., 2006)

<table>
<thead>
<tr>
<th>Short term (0 - 5 yrs)</th>
<th>Midterm (5-10 yrs)</th>
<th>Long term (10-15 yrs)</th>
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</thead>
<tbody>
<tr>
<td>Bypass system</td>
<td>SCR system</td>
<td>Mercury capture</td>
</tr>
<tr>
<td>Low NOx burners</td>
<td>Oxy fuel combustion</td>
<td>CO2 Sequestration</td>
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<tr>
<td>SPM2.5&amp;SPM10</td>
<td>Hydrogen combustion</td>
<td></td>
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<tr>
<td>125 MW PFBG capture</td>
<td>Hydrogen combustion test</td>
<td></td>
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<tr>
<td>Hot gas filteration &amp; H2S capture</td>
<td>Higher capacity IGCC</td>
<td></td>
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<tr>
<td>Coal washery-national model</td>
<td>Ash utilization technology</td>
<td></td>
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<tr>
<td>800 MW OTSC</td>
<td></td>
<td>OTSC-CFBC plants</td>
</tr>
<tr>
<td>250MW CFBC</td>
<td></td>
<td>OTSC-CFBC plants</td>
</tr>
<tr>
<td>Co-Firing of Bio-Mass</td>
<td></td>
<td>OTSC-CFBC plants</td>
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</tbody>
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<tr>
<th>Economics</th>
<th>Environment</th>
<th>Efficiency</th>
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Research and Development in CCT
Future technology options under R&D in advanced industrialized countries attempting with very large funding effort in CCTs are:
Integrated gasification combined cycle with fuel cells and with Hydrogen co-production.
Use of advanced fuel cells together with coal gasification in integrated gasification fuel cell (IGFC) cycles could permit higher thermal efficiencies than IGCC. However, high temperature fuel cell stacks are currently still at the scale of a few MWe, even on natural gas or reformed natural gas-derived feeds, so commercial-scale IGFC lies some way off.
In addition, Government of India has launched plans to utilize the Coal Bed Methane (CBM). Coal basins are sources for Coal-Bed-Methane, a clean non-conventional energy. In situ CBM resource of 564 BCM was estimated from different Gondwana basins in India, among which, the Jharia and the East Bokaro basins were regarded to be most potential.
Under ground Coal Gasification is also being attempted as a possible method of CCT, world around. Underground coal gasification (UCG) involves the gasification of coal in the coal seam so that the gas can be utilized for power generation. Its prospects have benefited from new underground exploration and production technologies, developed for oil and gas exploration, which now makes possible a reliable process that can be used in deep coal seams, of 600 meters or more. BHEL with its sound understanding of high ash coal utilization & successful surface gasification of Indian coals has lot of strengths to become a strong player in UCG. Most of the equipment above surface including gas cleaning systems, Gas turbine, generators; HRSGs, compressors are already in the range of BHEL.
For long-term beyond 2030 acceptability of coal for power generation, near-zero emissions are likely to be required, as the link between CO2 emissions and the greenhouse effect is becoming accepted as established. Many of the conventional CCTs are technically suitable for development to give zero emission technologies encompassing CO2 capture for sequestration. Reductions in CO2 emissions from efficiency advances alone, of CCTs are limited to around 30% compared with sub-critical PCC systems. For zero or near-zero emissions, the CO2 will have to be removed and permanently stored. Despite lack of data it is recognized that coal combustion can be a significant source of some trace elements, especially mercury. In preparation for possible introduction or tightening of limits for trace elements, especially mercury, a deeper effort on the Indian coals is required.
BHEL have done pilot scale Circulating granular bed filtration for Hot gas clean up in Integrated Gasification Combined Cycle (IGCC) applications and is interested in Development of Ceramic Candle Filters.
BHRL is further proposing for an Oxy fuel combustor test facility for future development of a novel oxy-fuel boiler. Collaborative action by governments and industry is also required now to encourage worldwide co-ordinated research, development and demonstration of clean coal technologies such as carbon capture and storage, which will in the longer term deliver near-zero CO₂ emissions from the use of coal. The scale of the emissions limitation challenge means that all potentially viable energy sources and technologies need to be developed to their practical and commercial potential (Selva Kumaran et al., 2006).

CONCLUSION
Coal fire is a widespread problem with long and complex histories in most coal-producing countries. Their extent and frequency varies according to the local climate, terrain and social factors such as the prevalence of illegal mining or mining techniques. The impacts of coal fires are large and wide-ranging, extending from local (pollution) to global climate change. An important problem in coal fire studies is to determine the location, extent and intensity of the fires, and in this respect, we suggest the use of remote sensing technology. Remote sensing can play a significant role in detecting and monitoring coal fires, potentially leading to the optimization of strategies for their control and thus minimizing economic and environmental impacts. Though most researchers concentrate their study primarily on coal fire detection and monitoring, the measurement of greenhouse gases emitted from coal fires needs to be considered more seriously. The coal fire-related greenhouse gases have a significant adverse contribution to global climate. It is clear that to reduce the steadily increasing greenhouse gases in the atmosphere, emissions related to coal fires need to be examined more intensively.

Remote sensing can play a significant role in detecting and monitoring coal fires, and perhaps in preventing huge economic loss and environmental disasters. Though most of the researchers have concentrated their studies primarily on coalfire detection and monitoring, the green house gases emitted from coalfires need to be considered more seriously. Coalfire-related green house gases make a significant adverse contribution to the climate globally. Proper investigations on fire will reduce the sterilization of the coal resource and hence the production will increase. By taking proper precautionary measures against fire, the safety level will definitely improve.

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Source of support: Nil; Conflict of interest: None declared