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# Underground Mining for Meeting Environmental Concerns – A Strategic Approach for Sustainable Mining in Future

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**Abstract**

In order to meet the ever-increasing demands of the modern society, the mineral production in our country is continuously increasing along with the scale of mining operations. However, mineral production is often not in consonance with conservation of environment and forests, since many mineral deposits including iron, manganese, chromite, bauxite and coal etc. exist below thick forests. Mining has several adverse impacts including air, water and soil pollution, socio-economic problems and effect on wildlife population and their behaviour. There has been greater stress on surface mining for boosting the production in our country, which has a larger environmental footprint compared to underground mining. As the deposits near the surface are exhausted underground mining may become cost competitive. Moreover, the technological developments in the field of underground mining, viz. mass production equipments, roof support, communication and automation is helping the decision makers to consider underground mining practice for sustainable mining while meeting environmental concerns.


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*Keywords:*mining; surface; underground; automation; sustainable development.

## 1. Introduction

Though the mineral sector's contribution to India's GDP is around 2.2 to 2.5%, its importance arises from the fact that it supplies basic and strategic raw materials for the country's industrial and economic development. Due to the sharp rise in prices and demand of a number of mineral commodities, the production of many minerals has shown steady increase, both in quantity and value since 2004-05[1]. Demand for minerals is expected to grow fast due to increasing level of consumption, infrastructure development and growth of the economy. In India 80% of mining is in coal and rest 20% is in various metals and raw materials such as gold, copper, iron, chromium, lead, bauxite, zinc and uranium. India with diverse and significant mineral resources is the leading producer of some of the minerals. On one hand, achievements in mineral technologies are constantly providing new opportunities but on the other, globalization in all its socio economic dimensions is posing increasingly complex challenges. The strategies to meet the increasing demand of raw material and to mitigate the adverse impacts have therefore to be a part of the mineral development strategy.

India produces as many as 87 minerals which include 4 fuel, 10 metallic, 47 non-metallic, 3 atomic


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and 23 minor minerals[2]. Today, India is a major minerals producer ranking among the world's leading producers of chromite, coal (bituminous), iron ore, manganese, bauxite and zinc. The production of some selected minerals from the year 2006-07 to 2011-12 has been presented in Table 1. In meeting the domestic mineral-based industries, India is largely self-sufficient in bauxite, chromite, iron and manganese ores, ilmenite and rutile among metallic minerals and barite, dolomite, feldspar, limestone, silica minerals, sillimanite and talc among industrial minerals with very few exceptions[1]. In the area of imports, petroleum crude and products accounted for more than 40% of India's imports during the years 2009-2011, while two groups namely, metalliferrous ores, metal scraps and coal, coke and briquettes each accounting for around 3%[3].

Table 1. Quantity of production of selected minerals in India

*(In thousand metric tonnes unless otherwise specified)*

| Mineral | 2006-07 | 2007-08(R) | 2008-09(R) | 2009-10(R) | 2010-11(P) | 2011-12(E) |
|---|---|---|---|---|---|---|
| Fuel Minerals | | | | | | |
| Coal(MT) | 431 | 457 | 493 | 532 | 533 | 533 |
| Lignite(MT) | 31 | 34 | 32 | 34 | 38 | 41 |
| Natural Gas(MCM) | 31747 | 32417 | 32849 | 47510 | 51203 | 46853 |
| Petroleum(Crude)(MT) | 34 | 34 | 34 | 34 | 38 | 39 |
| Metallic Minerals | | | | | | |
| Iron Ore | 187696 | 213246 | 212961 | 218553 | 207998 | 191522 |
| Chromite | 5296 | 4873 | 4073 | 3426 | 4262 | 3900 |
| Manganese Ore | 2116 | 2697 | 3620 | 2492 | 2881 | 2481 |
| Bauxite | 15733 | 22462 | 15460 | 14124 | 12641 | 13172 |
| Non-Metallic Minerals | | | | | | |
| Phosphorite | 1587 | 1849 | 1804 | 1605.49 | 2152 | 2655 |
| Baryte | 1681 | 1076 | 1686 | 2152.55 | 2334 | 2208 |
| Dolomite | 5172 | 5852 | 5504 | 5911.76 | 5065 | 5836 |
| Kaolin | 1460 | 1350 | 2084 | 2798.34 | 2522 | 3318 |
| Limestone(MT) | 197 | 193 | 222 | 232.95 | 238 | 253 |

(R) Revised, (P) Provisional, (E) Estimated, MT: Million tonnes, MCM: Million cubic meters
(Source: Annual Report 2011-12, Ministry of Mines, Government of India[2])

## 2. Environmental impact of mining

Mining industry is one core economic activity which has profound relationship with Mother Earth. Out of more than 0.8 million hectares of land in under mining, a substantial portion of it lies in forest areas. Important coal, bauxite, iron ore and chromite deposits in India are found in forests. Good limestone deposits are also available near the wildlife sanctuaries, national parks and coastal areas. Mineral production is often not in consonance with conservation of forests since many places at commercial reserves exist below thick forests. More than other industrial activities, mineral extraction tends to leave a strong environmental footprint. Although the effects vary between different types of minerals and the stages of their production, they can have profound impact near the project site in the neighbouring areas as also at the global level (e.g. through global warming). The environmental impact caused by mining takes three main forms[4] :

- Land disturbance that covers change of land use and land forms, visual impact of an open pit or waste dump and subsistence of the ground surface due to mining;

- Destruction of habitat including flora, fauna, natural watersheds and drainage pattern and of aquifer that causes lowering of water table;
- Adverse chemical impacts of improperly treated wastes which cover air pollution due to dust and noxious fumes, water pollution due to surface run off from different areas of mines, waste dumps, seepage from tailings dam etc., effluents including acid mine drainage, associated with many past and present coal and metalliferous mines as also noise and ground vibration due to blasting. The total area of mining lease with active mining operations is the minimum area which is affected by waste generation. However, the actual off-site area affected by pollution and degradation by the accumulation of waste material is far more than the area of the lease in which the operations are in progress. It is also possible that a number of mines may exist in a close cluster adding to the adverse effects. Accumulation of tailings adds to the seriousness of the environmental adverse effects.

Some of the other impacts associated with mining are:

In case of an underground mine, caving of the roof material causes abrupt collapse of the overlying strata leading to subsidence of surface. Subsidence features can be small, shallow depressions or deep pits gradually sloping troughs or steep offsets, cracks or fissures or combination of these.

Often acquisition of private land for mining activities and development of township involves displacement of people.

Construction of long embankment to prevent entry of flood water into the mine modifies existing high flood line which could further lead to entry of water into nearby settlements if any, necessitating additional displacement of families.

## 3. Why underground mining?

There are essentially two methods for mining, viz. surface and underground mining. Surface mining methods are by and large regarded to be advantageous over underground methods, because of recovery, production capacity, mechanize ability, grade control and cut-off grade, economics, and safety. All mining operations have a negative effect on the environment but the high volume of material involved in surface mining makes the impact on the environment very acute. Underground mining can be considered to be more acceptable than surface mining from environmental and social perspectives since, it often has a smaller footprint than an open-pit of comparable capacity.

The main advantage of underground mining compared to surface mining is that in general only the ore is extracted and waste rock is left behind. In open pit mining, excavation goes deeper and deeper with time and the cost of transportation increases. Also, larger amounts of waste rock must be removed to get access to the same amount of mineral which means removal of the material without economic value can be avoided to limit the environmental impact. The operational costs for an underground mine are not necessarily higher for surface mines. There are three major trends reducing the attractiveness of mines that have an impact on surface[5]:

- Many of the attractive ore bodies are either fully exploited or contain mines that are now mature.
- Increasingly, populations living close to the remaining surface-accessible ore bodies are taking a negative attitude towards a proposed open-pit development. They don’t want their lives disrupted even if offered financial compensation. They are unwilling to accept the loss of farmland, the possible impacts on ground and surface water, loss of recreational space or the noise and traffic issues stemming from truck traffic. In times past, surface mining was allowed to go ahead despite the wishes of the local population. However, with growing democratization, increased level of awareness and publicity campaigns, currently the governments need to be more responsive to their peoples’ expressed needs. Moreover, the instant publicity campaigns through electronic media and internet reaches the global audience very fast and the effects are felt in shareholders’ meetings and the stock price of the companies in question. Increasingly, large institutional investors are making their investment decisions based on environmental and social considerations that go beyond the financial bottom line.
- There has been a major change in the ways business is conducted around the world responding to pressures to improve corporate performance from a social and environmental perspective

## 4. Strategy for increased production and productivity from underground mines

Some of the measures that can be adopted for increased production from underground mines are:

### *4.1. Adoption of appropriate technology*

Adoption of proper technology is one of the major parameter to increase production and enhance safety at the same time. Some selected innovations for mining industry has been presented in Table 2. The technology should suit the geo-mining conditions[6]. Development of semi-autonomous and tele-remote technologies enable the operation of mining equipments without human operators on-board the machines. This type of technology in underground mines keeps the miners out of hazardous environments.

Table 2. Selected recent mining industry innovations

| Innovation | Description | Purpose | Outcomes |
|---|---|---|---|
| Improved rock bolts | New rock bolt design to absorb energy and control rock mass deformation while providing containment of materials | Human safety | Improved control of rock failures, collapses of stopes and drifts<br>Reduced risk of rock bursts at increased mining depths and mining scales |
| Collision avoidance system | Personnel and vehicle tags communicate wirelessly with moving vehicles<br>Driver alert and vehicle unit display of number of people and other vehicles in proximity | Human safety | Vehicle operators are alerted to the presence of personnel or other vehicles in the vicinity |
| Trapped miner location system/ paging system | Very Low Frequency (VLF) signal can penetrate through earth over large distances | Human safety | Reliable means of quickly locating trapped miners<br>Reliable means of transmitting alert, warning and evacuation messages |
| Intelligent drill rigs | Intelligent drill rigs:<br>- drill according to drill and bolt plan design<br>- ongoing measurement and reporting on tunnel profile<br>- remote access to program new drill plans<br>- ongoing monitoring of status of drill rigs and remote diagnostics | Process/efficiency improvements | Improved/more precise tunnel drilling<br>More rapid response/navigation of drill<br>Eliminates the need for surveyors<br>Enables remote evaluation of drill profile |
| Extra low profile (XLP) mining equipment | Track mounted XLP dozer, bolter and drill rig capable of operating in a 'narrow reef' (<1.2 m height) and undulating mining environment | Improved access/efficiency improvement | Reduced waste rock/increased useful excavation<br>More accurate drilling and higher face advance |

### *4.2. Communication and safety*

Safety is a major concern for underground mining operation. However, there have been a number of developments for improvement of safety in underground mines. Many types of equipment are now fitted with onboard camera systems which monitor the working face locating personnel in remote locations and provide a real time look at the progress of the operation. Roof support in underground mining is a major challenge. As a result of this demand for increased production, manufacturers have made significant advances in development of advanced support systems. Several Russian and Australian mines have recently installed the latest continuous miner-bolter equipment (Figure 1) which has significantly increased the reliability and development rates[7].The area of underground mine communications is undergoing rapid technological development and consequently several generations of communication systems are currently in use at mine sites. Radio-frequency identification (RFID) tagging systems are being used in mines to identify general location and information of tagged workers at the face[8]. Wireless sensor networks have been developed for structural as well as gas monitoring[9, 10]. By regulating the mesh sensor network deployment and formulating a collaborative mechanism based on the regular beacon strategy, the network is able to rapidly detect structural variations caused by underground collapses. The collapse holes can be located and outlined and the detection accuracy is bounded.

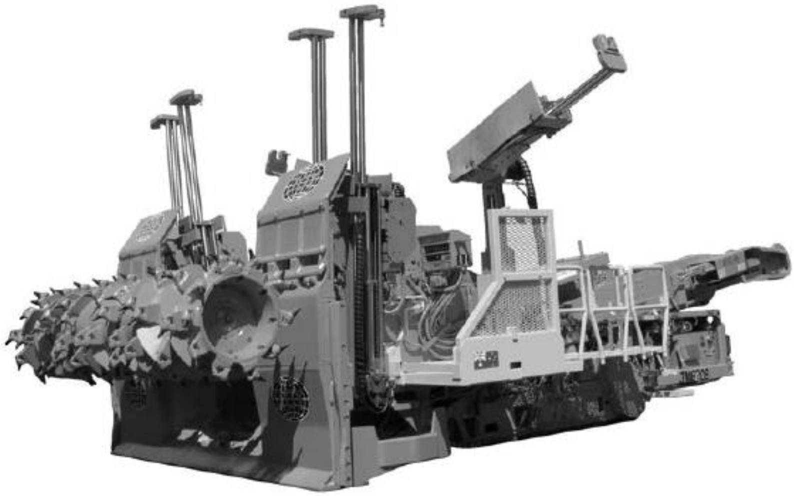


Fig. 1. 12CM30 miner bolter with bolting shield and roof bolts 2m from head end

### 4.3. *Automation*

Automation is one approach for mines to improve safety and productivity but equipment availability is also key to every underground mining application. Unplanned downtime can slow down or stop any operation;however, equipment monitoring technology is helping operations track the health of their equipment. Proactive equipment management allows mine operators to review fault codes, track maintenance records and plan scheduled maintenance. In underground applications like room & pillar, this could mean the difference between a continuous miner in full production or a complete shutdown.

Automated production drills have been available since the mid-1980s. Automated LHDs are now commercially available although automation of the dig cycle is problematic in anything but very well broken rock. Automated trucks have operated reliably at the Finsch mine in South Africa for some time. Longwall coal mines have achieved partial automation of a relatively repetitive (continuous) mining system by automating one easily defined machine operation or task while the rest of the operations remained manual. The focus today has shifted to build the ‘autonomous mining system’ that can carry out tasks automatically or with a minimum of external control[11]. Under full automation, a machine controls all aspects of its functions including monitoring and correcting for defects. These machines remove humans from hazardous areas, increase productivity as mining equipment moves faster, cover longer distances, and require fewer operators to control machines.

## 5. Improving underground efficiency

Underground mines are one of the most challenging environments for operators and their equipment. Loading and haulage are large contributors to cost per ton and they’re impacted by a number of factors including mine design, application, product quality and maintenance. Aside from the environment in which machines operate, almost all of these factors can be managed and improved to lower cost per ton. Even simple improvements can have a significant impact. Some approaches for improvement of efficiency in underground working have been presented below.

*5.1. Optimizing underground mining truck performance*

Truck exchange time which is the elapsed time after a loaded truck receives its last loading pass until the next truck receives its first loading pass, is a key to improving underground truck performance. The shorter that cycle is, the greater the opportunity for more cycles per shift. It's important to match the truck fleet to the size of the loader to ensure the maximum output for that area is achieved. It is also to be ensured that the loader has an adequate fleet of trucks so that it does not remain idle. Proper positioning of the truck, viz. away from overhead services, ensuring that it doesn't have to turn around after being loaded, faster cycle times and keeping the tires away from loose rocks and depressions also enhances its performance.

Proper load placement is critical to improving underground operations. The load should be centered over the hoist cylinders or on the body arrow as well as on the center line of the body. Enough freeboard should be ensured to minimize spillage from the sides through corners and from the rear of the body on grades.

*5.2. Evaluating a chute loading site*

Some underground mines install chutes designed to load trucks quickly. It's important to provide adequate entry and exit areas and provide the operator a way to control the chute. Favorable conditions for chutes include a stable, level floor with an easy entry under the chute. The chute size and discharge should be matched to the truck size and drop height should be minimized. Material should be well shot. Unfavorable conditions include an uneven, debris-littered floor; poor feed control; and tight access. The exit from the chute should give the operator good visibility for approaching traffic. The operator should also be able to see his payload.

*5.3. Optimizing LHD performance*

The optimum cycle time for LHD loaders is 28 to 42 seconds with an average of 35 seconds. The most efficient pass match is three to four passes. LHDs perform best in areas where floors are level, dry, smooth and firm. Sufficient cross fall and drainage will minimize tire damage. Additional considerations include well-fragmented materials that minimize crowding time particularly in the toe-area of the cut; a lower face profile and the ability to work multiple faces. LHDs will not perform as well in poor underfoot conditions, tight load areas and when moving poorly shot material.

*5.4. Evaluating haul roads*

Haul roads have a profound impact on underground machine performance and a small improvement in their condition can have a big impact on cycle time. The three key factors in the design of underground haul roads are material quality, design and maintenance. Grade should be smooth and constant with rolling resistance kept to a minimum.

*5.5. Following best practices*

Improving loading and haulage efficiency is the easiest way to lower cost per ton. By following best practices for operator performance, cycle times and payload and ensuring good haul road design and maintenance underground mines can experience greater profitability.

*5.6. Haul road design and maintenance*

Proper design and maintenance of the haul road plays a significant role in increasing production and productivity. The following points should be kept in mind for design and maintenance of haul roads:
Design considerations

- Maintain smooth grade and transitions
- Maintain 15%t nominal grade with18% lifts to prevent the truck from up-shifting
- Apply minimum slope to maintain drainage
- Avoid areas where drainage cross flow is required; a small bore hole may be required
- Maintain minimum number of cross-slopes

Maintenance considerations

- Begin at face; end at dump
- Truck should travel at a reasonable and constant speed
- Where trucks slow down, evaluate the cause and repair
- Remove and repair wet / soft spots

## 6. Strategic approach for underground coal mining in India

The Working Group on Coal and Lignite have worked out two scenarios for coal demand for XII Plan period after consultation with the major consuming sectors, Under Scenario-I (Consumers' perspective demand), the demand works out to 1203.88 MT implying a CAGR of 11.5% against the demand of 2011-12 projected in Annual Plan. Scenario-II is the realistic requirement of coal arrived at taking into consideration the envisaged demand of end use products and likely production of major coal consuming sectors and the trend of specific coal consumption by each of the sectors. The coal requirement in Scenario-II has been projected at 980.50 Mt implying a CAGR of 7.1%. Out of the projected demand of 980.5 MT, the demand of power utilities is 682 Mt which is almost 70%. If the demand of captive power to the extent of 56.36 MT is included, the projected demand for power sector works out to more than 75%. The share of steel sector at 67.2 MT forms 7% of the total demand. The share of cement and sponge iron sectors works out to 4.7% and 5.1% of the total demand respectively[12].

The widening gap of coal demand and availability over the plan periods has been presented in Figure 2. In overall terms the gap between the projected demand of 980.50 MT and the projected domestic availability of 715.0 MT works out to 265.5 MT in 2016-17. This comprises of 35.50 MT of coking coal and 230.0 MT of thermal coal. If the production is enhanced to the level visualized in the optimistic scenario, the demand-availability gap would reduce to 185.50 MT (Coking: 35.50 MT& Non-coking 150.0MT). This requirement would need to be met from imports. This gap in fact is the prime driver of all initiatives for increasing the coal production in the country.

Furthermore, the demand-indigenous availability gap projected for 2016-17 would rise further during successive plan periods. This necessitates immediate strategy to augment the coal production to the extent possible to reduce the gap and import requirement. CIL, being the major coal producer and supplier of over 40% of the commercial energy of the country has to come out with pro-active strategies for enhancing its coal production level.

### *6.1. Coal production in India*

More than 80% of coal in India is produced by the public sector undertaking Coal India Ltd (CIL) and the rest comes from Singreni Collieries Company Ltd (SCCL) and other private companies. The coal production from CIL mines (surface as well as underground) over a period of 1974-2011 is shown in Figure 3[13]. It may be observed that there has been constant increase in coal production since nationalization. However, the bulk of production from the mines of CIL is from surface mines. Further, it shows a gradual but consistent decline of coal production from underground mines in CIL since nationalization of coal mines which is a matter of serious concern.

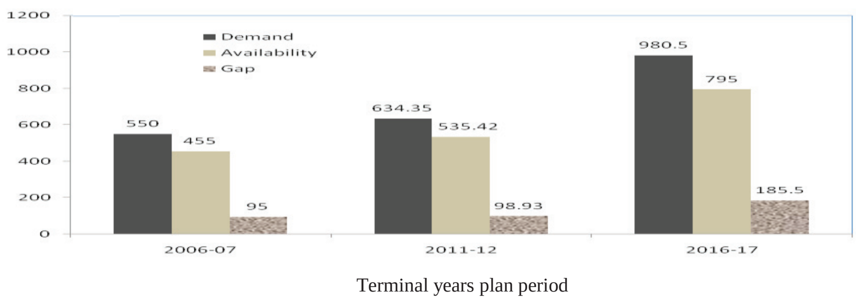
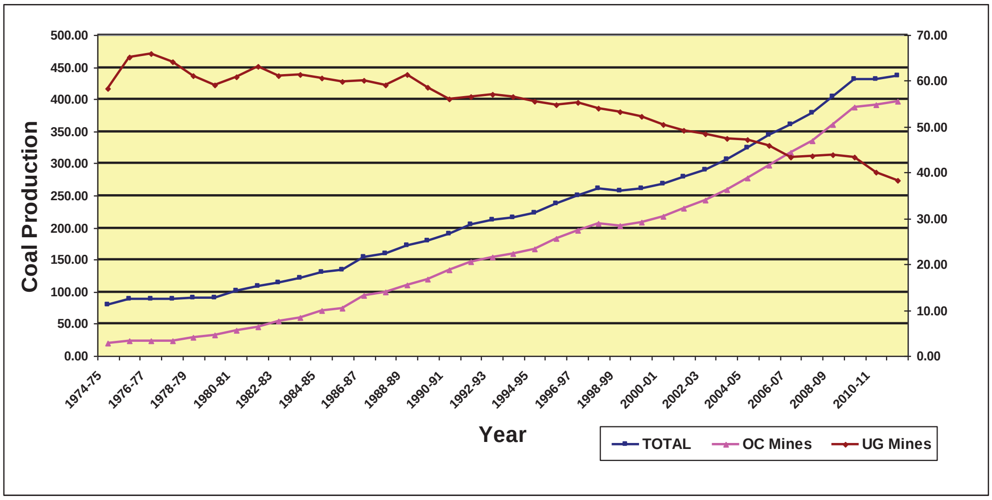



Fig. 2. Coal Demand and availability from indigenous sources

In 2012, opencast coal mines produced 488 million tons of coal and underground mines only produced 51 million tonnes. The amount of coal retrieved from underground mines has decreased from 18.5% in 2003 to 13.4% in 2007 to 9.6% in 2011 and 2012. This decrease in production from underground mines may be attributed to:

- UG operations at shallow depth has given way to quarry or surface mining
- Closure of number of underground mines due to exhaustion of coal reserve or losses
- Reduction or stagnation in production due to attrition of workforce or natural retirement
- Reduced production and productivity due to old, long & arduous mines
- Low technological, R&D or skill-development input in underground mines
- A number of underground mining operations or processes involve human effort or drudgery
- Low productivity of manpower
- Geological disposition and exploration of coal seams has also affected indirectly




Figures in MT

Fig. 3. Trend Coal Production from CIL mines (1974-75 to 2011-12)

### 6.2. Thrust areas

Table 3. Depth-wise Geological Resources of Coal in India

| Depth Range (in metre) | Proved (MT) | Indicated (MT) | Inferred (MT) | Total (MT) | % Share |
|---|---|---|---|---|---|
| 0-300 | 92251.33 | 70830.45 | 10760.74 | 173842.52 | 59.23% |
| 300-600 | 10422.74 | 57244.92 | 16255.52 | 83923.18 | 28.59% |
| 0-600 (for Jharia only) | 13710.33 | 502.09 | 0.00 | 14212.42 | 4.84% |
| 600-1200 | 1760.42 | 13591.39 | 6167.22 | 21519.03 | 7.33% |
| Total | 118144.82 | 142168.85 | 33183.48 | 293497.15 | 100.00% |

Before adopting the strategy, it is worthwhile to note the geological resources of coal in our country. Geological Survey of India on the basis of resources estimated a total of 2,93,497 Million Tonnes of geological resources of coal as on 01.04.2012. Out of the total resources, the Gondwana coalfields account for 2,92,005 Mt (99.5%), while the Tertiary coalfields of Himalayan region contribute 1493 Mt (0.5%) of coal resources. The depth-wise break-up of Indian coal resources are as given in Table 2.

Nearly 61% of the total reserve of coal is estimated within 300m depth cover distributed in all coalfields from Godavari Valley to Upper Assam. The prime quality coking coal of Jharia is available mainly in upper coal horizons while the superior quality non-coking coal of Raniganj is available in lower coal horizons. The quality coal of central India to Maharashtra is also available mainly in seams within this depth range. As a result, all the mines worked such seams extensively, primarily developing on pillars and depillaring with sand stowing. With the unfavourable economics of sand stowing and non-availability of virgin patches for further development, most of the mines have been working-splitting or slicing the pillars, winning roof or floor coals manually or with SDL, conveyor combination.

The resource position of coal shows nearly 33.4% within 300-600m depth cover. Quality coal below 300m depth cover in Raniganj, Jharia, East and West Bokaro, North and South Karanpura, Sohagpur, etc should be the main targets for underground mining. The coals of Godavari and Wardha Valleys may also be included in this category because of preferential pricing structure. The options world over for such deposits are pillar mining using continuous miner, longwall mining and sublevel or integral caving with special support system in case of complex thick seams.

Best performance of pillar mining is reported from that of Churcha mine, the only unit to cross 1MT annual production in the country. Flat 3m thick seams was worked with shuttle car and scraper loaders imported in 1960 used without design modification and even spare back up support. The valuable experience has not been repeated in any other mine even though the identical equipments were introduced in a few other mines.

The next generation pillar mining equipment viz. continuous miner loader and bolting assembly has entered in the mines after nearly 4 decades with very encouraging performance at Chirimiri and Tandsi mines The system has given 12-15tonne productivity and average production of 40000 tonnes per month. Identical mines under suitable geo-mining condition should be identified and detailed geological exploration should be done for the deployment of such machines. From coal reserve and quality analysis and seam thickness and gradient,such sites appear to be in Rangundam, Sohagpur, East and WestBokaro, North and South Karanpura, Jharia and Raniganj coalfields where a large share of quality coal seams are still virgin. Isolated patches with quality coal seams in near by flat seams beyond limiting stripping ratio in Madhya Pradesh and Chhattisgarh may also be explored for the introduction of continuous miners.

Longwall technology should be adopted with due consideration of coal seam parameters, panel geometry and coal quality in seams below 300m depth cover in Jharia, Raniganj, Godavari Valley, Sohagpur, E Bokaro and S Karanpura where bulk of coking and superior grade non coking coals within 300-600m and below 600mdepth are estimated. The faces should be equipped with high capacity support with rapid yielding valves to sustain ground movement shocks frequently felt due to massive roof. High supports suitable for 3-5m seam thickness should be used in areas where 12 - 15km long panels could be formed, each of 2 to 3km length and face length of 250 to 300m. Gate road drivage technology using continuous miner, bolter and loader assembly should be perfected to maintain advance preparation of the panels so that the faces could get unhindered operation for its life.

Mining of complex deposits often worked with sand stowing has failed to meet the production target, productivity and economics. The method of slicing with mass caving in vertical section like horizontal slicing inclined slicing or sublevel and integral caving used successfully in complex deposits of Yugoslavia, Romania, Soviet Union, Poland or France may have to be perfected for underground mining of thick seams. Power support for working over sand stowed floor while mining thick seams in slices is available in the world market particularly in Hungary may prove to be suitable for working of thick seams under riverbeds in different coalfields. Methane drainage from the seams under mining should be done to ensure better working environment, safety of the workers and the workings. The operating mines with small patches declared to be virgin till date should not be selected for the deployment of longwall mining or continuous miners as invariably they lack vertical and horizontal transport facility and adequate number of panels for equipment life time.

Geological exploration to locate suitable panels for each set of equipment with seam thickness variation within the permissible limit, coal of quality and roof rock formation should be done in depth before introducing any such cost intensive technology with continuous miners in 300-400m depth cover and longwall technology below 400m depth cover[14]. Necessary steps to ensure their success is summarized as follows:

- Shaft sinking technology should be perfected to develop access to deeper seams
- Back up facility – vertical and horizontal transport, processing and dispatch system should be compatible to the mass production technology.
- Equipment supply and spare availability should be ensured for efficient full life performance
- Man power preparation including training and on face operational skill should be developed on priority. Work culture should be improved in respect of devotion, commitment and adaptation of modern technology with efficiency
- Program should have support of the nation for continuity and financial back up
- So far as possible, the equipment should be imported lock stock and barrel to start with, followed by manufacture within the country.

The nation has to gear up for large underground production within next three to four decades; for 300 to 400MT annual production. The involvement of industrial houses and those of leading global players should be encouraged for State of Art resource input and managerial support.

## 7. Conclusions

Mining of mineral deposits is an essential operation required for meeting the ever-increasing demands of the society. Keeping in pace with this, mineral production is continuously increasing along with the scale of mining operations. As mining goes deeper in response to depleting resources, declining ore grades and the quest to reduce costs, the future of underground mining will be driven by better utilization of resources and innovative methods to advance safety and increase productivity. The technological developments in the field of advanced and more efficient production equipments, better communication systems and automation in mining industry would make the underground mining safer while at the same time boosting production.

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