INTERNATIONAL CONFERENCE ON SUSTAINABLE MINING OPTIONS… WAY AHEAD

PROCEEDINGS

ICSMO 2022

03-05 June 2022

Organized by :

IMMA (NAGPUR), MOIL, WCL, VIMA, THE MINER'S ALLIANCE

NAGPUR INDIA

INTERNATIONAL CONFERENCE ON SUSTAINABLE MINING OPTIONS... WAY AHEAD

EDITED BY

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मनोज कुमार
अध्यक्ष-सह-प्रबंध निदेशक

Manoj Kumar
Chairman-cum-Managing Director

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Message

It gives me an immense pleasure to know that The Nagpur Chapter of Indian Mine Managers' Association is organising a National Summit on "Sustainable Mining Options.....Way Ahead" from 03rd to 5th June, 2022 at Nagpur with wide participation from various Mining Companies – Coal and Non Coal, Academia and different Government Organisations.

A sustainable and robust mining sector is an essential element in Indian growth story and this can be achieved only if socially and environmentally acceptable methods are adopted. Mining sector contributes approx. 2.2 to 2.5 % of the GDP and is poised to grow at a faster pace for firing and fuelling the country's growth engine. As a custodian, of natural resource, to future generation, we are responsible for preventing its misuse and degradation. An effort to find solution towards sustainable mining through technological intervention and making it effective, efficient and responsive to quantum need is sine quo non for existence and growth of mining industry. I am sure that this summit would help towards identification and adoption of suitable technology for exploitation of natural resources and bridge the existing impediments.

I am also happy to learn that on this occasion a souvenir is being brought out for assimilating the technical papers and key notes which would serve as a reference and guiding light towards adoption of outcome of the summit.

I convey my best wishes for the grand success of the National Summit on "Sustainable Mining Options......Way Ahead" while commending the Organizers for their endeavour and commitment towards technological and societal betterment.

(Manoj Kumar)

MUKUND P. CHAUDHARI
Chairman-cum-Managing Director

Azadi Ka Amrit Mahotsav

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Date: 31st May, 2022

MESSAGE

It gives me immense pleasure to know that The Indian Mine Managers' Association, Nagpur Chapter has taken great initiatives for organizing an international conference between 3rd June and 5th June, 2022 on *Sustainable Mining Options.... Way Ahead*, to deliberate on sustainable mining options for feasible solutions to protect the environment, flora and fauna.

It is worthwhile to put on the record that our aim is to stop degradation of environment and to build a future in which humans live in harmony with nature by conserving the natures biological diversity, ensuring that the use of natural resources is sustainable and promoting the reduction of pollution and wasteful consumption.

Minerals are depleting resources of the mother earth and, therefore, need to be exploited scientifically and utilized optimally. Hence, all mining activities should be planned meticulously and systematically for conservation of the resources. Sustainable development can occur only when there is a balance between environment management and industrial management. Organizing an International Conference on *Sustainable Mining Options.... Way Ahead* will definitely go a long way in creating awareness amongst one and all towards the crucial facets of our working and, at the same time, also make us realize our role and responsibility in furtherance of the noble cause.

I extend sincere and best wishes to organizers of this endeavor and wish the International Conference a grand success.

मुकुंद चौधरी

M.P. Chaudhari
Chairman-cum-Managing Director

PREFACE

While world is grappling with the truth of environmental issues due to exploitation of mineral resource, particularly, hydrocarbons – both coal and crude oil, the technologists are giving their best to meet the challenges of the industry. The international conference ICSMO2022 was converged to bring the planners, executors and researchers on one platform to discuss the need of the hour and how different issues of mining are being addressed by way of research or technological developments.

The conference was attended by several stalwarts of the mining industry from India and abroad. The technical deliberations have been summarized in th proceedings. The topics that have been covered include:

Sustainable development, dump slope stability, overburden dump accommodation, Mining-4, green mine closure planning, deployment and developments in mechanical excavations, use of rehabilitation methods using artificial soils, deep sea mining, mine closure planning for green options, economics of hydrocarbon minerals, use of flyash as void filling material, use of hydrogen as fuel in mining and technological innovations.

We are hopeful that the readers will definitely benefit from the contents provided herein. Please provide your feedback or questions on icsmo2022@gmail.com that we will be happy to share with the authors for getting response.

Dr. Avtar K Raina

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Utilization of artificial soils created by industrial symbiosis & Holdfast GT phalaris in mine rehabilitation

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ABSTRACT: As time progresses and the need for a cleaner energy production substitute other than coal becomes more apparent, existing coal mines for the purpose of energy production face the reality of mine closure and shutdown. Coinciding with the need for natural preservation through the reduction of greenhouse gas emissions is the need to preserve the natural environment through successful rehabilitation of land effected by mining efforts. This report looks at the application of Holdfast GT phalaris in conjunction with four artificial topsoils (ATS) to overcome deficiencies in topsoil (TS) associated at AGL's Loy Yang mine site. The ATS were created through industrial symbiosis of brown coal (BC), overburden (OB), fly ash (FA), subsoil (SS), SORF compost and TS. Greenhouse and field styled growth trials were conducted to assess the performance of each ATS as well as the performance of the Holdfast GT phalaris in utilisation of macro and micronutrients. Analysis of results has shown that ATS using a combination of OB, FA, BC and compost provide the most likely means of sustainable plant growth in Holdfast GT phalaris however additional fertiliser or sowing in conjunction with clover will increase the productivity and quality of pasture.

1 INTRODUCTION

1.1 Problem definition

As the brown coal mines of the Latrobe valley approach closure and the energy sector moves to create a more carbon neutral system, the need for successful and sustainable rehabilitation methods is becoming more apparent. Unsuccessful rehabilitation poses a variety of risks to the safety of personnel and the health of the natural surrounds. The primary threat is from erosion caused by water runoff during rain events and the potential of heavy metal leaching. Without established vegetation the water runoff will cause substantial erosion which can result in unstable batters that have the potential to collapse over time.

A successful rehabilitation process involves the following stages in order to mitigate the adverse effects previously mentioned:

- Initial layering of overburden (OB)
- Capping of the OB with topsoil (TS)
- Seeding of desired vegetation

Initial layers of OB are used to cover the remaining exhausted coal beds and to create a suitable profile for the batters. The TS layer is used as a nutrient rich bedding for successful seed germination and plant growth. Due to the reshaped landscaped caused by the large-scale surface coal mine, previous stockpiles of TS lack the volume required to allow successful rehabilitation. Artificial topsoils (ATS) are being investigated as a real solution to the demand for a topsoil substitute and a use for an ever-increasing stockpile of fly ash, OB and lignite/brown coal (BC) through industrial symbiosis with compost. To render the ATS's successful, there must be an ability to support sustainable plant growth and allow the nullification of erosion and heavy metal leaching.

This research paper investigates the ability of a variety ATS's to support the germination and growth of Holdfast GT phalaris in the aim of producing a reliable and long-lasting solution to successful rehabilitation of open cut coal mining batters with natural topsoil deficiencies.

Greenhouse and field styled trials were executed with data regarding seed germination and advancements in foliage height being recorded during the experimental procedure. After the completion of the growth trials, foliage and root masses were recorded and samples of plant tissue and soil were analysed, the results of which are presented within this report. A separate seed germination experiment was completed to indicate the potential of the Holdfast GT Phalaris seed used in the trials.

1.2 Previous experimentation

Previously a greenhouse experiment of a variety of combinations and subsequent ratios of waste streams were used to create several ATS's to assess plant growth and metal leaching. Perennial ryegrass and clover were grown in each ATS and monitored for germination and eventually assessed for dry mass and a plant tissue analysis conducted. The four best performing topsoils regarding dry plant mass and nutrition value were selected for further experimentation on performance. The selected ATS compositions are a combination of subsoil (SS), OB, TS, fly ash (FA), brown coal (BC) and compost with exact ratios seen below in figure 1.

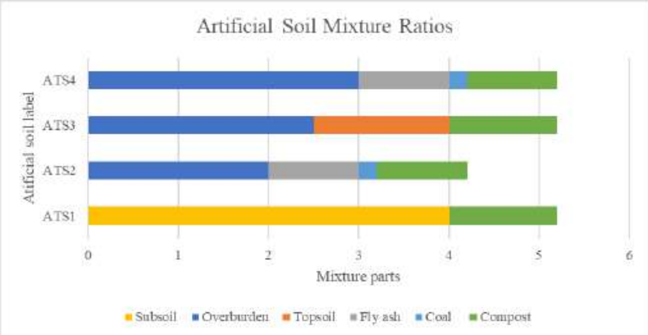

Figure 1. compositions of ATS's

2 LITERATURE REVIEW

2.1 Topsoil

A topsoil is defined by a combination of the minerals that have been eroded and the organic matter that has broken down in order to create the material that remains (Nortcliff, et al., 2012). These minerals and organic matter dictate the nutrients available and the structure of the topsoil which effects the ability for plant growth to be supported. In creating an ATS it is crucial to allow for effective plant nutrients and soil structure to be considered if effective plant growth is to be achieved. The crucial macronutrients by which a topsoil should contain in order to promote vegetation are nitrogen, phosphorus, potassium, calcium, magnesium and sulphur whilst some important micronutrients include boron, iron, manganese, copper, zinc, and Molybdenum (White & Brown, 2010). A productive soil will contain a healthy balance of macro and micronutrient levels so that the nutrients may be accessed by plants and utilized for growth.

2.2 Overburden/subsoil

The production of overburden (OB) within an open cut coal mining operation is unavoidable as it must be removed, as well as topsoil and subsoil layers, in order to access the valuable coal resource below. This is generally not the case for underground coal mining methods. Typically, as mine life increases, the stripping ratio of mining activities increases due to coal seams becoming deeper below the surface as well as becoming more complex (Westcott, et al., 2009). As a result, the volume of OB that is removed increases per tonne of coal that can be mined. This is problematic due to the hazardous nature of OB as it contains sulphide minerals and heavy metals. If the sulphides are exposed to oxidising conditions, pH levels can decrease and cause the mobilisation of heavy metals or heavy metal leaching. Acidic pH levels and heavy metal leaching is detrimental to the natural environment which hinders the ability for successful rehabilitation (Park, et al., 2014). Addition of OB to ATS's provides an alternative to the creation of OB stockpile, which are both a hinderance to the natural environment and the aesthetic of a mine and creates an opportunity for a reduction in waste. OB is an abundant source that can be used as a major constituent of ATS's however it contains poor levels of the major nutrients required to support plant life (Wong & Bradshaw, 2002) and is composed of mainly rock and clay. Other additional constituents must be utilized to overcome the extreme deficiency or excess of nutrients supplied by OB.

2.3 Fly ash

Fly ash (FA) is a bi-product of burning coal at high temperatures using coal-fired power plants. The production of energy from coal-fired power stations in Australia per annum is said to 'produce 12 million tonnes of ash from burning coal' (Millington, 2019). This creates a large amount of pressure to correctly dispose of FA as it poses a serious threat to the natural environment due to the ability to leach heavy metals. Correct disposal of FA from wet processing requires the slurry to be hydraulically pumped to settling dams in which the FA can settle and be separated. The FA must then be put into a dump facility so that it remains undisturbed. The process of allowing FA to settle and be dumped requires large portions of land increasing the negative environmental impact and increasing the cost associated with energy production (Black, et al., 1992). The possibility of wind erosion and the mobilization of FA at designated dumps remains a threat to the environment. FA is, however, abundant in many of the macronutrients required for successful plant growth and is alkaline in pH (Mupambwa, et al., 2015) which provide an opportunity for increasing the a soils nutrient capacity and neutralizing a soil that is acidic in nature.

2.4 Brown coal/lignite

Brown coal (BC) may be rejected as waste if it doesn't possess the desirable qualities regarding moisture, ash or sulphur content required for energy production. This results in increased waste production which creates cost through disposal. BC within soil can increase the availability of phosphorous and is a rich source of humic substances whilst also decreasing the ability for heavy metals to be leached (Tran, et al., 2015). Humic substances are what make up the majority of soil and are essentially the decayed or decaying biomatter. This provides that the addition of BC or lignite to an ATS will provide the benefit improving the structure of the soil whilst helping to reduce the ability for the heavy metals of other constituents to become mobile.

2.5 Soil and Organic Recycling Facility (SORF) compost

Derelict soils that are unproductive in the growth of plants are typically lacking in organic matter as organic matter plays an important role in both providing nutrition and increasing water retention capabilities. Organic matter, having once been a part of living plants, contains many of the valuable nutrients that plants consume during a lifecycle. As the organic matter is further broken down into the soil that it exists within through microorganisms, the stores of predominantly N and P become available to the plants that require it. This makes organic matter an important resource of insoluble N and P that cannot be substituted by additional fertilizer (Wong & Bradshaw, 2002). Organic matter can be substituted through the addition of green waste, which is essentially recycled plant matter, until the process of plant growth and decay can be assumed. An anaerobic green waste compost supplied by Gippsland Water's Soil and Organic Recycling Facility waste stream has been utilized as an organic waste substitute in some ATS creation.

2.6 Holdfast GT Phalaris

When considering which grass is suitable for a mine site environment, it is important to consider the conditions that it will be exposed to. A mines focus is on production so it can be said that selecting a grass variety that is able to be durable and persistent is paramount. Phalaris, once established, is an extremely hardy deep-rooted perennial grass that has resistances to a variety of conditions that could potentially cause other pastures to fail. Phalaris shows tremendous winter pasture productivity, resists water logging and common agricultural pests, has few diseases and has periods of dormancy during times of drought which aid in its longevity and with the prodictability and reliability of seasons declining, proves to be a valuable trait (Smith, 2013).

In Australia's eastern states it is estimated that up to 5.2 M hectares are sown to phalaris (Hill & Donald, 1997) with a split of 61% in NSW, 21% in Victoria, 16% in South Australia and 2% in Tasmania (Smith, 2013). This proves the versatility of phalaris in Australian agriculture.

Holdfast GT phalaris was bred after the desire to create a strain of phalaris that is more winter active and more persistent to consistent grazing. It performs optimally in areas of rainfall averaging over 600mm per annum (Smith, 2013).

3 METHODS AND MATERIALS

3.1 Preliminary soil analysis

Prior to the commencement of any experiment, sample of the ATS's, weighing roughly 300g, were taken and sent away for external examination by the Environmental Analysis Laboratory (EAL). Samples of each ATS type can be eventually compared to samples taken post growth trial for indication of soil performance and potential areas of improvement.

3.2 Growth trial location

Due to restrictions faced during the Covid-19 pandemic, this study was carried out on farmland provided by DK and KM Edgerton located just north of Balmoral in the Southern Grampians shire, Victoria (-37.21, 141.82). The region that this experiment is associated with is the Loy Yang mine site which is located east of Morwell in the Latrobe Valley, Victoria (-38.23, 146.57). Soil samples were initially collected from site for use in this experiment. Both regions are in productive farming regions of Victoria that have a mild climate and exposed to similar rainfalls and frost risks. (Bureau of Meteorology, 2020). This allows the plot data found in the experiment to be relevant to what can be predicted to be achieved at the Loy Yang mine site.

3.3 Field and greenhouse trials

Both the field and greenhouse experiments were designed to be small scaled growth monitoring trials consisting of 4 separate plots of each ATS in question and 4 separate plots of natural TS found on site at the Loy Yang mine site. The decision to use 4 plots of each ATS and TS within both the field and greenhouse trials was to increase the experimental data so that any outlying results or possible errors can be predicted and eliminated. As there are 4 different ATS and a natural TS being examined, there will be 20 plots for both the field and greenhouse trials. The plots were arranged in a grid like formation that allowed for each individual soil type to be exposed to all positions so that any biased data may be eliminated. The arrangement of the plots can be seen in figure 2.

Topsoil	ATS4	ATS3	ATS2
ATS1	Topsoil	ATS4	ATS3
ATS2	ATS1	Topsoil	ATS4
ATS3	ATS2	ATS1	Topsoil
ATS4	ATS3	ATS2	ATS1

Figure 2. Plot arrangement for field and greenhouse trials

Each individual plot of soil was created by using a small sized garden plant pot of 67.5mm radius and 140mm height, with each plant pot containing 30mm of overburden to line the bottom followed by 80mm of a specific soil type. This gave an accurate representation of the field conditions expected to be created on the batters on site of the Loy Yang mine site. Each plot, once filled with a layer of overburden and corresponding soil, weighed on average 1500g.

It was decided that sowing regimes at the Loy Yang mine site were to be at least double that of recommended rates thus at a normal recommended sowing rate of 3-4 kg/hectare (Watson, et al., 2000), a sowing rate of 9 kg/hectare was to be displayed within each plot. This process involved finding the cross-sectional area of the plant pots and converting it from a value of mm2 to a value of hectares. After finding the cross-sectional area in hectares, this value could be multiplied by the sowing rate to find the weight of seed needed to be applied to each plot in order to achieve a sowing rate of 9 kg/hectare. This can be converted into the number of phalaris seeds required by multiplying by the number of phalaris seeds needed to make a kilogram (880’000 seeds/kg). The results of these calculations and the subsequent number of seeds required are summarised below in table 1.

Table 1. Summary of seeding rate calculations

Plot attribute	***Result***
Sowing rate	*9 (kg/hectare)*
Plot cross section	$1.43*10^{-6}$ *(hectare)*
Seed mass per plot	*0.013 (g)*
Seeds per kg	*880’000*
Seeds per plot	*12*

Having placed the 12 individual seeds into each of the plots, covered with a thin layer of corresponding soil and the plant pots arranged into the required formation in both the field and greenhouse trials, a watering and monitoring regime was implemented. The watering regime was implemented only for the greenhouse trial whereas the field trial was exposed to natural rainfall instead. The water regime consisted of applying 250ml of rainwater per plot twice a week for the entirety of the experiment. The monitoring regime consisted of measuring the foliage height once every two weeks once plants begun to mature beyond seedlings. This was to give an indicator of performance throughout the experimental process.

At the conclusion of the field and greenhouse trials, the grass was to be cut off level with the soil in each plot, weighed and stored so that is could be sent away for plant tissue testing. The plant tissue testing will provide data regarding the health of the phalaris that has been grown and the potential for it to be grazed by stock. The roots will also be extracted from the soil, weighed and stored for eventual dry weight. The mass of roots present will give an indication of the quality of grassland production (Skuodiene & Tomchuk, 2015). As well as foliage and root samples, soil samples of 300g were taken of each soil type in both greenhouse and field trials and sent away for external assessment.

3.4 Germination test

In conjunction to the growth monitoring tests in field and greenhouse environments, a germination test was completed to indicate the seed performance of that used within the growth monitoring trials and to indicate if the soils had any properties which would inhibit the germination of phalaris seed. The test was completed over the month of June when normally winter sowing would occur prior to the cooling of the soil. Typically a warm germination test will be completed maintaining 25˚C and 95-100% humidity for 5-8 days however due to the inability to access a facility to complete such a test due to Covid-19, alterations were made in order to complete the germination test locally at the property provided by DK and KM Edgerton. The germination test required the use of paper towel, 5 petri dishes, 100 phalaris seeds and deionised water. Each petri dish had the bottom lined with paper towel with 20 seeds evenly placed on top of the paper towel. The seeds were then watered in by addition of 6mls of deionised water per petri dish. The lids of the petri dishes were added, and the dishes placed in a secure location that was in direct sunlight. The dishes were moved under cover during the night to avoid the possible frost risk. After four weeks the germination test was terminated and the seeds that didn’t germinate were tallied for results as a percentage germination.

4 RESULTS

4.1 Germination results

As seen in figure 3, the results of the germination test as represented by the green horizontal line depict that the Holdfast GT phalaris seed utilized within the trials has an average germination result of 68% due to 32 of the 100 seeds analyzed being unable to germinate.

Figure 3. Plot average germinations & germination test results

In the early stages of the field and greenhouse growth trials the seeds planted within the plots were monitored for germination. Aside from ATS4 which showed improved germination, all other soils were below the tested percentage germination. Another trend was that the field trial had a lower percentage germination than that of the greenhouse.

4.2 Growth monitoring

The fortnightly foliage height measurements taken at the intermediate stages of the greenhouse and field trials are presented in figures 4 and 5. The results were generally tightly grouped with average plot foliage heights differing 30-40 mm. The results from the greenhouse trial far exceeded that of the field trial although the ATS performance trends were similar in nature with TS, ATS2 and ATS4 performing better as time progressed while ATS3 declined after a faster initial growth rate. ATS1 generally struggled to perform at the level of the other plots. It should be noted that foliage height was just one key performance indicator utilized in the trials and others such as leaf count or leaf width may also be used.

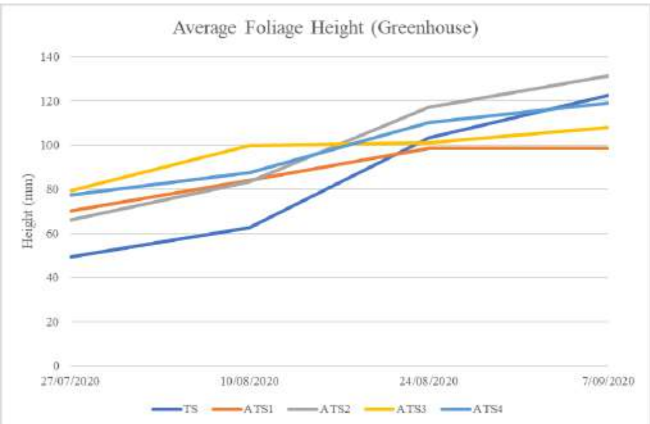

Figure 4. Greenhouse growth monitoring

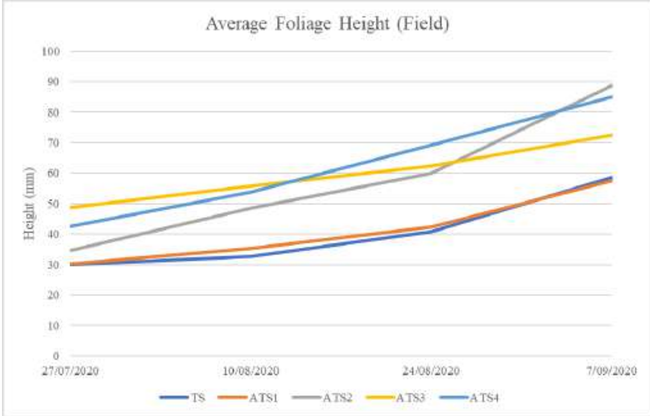

Figure 5. Field growth monitoring

4.3 Plant mass analysis

The results of the weighing the foliage cut from ground level after 4 months of growth are presented below in figure 6. Results from the greenhouse trial far exceed that of the field trial but the best performing soils in ATS2 and ATS4 remain the same in both cases.

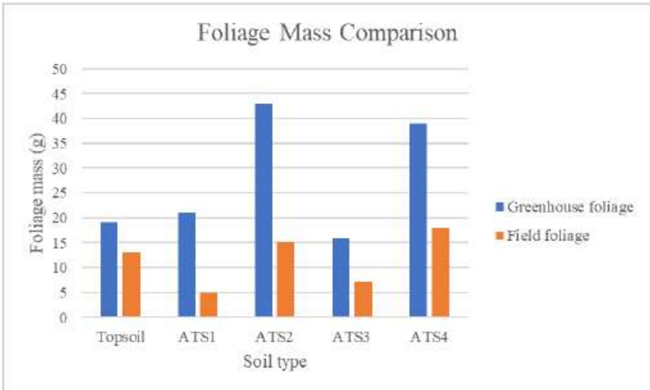

Figure 6. Total foliage mass of each trial

The mass of the root systems of each soil type is summarized below in figure 7. The results depict trends that match that of the foliage mass in figure 6 with ATS 2 and ATS4 outperforming the other soils in both field and greenhouse trials.

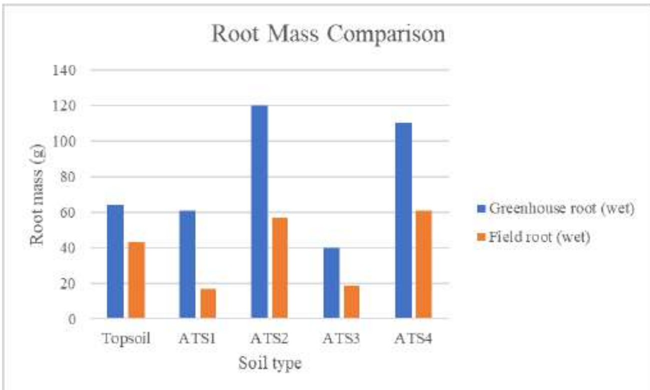

Figure 7. Total root mass of each trial

4.4 Plant tissue analysis (macro and micronutrients)

Results to the tests completed by the EAL regarding the relevant macronutrient values of the phalaris foliage for each soil type can be seen within figure 8. There is also the addition of results from past testing completed for the growth of perennial ryegrass and clover for additional comparison. Figures 9 depicts the crude protein and the micronutrients of the phalaris trials alongside of the perennial ryegrass and clover.

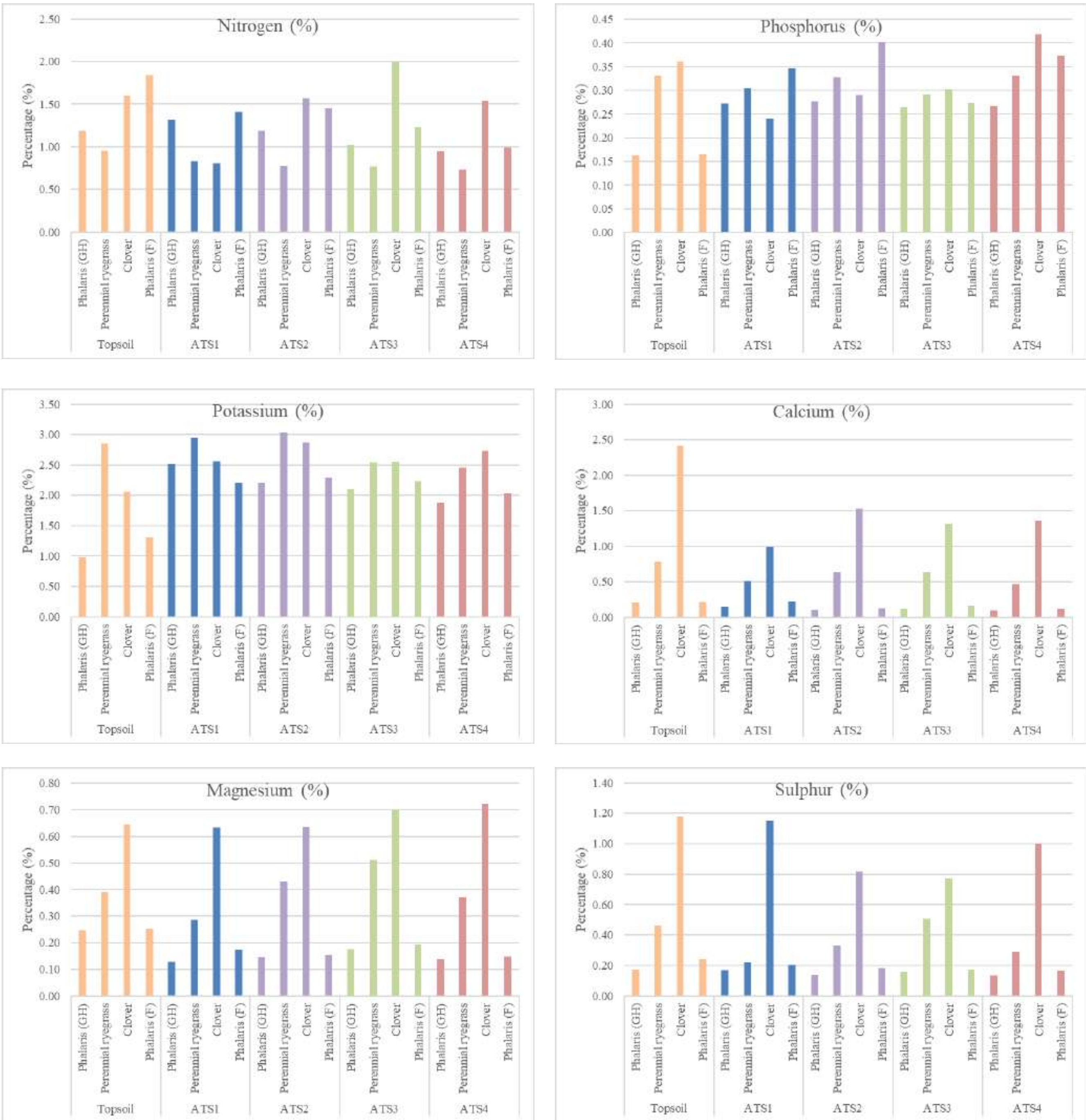

Figure 8 Macronutrients for Holdfast GT phalaris in both greenhouse and field trials alongside trials for clover and perennial ryegrass

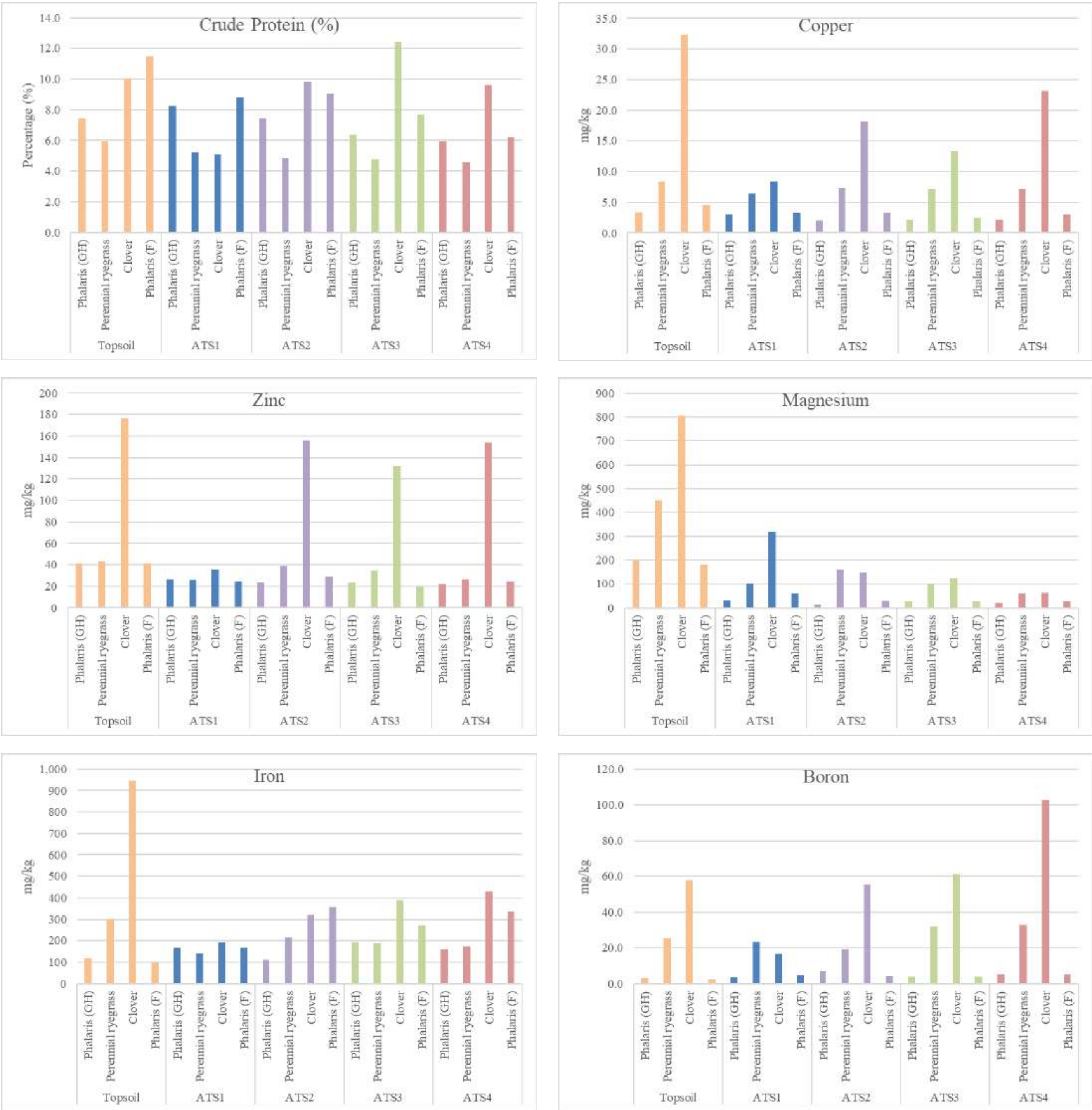

Figure 9. Crude protein and micronutrients for Holdfast GT phalaris in both greenhouse and field trials alongside trials for clover and perennial ryegrass

5 DISCUSSION

5.1 Germination

Aside from ATS4, which displayed a percentage germination higher than that of the germination test, all soils had a reduced percentage germination in comparison to what was tested. This response was expected as the germination test was completed under controlled conditions with little variation in temperature and climate whereas the seeds in the trials, particularly the field trial, were left alone after sowing with only the greenhouse trial seeds being watered twice a week. This exposure to a more natural climate is less ideal for seed germination which is seen within the results of the trial germination.

The TS plots in both the field and greenhouse trials performed evenly in terms of percentage germination and several ATS plots showed promising signs in comparison. All ATS plots apart from field trial plots for ATS 1 and ATS2 performed better than that of the TS plots. This proves that the ATS are suitable in comparison to TS when aiming to germinate Holdfast GT phalaris and it shows that the combination of ATS and Holdfast GT has overcome past problems of increase salinity.

A major difference observed in percentage germination results was between the field and greenhouse trials for ATS 1. ATS 1 is comprised from SS and compost alone without any addition of BC or FA. The addition of BC and FA to soils provides an improved soil structure and water retention. It is thought that the less frequent watering through rain may have allowed the soil to dry and subsequently had a negative impact on the germination of phalaris seeds.

5.2 Plant growth and mass

Comparing the results from the greenhouse trial and the field trial it is obvious that the greenhouse foliage performance was superior in all examples of soil which is as expected due to the controlled climate conditions. The regular watering maintained moisture levels which provided a water source for the plants but also improved the structure of the soil. It became apparent during the field trial that the infrequent rain allowed the plots to dry and the soil to harden and shrink. This had a flow on effect of reducing the ability of water to be absorbed into the soil and for the roots of the phalaris to penetrate the soil. As the trials progressed it appeared that this only resulted in a slower process of plant growth as the field trial plant growth continued to increase as seen with a positive gradient in figure 5.

5.2.1 *ATS 1*

The growth of ATS1 in both trial scenarios was well below that of the other ATS plots trialled and at the cessation of the growth monitoring it exhibited the lowest foliage height recorded. It was similar to TS in the field trial which showed similar growth results and in the greenhouse trial the growth appeared to have ceased all together. The combination of SS and SORF compost aimed at providing a use for the biproduct in SS whilst providing a means for plant nutrition through the application of the anaerobic green waste. The growth monitoring indicates that ATS1 proved successful in the early stages of plant growth being able to successfully germinate and promote growth for a period as can be seen with the initial positive gradient in the greenhouse trial and throughout the field trial. After the plants began to be established the growth waned and eventually came to a halt giving reason to believe that the phalaris had begun to exhaust the supply of accessible nutrients provided by ATS1. Although the SORF compost is a valuable resource for plant nutrition as it is broken down by microorganism, perhaps the ability for ATS1 to support the necessary microorganisms to break down the compost into nutrition that is soluble and can be utilised by phalaris. The lack of nutrition may also be down to the fact that all of the nutrients from the supplied compost had been utilised and that an increased ratio of compost to SS is required to support the growth of phalaris until commencement of a healthy and sustainable lifecycle can be achieved.

The mass of both the foliage and root systems of phalaris in ATS1 displayed poor results in the field trial but results comparable to TS in the greenhouse trial. Concentrating on the greenhouse trial in which the plots weren’t allowed to dry, the foliage and root mass results show that ATS1 was successful in the growth of Holdfast GT phalaris however tapering of growth rate toward the end of the trials gives reason to doubt the longevity of plant establishment.

5.2.2 *ATS 3*

The growth of ATS3 appeared to follow a trend of providing rapid early productivity yet in the latter stages of plant growth failing to be able to maintain such a level of plant growth. The initial growth in both field and greenhouse trials was the largest out of all topsoil varieties yet in the space of two weeks was abruptly overtaken and although growth never ceased, the rate of growth declined substantially. OB is the main constituent of ATS3 and is boosted by the addition of TS and SORF compost. Having a large amount of OB which is largely made from clay is a positive in terms of waste reduction however posed the problem of providing a pore texture due to the high clay content as well as a lack of fundamental plant nutrients. The addition of the SORF compost, as mentioned previously, should bolster the nutrients required for plant growth and aid in water retention and the TS should be provide the benefit of likening ATS3 to the natural occurring TS of the Latrobe Valley region in both nutrition and texture. Much like ATS1, ATS3 appeared to exhaust the nutrients available and was unable to maintain a suitable level of moisture. The lack of sufficient nutrients to continue plant growth can be seen to be associated with insufficient compost or microorganism activity whilst ATS3 was also visually lumpy and inconsistent in texture with large portions of clay and rock that had not properly combined which didn’t allow for effective water retention. In the environment of small garden pots the lack of water retention cause the clay to harden and shrink which made water retention progressively worse.

The final masses of ATS3 plots in both forms of trial are roughly 30-50% less than that of the results seen in the TS plots. This indicates that the combination of phalaris and ATS3 could be unsuitable as a sustainable plant lifecycle may not be able to be achieved.

5.2.3 *ATS 2 & ATS 4*

Phalaris growth in both ATS2 and ATS4 was similar to each other and followed the same trends in both the field and greenhouse trials. This was expected as the constituents of both topsoils were the same utilising OB, FA, BC and compost, only differing in the amount of OB with ATS2 containing 1 part less. Both ATS performed particularly well with ATS4 displaying a larger growth rate in the beginning and ATS2 finishing strongly being the most dominant regarding foliage height out of all the topsoils. The combination of OB, FA, BC and SORF compost in the defined ratios has proven particularly effective in creating a balanced ATS regarding nutrients, soil texture and water retention capabilities. The amount of OB that was utilised within each ATS displays a positive outcome in reducing what would otherwise be considered waste. Incorporation of FA, BC and compost successfully overcame the lack of nutrients, poor texture and water retention displayed by OB and allowed sustained access to required nutrition for successful phalaris growth throughout the period of the trials. The major difference between ATS2 and ATS4 and the other ATS is the addition of FA and BC. The additional FA and BC is considered to have further neutralised the pH of the acidic OB whilst adding increased levels of accessible nutrition and increased water retention beyond the level of what was achieved in other ATS by SORF compost alone. Soils with lower pH levels decrease the ability for some soil nutrients to be accessible to plants so application of alkaline or neutral substances such as FA or BC can aid in raising the pH level of soil and essentially unlocking the soil nutrients to be utilised for further plant growth.

The results for the mass of root and foliage of phalaris grown in ATS2 and ATS4 far exceed the results seen in TS, which when coupled with the data received from the growth monitoring proves both instances of ATS are capable of producing a Holdfast GT phalaris pasture that is both fast establishing and healthy in comparison to TS.

5.3 Macro and micronutrients

The value of agriculture comes from the quality of the plants that it can grow which is directly related to the nutrient value that the plants possess. Due to the fact that the aim of rehabilitation of the Loy Yang mine sites pit batters is to create land that is suitable for grazing by stock, it is essential that the nutrient value of the resulting pastures are known as this indicates the potential it has for increasing stock mass and also for the nutrients it can further provide future pastures as old foliage comes to the end of its life cycle. The comparisons in macro and micronutrient values also consider the results which were obtained in previous experimentation of perennial ryegrass and clover with the same ATS and TS varieties.

Considering the macronutrients of the phalaris produced by the 4 ATS and TS plots, results regarding percentage of nitrogen are particularly noteworthy as the phalaris shows results that are comparable to clover. Clover, being a legume, typically displays higher levels of nitrogen which is particularly useful for consumption by other plants when growing. The Holdfast GT phalaris also displays decent levels of phosphorus and potassium in comparison to ryegrass and clover. Calcium, magnesium and sulphur content of Holdfast GT phalaris is noticeably less than that of ryegrass and clover plant tissue however all macronutrient levels within the phalaris plant tissue grown in ATS are thereabouts in comparison to that grown in TS. This shows that the addition of compost and FA successfully provides the necessary macronutrients.

The percentage of crude protein present within the Holdfast GT phalaris foliage grown in ATS was down from what was produced in TS as well as that which was measured in clover and ryegrass, aside from ATS1. As increased crude protein is related to increased stock performance, this is an undesirable result. In ATS2 and 4 the crude protein of phalaris was however larger than that of the ryegrass.

In all measurements of micronutrients, Holdfast GT phalaris was lower than that of clover and ryegrass. For grazing purposes and for future plant growth this may have to be rectified so that imbalances do not occur.

6 CONCLUSION

The use of industrial symbiosis to create ATS was aimed at creating a substitute for a deficiency in naturally occurring TS at the Loy Yang mine site for rehabilitation aimed at future agricultural purposes. Four ATS were created from waste streams produced by AGL's Loy Yang mine site and power plant as well as Gippsland Waters SORF to create products that both aided in the preservation of the natural environment as well as a reduction in cost for waste disposal. The purpose of utilising Holdfast GT phalaris was to complete the rehabilitation process by growing a production and sustainable covering of pasture to prevent erosion of rehabilitated mine batters.

From the completion of greenhouse and field style growth trials it is observed that all ATS were successful in the germination and growth of Holdfast GT phalaris however performances by ATS2 and ATS4 produced unrivalled results that suggest that sustainable growth is achievable. Upon conducting tests on the level of nutrients available it is apparent that deficiencies may present regarding some macro and micronutrients as well as crude protein which could have adverse effects on future plants or stock when grazing.

It is recommended that for more effective and rapid growth that a suitable fertilising program is considered as this will aid in combatting any deficiencies in nutrients. Another possibility would be to sow Holdfast GT in conjunction with clover so to provide additional nutrition however a low rate of clover is advised so to that a negative impact is had on the establishment of phalaris.

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Study of Effectiveness of Hydrogen Vehicles in Mining Industry

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ABSTRACT:

Hydrogen has the potential to provide abundant quantities of clean transportation energy. This research is based upon the issues associated with the sources of energy for the sustainability of current mining equipment or vehicles such as shovel, trucks, excavator, underground loader, mining truck, crane, bulldozer and so on. In the current technology all mining equipment or vehicles are mainly run by non-renewable energy sources like fossil fuels, diesel, petrol and kerosene which are limited in nature and will runout after certain time. Therefore, for the longevity of the mining activities, choices of the energy sources play significant role. Without energy sources, no activities can be done. Moreover, it is a scenario of having energy crisis in the world for upcoming future to find out an alternative energy path is emerging demand. This work helps to find out the best viable solutions of current problem of energy sources by replacing sustainable fuel specially for the mining equipment. To evaluate hydrogen fuel economy in mining vehicles, data collection method and numerical calculation approaches have been done. Analysis is done based on the mining vehicles run by different energy sources like diesel "Sandvik TH551i" and battery "Artisan Z50' that are underground mining trucks, and purposed hydrogen "Nikola Tri sec'. Research results proved that suggested hydrogen powered mining industries are economic in production saved 63.18% energy cost with comparison to diesel. Energy cost per km hauled up decline at 1:7 for diesel is 9.1 $/km,4.2 $/km for electric and possible hydrogen is 3.35$/km. Furthermore, hydrogen transition saved safe USD 1038800 ventilation cost in Meikle-Rodeo mine. From the environment point of view hydrogen vehicle reduces 4.44 megatons of carbon footprint annually in Australia. By evaluating all the parameters, it can be concluded that overall hydrogen transition in mining equipment will provide future sustainable, cost effective, eco-friendly, safe, and better mining operation.

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1. Introduction

The purpose of this research is to find out feasibility of the hydrogen economy in the mining industries related to alternative power supply and amount of ventilation cost saving, specifically effectiveness of the hydrogen fuel cell vehicles in mining in terms of the production energy cost saving. In current practices, transport system in the world mainly based on the fossil fuel like diesel, petrol and kerosene oil, which are evaluated non-renewable sources of energy. Hydrogen has possibility of plentiful supplies of future sustainable clean transportation energy. Hydrogen is the useful transportation fuel in such a way that it is a least polluting fuel that can use in internal combustion engine as well as fuel cell and it is potentially available wherever there is water.

With the continued consumption of fossil fuels, the daily demand has been increasing due to its limited storage in nature after certain period of time amount of fossils fuel will run out and will take many years to reform. Therefore, the concept of alternative fuels is emerged. Hydrogen is the most abundant and lightest element in the universe which is an odorless, tasteless nontoxic and colorless gas found in the air having concentrations of about 100ppm (0.01%) (Suban et al., 2001). To make a decision for choosing any fuel, an alternative fuel needs to have technically viable, eco-friendly, economically competitive, and readily available (Mehar, Sagar, Naik: 2006). Many researchers suggested potential alternative fuels including hydrogen, natural gas, Liquid gas (LPG), boron, biodiesel, methanol ethanol, Fischer-Tropsch fuel and so on. Among them, the researcher found one of the best alternative fuels for the future end use is the hydrogen which contains the highest specific energy of all conventional fuels.

Hydrogen has a very low density. This leads to two problems when used in an internal combustion engine (Balat, 2007). It takes a very large volume to store enough hydrogen to give a vehicle an adequate range, and the energy density of a mixture of air and hydrogen and thus reduces the output power. However, the fuel cell has better performance than internal combustion.

In the global scenario, hydrogen fuel will play a crucial role in the sustainable development of all nations and their future mining activities. The idea for commercialization is first introduced by U.S President George W. Bush in 2003. He declared a US$1.2-billion budget to develop commercial hydrogen fuel cell- vehicles aiming to reduce carbon footprint and dependencies on fossils fuels (Jeff, 2010). After the strong research and development, most of the U.S.A market commercially launched hydrogen vehicles such as The Toyota Mirai, Honda Clarity, and Hyundai iX35 available in the market. From the data available in open source till February 2019, there were 6,558 number hydrogen fuel cell vehicles on the road in the U.S. Roughly 5,000 of them are Toyota Mirai. Currently, there are two car models in Australia that have launched the Toyota Mirai sedan and the Hyundai Nexo SUV. By increasing the global vehicle ownership, the rapid increment of consumption of fossil energy and environment pollution have become a global issue. Hydrogen vehicles have the benefits of long driving range and short refuelling time, which is complementary to electric vehicles (EVs) (Yi, 2018). Due to the increasingly prominent role of hydrogen energy in the world energy revolution, many developed countries have issued hydrogen energy roadmaps or action plans (Liaowang Institute, 2019). As an important application field of hydrogen energy, the promotion of hydrogen fuel has received strong support from governments of various countries.

2. Background Theory

This paper focuses primarily on the cost, safety and efficiency of hydrogen fuel vehicles in mines. Hydrogen is a dream in a mining industry, one that primarily consists of reducing fossil fuel spending and providing important environmental protection for future generations. with many social, economic and environmental benefits. It has the long-term potential to reduce reliance on foreign oil and reduce carbon and tax emissions from the

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transport sector. It was only in the last decade that the idea of a hydrogen-based economy based on fossil fuels began to gain interest. Hydrogen has a high energy yield of 122 kJ / g (kilojoules per gram), which is 75 times higher than that of hydrocarbon fuels (Barnwal and Sharma, 2005). It is being investigated for use in internal combustion engines and fuel cell electric vehicles. The global hydrogen market already exceeds $40,000 million a year (Kraus, 2007) including hydrogen used in ammonia production (49%), petroleum refining (37%), methanol production (8%) and various smaller volume applications (6%). Hydrogen sales have increased 6% annually for the past five years, closely related to the increased use of hydrogen in refineries due to stricter fuel quality standards (International Hydrogen Energy Magazine 33-258.2008). Current hydrogen use corresponds to 3% of energy consumption and an estimated growth rate of 5-10% per year. The US consumes around 1.5 EJ (exajoule) of hydrogen each year, an amount that is expected to increase at 6 EJ / year (exajoule per year) for 2010, mainly due to the increased demand for hydrogen for oil refining (Ogden, 1999).

Hydrogen may be used as a transportation gas, whereas neither nuclear nor sun electricity may be used at once. It has exact homes as a gas for internal combustion (IC) engines in automobiles. Hydrogen may be used as a gas at once in an IC engine now no longer lots special from the engines used with gasoline (Balat,2005). The mixing of hydrogen and ethanol has been used as an opportunity renewable gas in a carbureted spark ignition engine (Al-Baghdadi,2002).A hydrogen engine is easy to start in cold winter because hydrogen remains in a gaseous state until it reaches a low temperature such as 20 K (Ma et al., 2003). Such characteristics play a position to decrease engine cycle version for the safety of combustion. However, it is frequently observed that the values of cycle version for hydrogen-fueled engines with direct injection are better than the ones of hydro- gen-fueled engines with manifold injection or the ones of gasoline engines, due to a decrease in the mixing period with the aid of using direct injection in the process of compressing hydrogen (Kim et al., 2005).

In the context of mining, today mining industries are the center of the energy transition to curbs climate change. Minerals are everywhere in our lives from household to industrial products. The public now requests sustainable development manufacturing from renewable energies. The mining industry now faces an emerging challenge to reduce carbon footprint to meet public demand. This research helps to act on time action for reducing carbon in mining industries and hence targeting to switch industries to sustainable hydrogen-powered mining. In the current scenario, fossil fuel has greater impacts to ensure daily mining activities such as transportation, excavation, haulage system, and drilling operations, etc. Fossil fuel is already proved unstable because it is a non-renewable source of energy that will shortage after a certain time. Switching to competitive renewable energy is not only benefits energy transition but also ensures economic stability. It is clear that energy transition is crucial but the main question raising is how to get it in mining industries. To answer this, with the hope of zero-emission mine by applying all viable technologies. Renewable hydrogen is the best choice because it is the most abundant element in nature but it exists compounds such as water, ammonia, or methane. As mentioned above renewables hydrogen is obtained by electrolysis of water by applying renewable electricity to water to break down its molecule into oxygen and hydrogen. For any type of mine renewable energy and hydrogen are integrated with its entire production process the mine efficiently distributes energy to each of its areas for heavy-duty mobility. The mine has made the transition for fuel cell technology for higher productivity and lower emissions this technology allows the production of onboard electricity by combining hydrogen with oxygen. Mining trucks are automatically charged and make ease to their duty. In underground mining, the fuel cell technology that reduces emission and other combustion gas which intern reduces the need for ventilation and cooling infrastructure capacity this brings operations costs down. The aim of

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this experiment to analyze, evaluate and calculate the percentage saving of operation cost. Besides, it will help to reduce carbon emissions and improves both environmental and working conditions for mining employees.

Depending upon the type of mineral deposit in mining projects, different processing methods are applied. Hydrogen (H2) combustion is used within high-temperature processes like smelting while stationary fuel cells are used to have 24/7 renewable electricity. By using the recovered heat within processes like Electra winning hydrogen is also used as feedstock for the blasting products and in mineral processing, after the processing, the mineral concentrates and cathodes are handled by fuel cell powered by machinery then fuel cell-powered train will transport everything to the nearest port.

To evaluate the amount of carbon emissions from the mining vehicles, data were collected from 'survey of motor vehicle use' statistics data published by Australian Bureau of Statistics. Excel data having three different period four months each and total of a year were analyzed and with the value of total amount of fuel consumptions per year and by applying useful formula amount of carbon emissions has been calculated and presented in a bar chart. Also, for the production energy cost saving per kilometer hauled up of hydrogen-powered vehicles over conventional and electric and hydrogen vehicles, Diesel Sandvik TH551i, Artisan Z50 battery underground haul truck and hydrogen Nikola Tri Sec proposed hydrogen truck were taken into assessment so that by doing mathematical calculations on payload capacity, amount of energy used and hauled up distance three different data for each was calculated and presented in terms of energy cost per 100 km hauled up.

To calculate the amount of ventilation cost saving, different mining ventilation energy Kwh consumptions in the USA mining companies Turquoise Ridge Project, Deep post, Meikle-Rodeo, Henderson Questa, Galena, Lucky Friday were taken for analysis so that by multiplying total KWh of Electricity saved and cost per kwh total amount of ventilation cost were calculating and presenting it in the results.

For the rural mine which is far beyond from national electric power supply, by installing hydrogen manufacturing plant from renewables Turbine and solar power then with the use of hydrogen fuel cell power supply there will be viable option to supply electricity to mine from hydrogen fuel cell, here demo project was shown by taking 3Kw turbine, 2Kw solar source and 5Kw electrolyte that can produce 30nm3/day. By storing produced hydrogen and using hydrogen fuel cell having 2Kw capacity that can supply small electricity to the load. This concept as a demonstration if the capacity of hydrogen electrolyzer increases amount of hydrogen increases so that it will help to supply the electricity to the bigger load or for the whole mining operations.

2.1 Basic hydrogen vehicle working principle

The basic principle is based on the simple chemical reaction between hydrogen and oxygen after reaction water and energy is produced (Figure 1). This energy released an electric current which helps to run motor and motor drive wheel of car forward.

$2H_2+O_2 = 2H_2O$ + energy

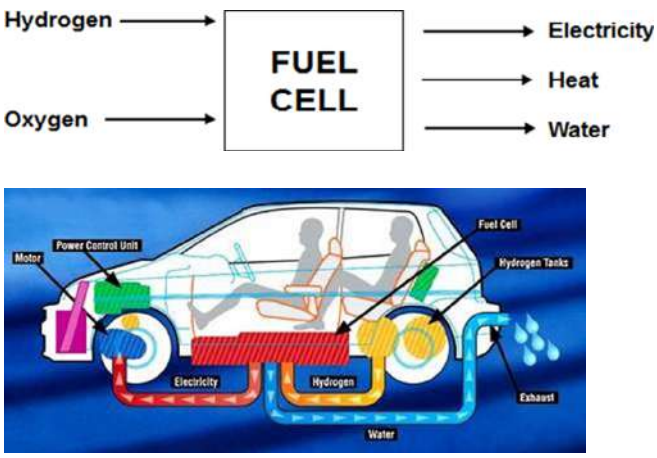

Figure 1. Working principle of hydrogen vehicle (source: http://www.startrescue.co.uk/blog/what-is-the-future-of-hydrogen-cars)

2.2 Fuel Cell Chemical Reactions

Reactions takes place in a fuel cell, the most common type of electrode reaction are

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polymer and acid base each fuel cell contains two electrodes, cathode and anode, where in between them catalyst placed so that reactions took place and electricity is generated (Figure 2).

At anode, $2H2 \rightarrow 4H+ + 4e-$

At cathode, $4H+ + 4e- + O2 \rightarrow 2H2O$

Overall reaction $2H2 + O2 \rightarrow 2H2O$

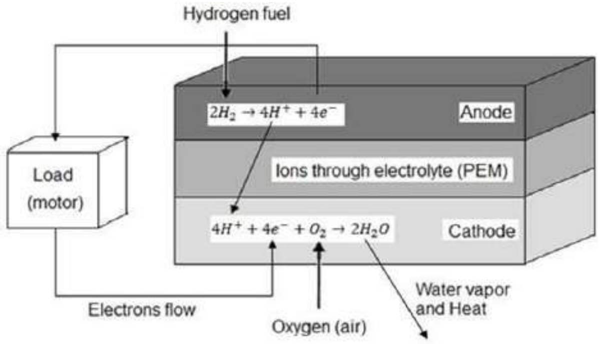
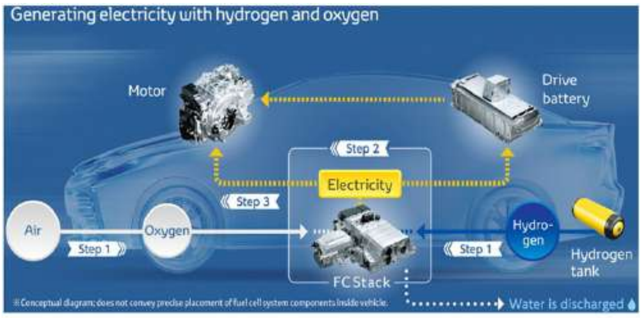


Figure 2. Fuel cell (Francesch, 2014)

When electrons flow from anode to cathode in the Proton Exchange Membrane fuel cell (PEM) it allows to pass of H+ ions through and react with oxygen at anode, electron movement took place and electricity is generated and by-product is only water vapor and heat.

2.4 Vehicle system:

The basic characteristics of the fuel cell vehicles are explained in Figure 3 (Daimler, 2011).



Source: **Toyota Innovation**

Figure 3. Hydrogen fuel cell car components

The main system is:

Hydrogen fuel tank system: Cylinder containing hydrogen at three to seven hundred (300-700 bar).

Battery system: Lithium or lead or calcium ion that stores energy

Electric motor: It is the high torque electric motor which located at the axle. When it motor gets energy wheel accelerates and drive the car.

Power control unit: Controls the flow of electricity so that speed of the car.

2.5 Hydrogen advantages

- Renewable in nature.
- Clean fuel due to zero carbon emissions.
- High purity level available.
- Requires low ignition energy.
- Can be produce from variety of feed stocks.
- Superior combustion characteristics.

For current hydrogen vehicle user perspectives:

- Quick refuelling time less than five minutes.
- Hydrogen cars are longer range around 300 miles or more (480 to 900 kilometers).
- Hydrogen fuel powered cars does not generate noise.

2.6 Hydrogen disadvantages

- Storage complications: It requires special storage massive pressure or low temperature.
- Hydrogen fuel stacks are heavy.
- Fuel cells require pure fuel.
- Platinum catalysts are expensive and rare
- Hydrogen is difficult to produce store and transport.

For current hydrogen vehicle user's perspective:

- A hydrogen engine is refuelled at special fuel pumps, very few refuelling stations for hydrogen-powered cars.

3. Description of Methods

The research method is based on data collections method and calculations approaches and aiming to evaluate the amount of carbon emissions from mining vehicle in Australia; production energy cost per km hauled up decline at 1:7 in the underground mining vehicle, amount of ventilation cost saving when hydrogen economy come into effective and future scope of hydrogen fuel as

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an electric source for the rural mine industry which are not connected with the national power supply.

For this, Sandvik TH551i, battery electric Artisan Z50 truck and proposed hydrogen Nikola Tri sec truck are considered. All required quantitative data such as amount of fuel consumptions, payload capacity, engine capacity, battery continuous power supply, engine efficiency, engine efficiency, current fuel cost and hauling distance etc. for the diesel and battery vehicles are taken from the mine site.Secondary data all the data related to vehicles such as amount of the fuel consumptions and number of vehicles used in a year are released by Australian Bureau of Statistics 'survey of motor vehicle use'. and are collected for further analysis.

To evaluate amount of ventilation cost saving analysis, the data published by U.S. Department of Energy1617 Cole Boulevard Golden, Colorado 80401-3393(LHD) associated with the KWh of Electricity saved annually, Electric Power cost $/Kwh etc that are taken for the analysis of annual ventilation cost savings (USD $).

Also, to analyse feasibility of the renewable hydrogen fuel as a source of future electricity which can storage and supply electricity for remote mining operations. Here, hydrogen, wind and solar coupled power supply sources at DRIs Northern Nevada Science centre are taken into analysis, having data of the capacity of each wind, solar and hydrogen fuel cell and further calculation is carried out that are explained in the result analysis part.

Amount of carbon emissions from the vehicles used in a mine.

3.1 Carbon emission calculations

To calculate carbon emissions the following formula is used: Eij = (Qi× Eci× EFijoxec ÷ 1000)

where:

Eij is the emissions of gas type (*j*), (j=carbon dioxide), Eij=CO2-e tones.

Qi is the quantity of fuel type (*i*) (kiloliters) combusted for stationary energy purposes

ECi is the energy content factor of fuel type (*i*) (gigajoules per kiloliter) for stationary energy purposes,

If *Qi* is specified in gigajoules, then *ECi* is 1.

EF_{ijoxec} is the emission factor for gas (*j*) (which includes the effect of an oxidation factor) for fuel type (*i*) (kilograms CO2-e per gigajoule).

In the context of the Australia, During the period 1^{st} of July 2019 to 1^{st} of March 2020 (a year period) 32981 megaliters of fuel used by different vehicles. Emissions of CO2 e -tones are estimated as:

Qi=32981megalitres=32981000Kilo litres, Energy content factor (GJ/kL) (ECi)=38.6, Emissions factor (kg CO2-e/GJ) (EFijoxec) = 69.9,

Emissions of carbon dioxide =(32981000×38.6×69.9) =88987355.340 tones=88.99 megatons

Hence, it is seen that 32981 megaliters fuel emitted 88.98 megatons of carbon in the entire Australia.

From the mining sector: 5% of total emissions = 4.44 megatons of carbon emissions per year.

3.2. Production energy cost:

Here, diesel "Sandvik TH551i" and battery "Artisan Z50' and hydrogen "Nikola Tri sec' are taken for the calculations of the energy cost per km,

Collected data:

Fuel cost according to today market value; diesel cost=0.7USD/litre, electricity cost=0.1USD/kWh, hydrogen fuel cost =3.8 USD/kg.

Fuel capacity of each; diesel=840-liter, battery=350kWh, hydrogen fuel=8kg;

Hauling distance 1in 7 incline: diesel=64.6 km, battery=7.5 km, hydrogen=9.1km

Then,

Energy cost per hauled up at 1:7 decline($/m)= ((Fuel cost ×Fuel Capacity) ÷Hauling distance 1 in 7 decline)

Energy ($/km) for diesel 'Sandvik Th55i' = (0.7×840) ÷64.6=9.1$/km.

Energy ($/km) for 'Artisan Z50'= (0.13×50) ÷7.5=4.6$/km.

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Energy ($/km) for hydrogen 'Nikola Tri sec' = (3.8×8) ÷9.1=3.34$/km.

3.3 Ventilation cost

To calculate the ventilation cost saving, data having Kwh of electricity saved annually and electric cost ($/Kwh) for different mining in the USA are collected given in the table below

3.4 Alternative power supply

Energy sources: Turbines 1.5 kw @ 2=3kw, Solar 1kw @ 2 = 2w,
Hydrogen electrolyser=5Kw
Hydrogen production available 4kw (**1000S15-10**) electrolyser produces 1 normal m^3/hr
5kw ………………. (5/4=1.25 n m3/hr=30 m3/day
Fuel cell capacity=2kw
P=VI cosβ= 230 volt *0.0245 amp*0.9 =4.96kw varying computer control load.

4. Research Result

4.1. Carbon emissions

The Figure 4 shows the amount of carbon emissions per year from mining vehicles in different period which shows it shows conventional fuel cells vehicles has greater impacts in the environment and working conditions.

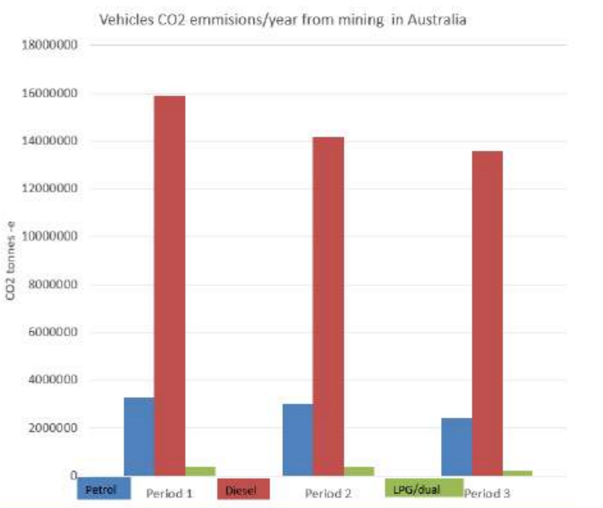

Figure 4. Total carbon emissions from mining vehicles

4.2 Production energy cost

Table 1 represents the amount of production energy cost in mine which shows hydrogen fuel cell vehicles has higher (63.18%) efficiency than diesel vehicles.

Table 1: Total production energy cost calculations

Measure	Units	Diesel Sandvik TH551i	Battery Artisan Z50	Hydrogen Nikola Tri sec
Calorific value of diesel fuel	MJ/kg	45.5		
Battery Technology	*	*	LiFePO4	*
Battery Capacity - Primary Pack	kWh	*	150	750
Density diesel fuel		0.852	*	*
Hydrogen fuel cell	kW	*	*	120
Energy by volume	MJ/l	37.5	*	
Fuel Capacity	l,kg	840	8255	8
Fuel or battery weight	kg	690	8255	*
Engine efficiency	%	30%	100%	35%
Energy Equivalence	kWh	3440	330	750
Payload	tonnes	51.0	50.0	40.0
Operating Weight	tonnes	46.9	48.1	36
Loaded Weight	tonnes	97.9	98.1	76.0
Engine Power	kW	515	460	480
Peak combined traction motor Power	kW	*	1432	*
Continuous combined traction motor Power	kW	*	980	*
Battery continuous power delivery	kW	*	400	*
Energy transfer to wheels from motor	%	70%	80%	35%
Vertical loaded tramming ability based on full tank or battery	m	9000	1047	1200
Hauling distance 1 in 7 incline	km	64.6	7.5	9.1
Regenerative breaking and idle efficiency	%	0.8	1.2	1.2
Operating Duration Level Ground with regenerative breaking 80kw average load	hr	59.4	5.5	11.3
Fuel Cost	USD/l,USD/kg,USD/kWh	0.7	0.1	3.8
Energy cost per km hauled up decline at 1:7	$/km	9.1	4.2	3.358453091

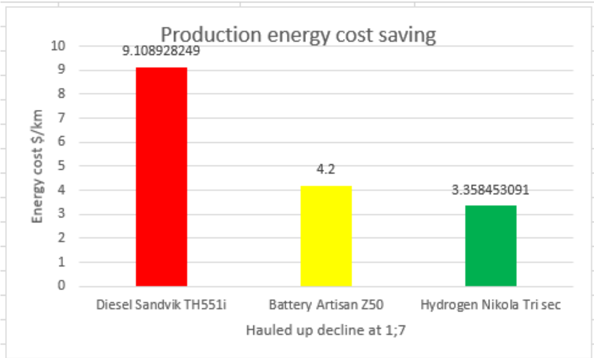

Figure 5. Total production energy cost per vehicle at hauled up decline 1:7.

4.3. Ventilation cost

The Figure 6 and Table 2 shows the amount of ventilation cost saving in the different mine in the USA in a year

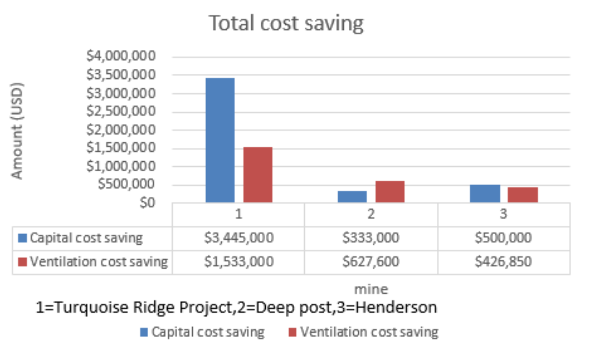

Figure 6. Total ventilation and capital cost saving in a year in different mine

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Table 2: Total ventilation and capital cost calculations

Mine	KWh of Electricity saved anually	Annual Ventilation cost savings (USD $)	Capital cost saving
Turquoise Ridge Project	21,900,000	1533000	$3,445,000
Deep post	8368000	627600	$333,000
Meikle-Rodeo	14840000	1038800	Possible reduction in airway size and main exhaust fans
Henderson	10671250	426850	$500,000
Questa	1346940	66000.06	Possible reduction in airway size and main exhaust fans
Galena	662500	26500	Possible reduction in airway size and main exhaust fans
Lucky Friday	1800000	63000	Possible reduction in airway size and main exhaust fans
Source: Fuel cell-Hybrid Mine Loader U.S. Department of Energy			

4.4 Hydrogen power supply

Table 3 represents the calculations of the hydrogen production and supply load.

Table 3: Hydrogen production and supply to the load

S. N	Energy source	Production	Electrolyser	Hydrogen Production
1	Turbines	3 KW	5 Kw	**30nm3/day**
2	Solar	2KW	*	*
3	**Hydrogen**	**2 kW**	*	*

*represents data are not valid.

5. Discussion

This research is based on the data collection method and calculations approaches where data are collected by means of both secondary and primary data collections method. Secondary method is used to evaluate amount of carbon emissions, ventilation cost saving and alternative power supply by establishing hydrogen plant. Primary qualitative method is used for the calculations of the amount of the energy cost per km hauled up decline 1:7, for this haulage truck diesel "Sandvik TH551i" and battery "Artisan Z50' and hydrogen "Nikola Tri sec' were taken into experiment. Amount of fuel consumption and distance travelled (mileage) data are taken for the calculations of energy cost for each truck (diesel, battery and hydrogen). By doing the energy cost calculations with the use of mathematical calculations it has seen that hydrogen powered truck 'Nikola Tri sec' production energy cost ($/km) is lowest among diesel and petrol.

Hydrogen is sustainable economically, climatically and environmentally, as well as societally (Winter, 2009).

From the experimental data analysis of the different energy sources in different vehicles hydrogen vehicles is 63.18 % efficient than diesel and 27.76% more efficient than battery vehicles because hydrogen can be economically viable to produce from anywhere there is water. It is basically energy transition from water to hydrogen by electrolysis. It has greater scope for the sustainability of the fuel.

Annual ventilation cost saving is calculated as by multiplying KWh of Electricity saved annually Electric and Power cost $/Kwh and capital cost is calculated as difference between purposed investment cost and amount of expenditure amount also it is called as amount of cost saving during construction Hydrogen saves the ventilation cost because it only produces harmless water, especially underground mining operation sufficient ventilation system is required for the mine workers safety and good mining environment that includes large amount of running energy cost once hydrogen fuel economy operation implemented it will safe existing ventilating energy cost i.e. in Miekle-Rodeo mine annual USD $1,038,800 ventilation cost was saved.

Also, the main possible options will be hydrogen fuel cell technology that will help to store large amount of energy and it will supply the power for mining operations whenever they needed. The effectiveness of the hydrogen vehicle in mining sector is obvious.

6. Conclusions

The purposed future sustainable forever hydrogen fuel plays crucial role in the mining industries, which aims to primarily for the reduction of the carbon footprint and minimizing the expenditure for fossils fuel energy, as per the analysis it is concluded that:

a. Hydrogen reduces carbon emissions from mining industries by 4.44 mega tones.
b. Production energy cost is economic (63.18 % efficient than diesel and 27.76% more efficient than battery vehicles).

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c. Ventilation cost is saved (Annual ventilation cost saving in Miekle-Rodeo mine USD $1,038,800).
d. Hydrogen will be the best option for the rural mining operations as it is produced locally and supply electricity if there is no national electric power supply.
e. Better environment is provided to the mine workers (no diesel particulate matters like pollutant helps to eliminate respiratory diseases).

From the above, it is clearly understood that that the effectiveness of hydrogen fuel in mining operations is significant. However, there are some challenges for the commercialization in the global market.

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Mine to recreational resort – Rgotina case study

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Abstract

Mining activities at Rgotina quartz quarry were suspended in 2011 and the owner, Jugokaolin, decided to follow the proceedure and close the mine in accordance with mining regulations in Serbia. Unfortunatelly, no mine in Serbia was ever closed following the legal proceedure so Jugokaolin approached Technical faculty in Bor with the assignment to prepare technical documentation in a form of Mine design for permanent suspension of mining activities at Rgotina mine. One specific requirement was to convert the mined area into a recreational resort so it could be, once the design is realised, given to the local community for management. This article is a brief description of this pioneering effort.

Key words: Quartz mine, open pit, mine closure, recreational resort

1. Introduction

Rgotina quartz sand quarry is located in Eastern Serbia, some 10 km North of Zajecar and 15 km East-South East from Bor (fig. 1). Since 2004 it is operated by Jugokaolin, subsidiary to German Quartzwerke gruppe, a leading European producer of quartz sands and industrial minerals.

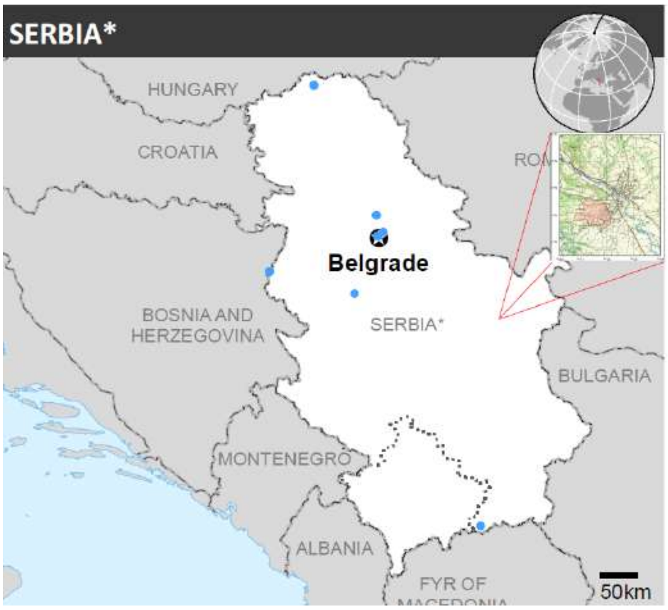

***Figure1** – The location of Rgotina quartz quarry*

Rgotina quarry consists of two open pits, Velika Poljana 1 (VP1) and Velika Poljana 2 (VP2) , in close proximity to each other (Fig 2). Mining activities at both pits were suspended in 1978 (VP1) and in 2011 (VP2) but the mine was never officially closed. The cavities of both pits slowly filled with water and the lakes which formed inside became popular recreational resorts for the people of nearby cities of Zajecar and Bor.

Since, in legal terms, both pits and lakes are active exploitation field the new owner decided to officially close the mine. Official closure of the mine is a legal requirement in accordance with Serbian Mining and geological exploration act and it is necessary to prepare technical documentation in the form of Mine design for permanent suspension of mining operations. Because of that, Jugokaolin approached Technical faculty in Bor with the assignment to prepare necessary documentation.

***Figure 2** – Position of Velika Poljana 1 and Velika Poljana 2 open pits*

2. Mine closure design

The Main design for permanent suspension of mining operation is legal requirement and the contents of this document are defined by the Rulebook on the contents of mine designs. However, the Rulebook only outlines the contents and particular design has to incorporate all of the specificities of the mine being closed. Having that in mind it became clear that Mine design for permanent suspension of mining activities at Rgotina quartz quarry has to cover three basic segments:

1. To ensure that the mined areas of VP1 and VP2 open pits are stabile and safe;
2. To meet the specific owners requirements and
3. To reclaim and remediate the land.

Upon inspection of the site three landslides in the pit slopes were identified.

The landslide in the western slope of VP1 formed due to high rainfall 2008 and extended in 2015. Water followed the local road alignment and were directed towards the pit slope causing massive failure. The slope has been stabile since but the mine closure design had to ensure future stability/prevent future slope failures.

Two landslides were identified within the area of VP2. The landslide in NW slope was triggered after a burst in water supply pipeline to nearby village of Rgotina. The pipeline was buried so the burst remained unnoticed for a long period of time during which the water continued soaking the slope. Eventually the slope failed exposing the pipeline failure. The landslide was mitigated and is now stabile except for the small part at the ridge between two pits. The ridge is prone to settling and sliding due to the traffic on the local road and due to the low bearing capacity of the soil in the ridge.

Third landslide was identified in the south slope of VP2. VP2 open pit is located in the valley of Dulan stream and, during the active period of the mine, the bed of Dulan stream was rerouted along the south slope. In time the stream formed a gully and eventually penetrated the pit filling it with water. In addition to the destabilizing influence of the stream the terrain south of the pit boundary is saturated with water and it is sloping towards the pit. Combination of slope, water saturation and geology caused the soil overlying the quartz sandstone to move and form a landslide. The landslide is still active (Figure 3).

***Figure 3** – Landslide in the south slope of VP2 and gully curved by Dulan stream*

The activities on mine closure include the demolition of the processing facilities located in the industrial zone of Rgotina village. This will result in 5 700 $m^3$of solid waste which has to be disposed. The waste is primarily concrete and bricks and was declared environmentally safe after tests performed by the Institute for public health in Zajecar city. One of the requests of the owner was to safely dispose this waste.

In spite of the fact that the area of Rgotina quarry is still, in legal terms, active exploitation field, the lakes, especially the VP1 lake, are used as recreation resorts during summer. Clean and warm waters of the lakes are perfect swimming areas for people from nearby cities of Zajecar and Bor. However, being flooded open pits, with sudden drops of deepwater make these lakes dangerous for inexperienced swimmers and have claimed several lives so far. The second request by the owner was to incorporate the recreational purpose of the lakes into the mine closure design. With increased safety, arranged and enriched recreational features the closed pits would be transformed into a recreational resort and given to the city of Zajecar for further management.

Having all this in mind the Mine design on permanent suspension of mining operation of the Rgotina quartz quarry had to present the solutions for mitigation and stabilization of the landslides, ensure safe disposal of demolition waste and convert the mined area into a recreational resort.

3. The Solutions

Mitigation of the landslide in the west slope of VP1 and prevention of further slope failures was fairly simple. It required the construction of the channel along the existing road. The channel would collect the water from rainfall and diverted away from the slo0pe and into the Dulan stream. The total length of the channel is 210 m, it has a trapezoid shape and is 0,7 m deep to ensure that maximum, storm waters can be efficiently collected.

The landslide in the NW slope of the VP2 was mitigated when the pipeline was replaced. However, to prevent further slope failures it was necessary to replace the whole pipeline. Additional reason for replacement is the asbestos the pipes of the original pipeline are made of. The replacement with HDPE plastic pipes will eliminate the danger of slope failure and increase the quality of life of the villagers by eliminating asbestos as a health risk. The portion of the landslide which is still active is triggered by the local traffic and the fact that the soil in the ridge does not have sufficient load bearing capacity. In order to mitigate the problem the Mine design for permanent suspension of mining activities suggested the replacement of soil. The original soil from the ridge, down to the stabile quartz sandstone layer should be removed and replaced by compacted demolition waste. In this way the road will keep the function and the ridge will be stabilized. Total volume of compacted fill was 60 m^3 and required 120 m^3 of loose material.

The south landslide at VP2 was a bit of a challenge. In order to stabilize it was first necessary to reroute the Dulan stream back into it original bed, away from the slope. Second, the gully which was carved by the stream should be filled and third, the sliding body of the landslide should be stabilized.

In order to stabilize an active landslide one can lower the slope angle by removing the sliding material. However, this was not feasible option since it would result in pit boundary to expand beyond the ownership line. It was not possible to bolt the sliding material since the material itself is almost loose and not even wire mash could ensure stability.

The best option for the stabilization was to add weight to the toe of the sliding body. The additional mass would act as counter lever and increase the stability of the slope (Fig.4).

The perfect solution for both gully fill and weight to slope toe was the demolition waste. The required amount of material for the fill and stabilization was 5 400 m^3 so there was sufficient amount of demolition waste. The remaining waste and the soil removed from the ridge and excavated during preparation of access roads was built in the safety dam at the east slope of VP1.

The initial condition of the slope

After the construction of stabilization fill

After eventual movement of surface soil

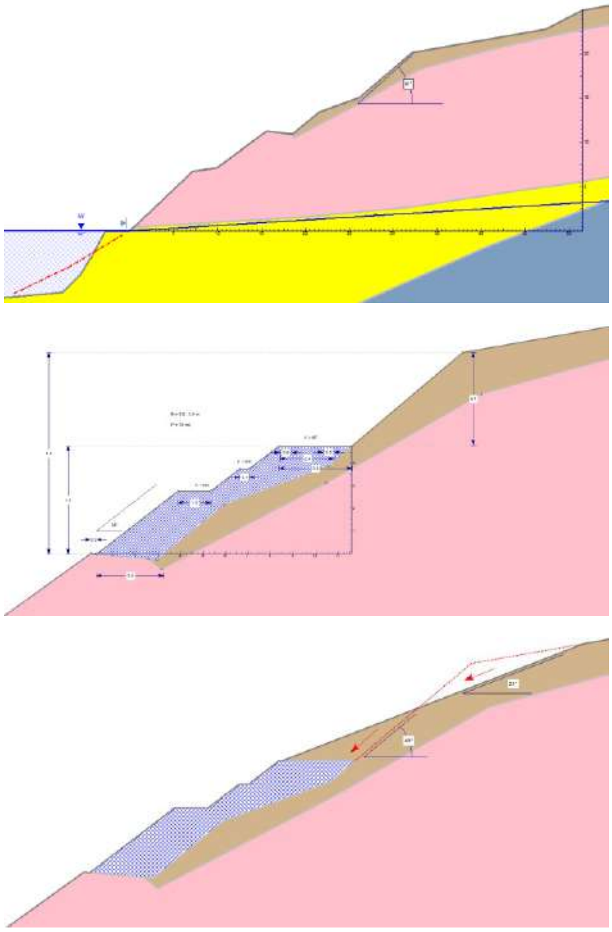

***Figure 4** – Stabilization fill for south slope landslide*

Since the Dulan stream was rerouted back into its natural bed it goes into the lake of VP2. Eventually, the lake would be filled and the water would spill at the east slope of VP2, following the old stream bed. To ensure controlled discharge of the lake the design suggested construction of the dam and spillway in the lowest part of the east slope. The spillway was at the level of 171.5 m and the crest of the dam was at 172.5 m. This would ensure the constant level of the lake surface and provide sufficient volume to retain the storm waters and prevent them to flood the village downstream (fig. 5)

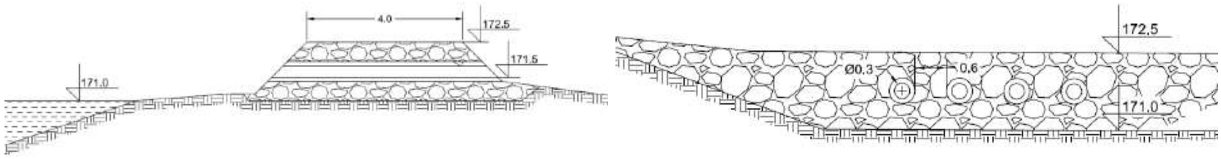

***Figure 5** – Cross sections trough the dam and spillway*

In order to meet the requirement to convert the mined area into recreational resort it was necessary to remediate and reclaim areas degraded by mining activities. Overburden dumps were previously forested and were not the subject of the design. However, some benches in VP2 along with the landslide areas and zones affected by the works on mine closure had to be reclaimed. Mine closure design suggested technical and biological reclamation. Technical reclamation considered earthworks on accessing, leveling and covering with fertile soil where possible. The most problematic part was the North slope of VP2. The benches are constructed in quartz sandstone and not enough soil was available to cover the benches and prepare them for reclamation. The solution was to reclaim these benches by container seedlings so technical reclamation was in fact digging holes for the containers. The bench slopes were prepared by covering with compost

Biological reclamation suggested grass seeding at all surfaces and tree planting at all horizontal surfaces and all accessible slopes. Total area covered by reclamation was about 4 ha and the main trees used were acacia, birch and willow.

In order to convert the mined area into recreational resort the mine closure design suggested the construction of 3 m wide hiking paths around both lakes, arrangement of the picnic areas (sunroof tables and benches), football terrain, beach volleyball terrain and arrangement of three beaches, two at VP1 and one at VP2.

Almost 3 km of hiking pathways allow hikers to go around both VP1 and VP2 and are designed to be horizontal and not demanding to walk. The beaches cover almost 10 000 m^2 and are arranged by covering the surface by 50 cm thick layer of white quartz sand. Football terrain is located at the North part of VP1 and is being constructed by leveling the ground and seeding grass.

4. The cost

The costs of Rgotina mine closure include the costs to prepare the site for closure, to mitigate and stabilize the landslides, dispose the demolition material and convert the mined area into the recreational resort. Total cost were estimated to a bit more than 100 000 EUR.

Earthworks and landslide mitigation accounted for 83 000 EUR, technical and biological reclamation accounted for 17 000 EUR and recreational features accounted for 10

000 EUR. With 8 000 EUR contingency total cost of Rgotina mine closure sums up to 118 000 EUR.

5. Conclusion

During history the propper way to close a mine at the end of its life was to put a lock on its gate and forget about it. There are numerous examples of abandoned mines being source of pollution. However, with encreased environmental awareness we found ways to close mines in a manner which minimises further impacts to environment.

Fortunatelly, the comodity extracted in Rgotina mine is not a pollutant. Specific course of events which caused flooding of the pits and nonhazardous comodity made it posible to do somethinh unthinkable, to convert mined area into a recreational resort and to add value to old mine. A hundred thousand euros is not a cost of reclamation but an investment into local community and example of corporate social responsibility.

The design for Rgotina mine closure was finished in 2019 and the plan was to start the realisation in 2020. Unfortunatelly the pandemic and minor ownership problems postponed the realisation. With ownership issues resolved we eagerly wait for the pandemic to end.

MECHANICAL ROCK EXCAVATION – A SUSTAINABLE TECHNOLOGY FOR RAPID UNDERGOUND METAL MINING

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ABSTRACT

The demand for various minerals and metals is increasing phenomenally all over the world leading to spurt in metal prices. Recent surge in prices of gold, silver, manganese and steel necessitates a boost in the production of the ores being mined more so from underground methods being more environmentally friendly. Base metals being scarce in India and deeply seated, it is necessary that underground mine development be given due emphasis. Time has come to search for faster development technologies as now production will come from more stopes necessitating huge mine development targets. Use of age old and cumbersome conventional drilling and blasting method, popular due to its flexibility and adaptability in different geomining conditions, is plagued by poor monthly drivage rates and has made it impossible to realise such enormous mine development targets. Thus, it is imperative that the successful application of new mine development techniques is indispensable. In this paper a discussion has been made about new mechanized techniques (Roadheader, TBM and raise boring) to conform to the need of such rapid development. Apart from presenting the advantages with mechanized cutting technology, the paper also focuses on performance prediction models as applied to a typical mining case for better understanding of the issues. Selection of these machines must be based on certain rock and rockmass properties as well as machine parameters suitable to a given excavation geometry.

Robust, reliable, high capacity and smart machines are being built and used the world over for underground metal mining and India too is gearing up with HZL, Vedanta leading from the front. The prime rock excavation technologies in underground metal mining that can be considered are roadheaders, tunnel boring machines and raise boring machines including various supporting equipment such as robotic scaling and shotcrete machines. Introduction of such sophisticated technologies throw a great challenge in scientific ways for selecting machine design and operating parameters for energy efficient rock excavation. This calls for suitable rock excavation tests at lab scale, modelling, design, selection and operation of these machines. Assessment of rock breakage under applied forces helps in optimizing the key machine design parameters particularly of cutting heads and cutting tools. In this key note the challenges faced by rock excavation machines have been highlighted covering three excavation equipment, namely, roadheaders, tunnel boring machines, raise boring machines that can be readily designed, selected and operated gainfully for elevating the metal production scenario, particularly, Zinc, Copper, Manganese, Chromite etc. The rock excavation testing facilities designed and indigenously built by IIT(ISM) Dhanbad are also highlighted alongwith selection strategies for these advanced rock excavation technologies.

1.0 INTRODUCTION

Minerals and Metals form the backbone for industrial development as well as standard of living. Most of the metals, in India, come from underground metal mines and thus development of underground metal mines is the base for ore production from a mine. Considering the increasing demands on base metals, there is a need to develop new underground metal mines or deepen the existing ones. Underground metal mining in India is synonymous with conventional drilling and blasting based mining methods, may it be development or extraction of ore. Most of the development headings in metal mines employ manual drilling using jack hammers, blasting by explosives, supporting with stull/crib sets/rock bolts, mucking by tubs on tracks and hoisting by cages/skips. Only a few mines namely, Narwapahar, Zawar, Rampura-Agucha, SK Mines, Khetri employ mechanized drill jumbos with advanced initiation systems obtaining higher pulls. Trials with bulk loading of explosive in underground were done in Narwapahar, UCIL with a reasonable success. Irrespective of the said developments the development rate desired for meeting higher ore production requirements is yet far from the desired. Here lies the need to explore the different technological options for timely and economically develop a metal deposit matching with the stoping method suitable for the deposit. Number of underground mines in operation(excluding atomic and fuel minerals) are presented in Table 1.

Table 1 – Number of underground mines in operation as on 2021-22
(Source: MoM, GoI Report)

Minerals	'A' Category	'B' Category	Total
Apatite	-	-	-
Chromite	7	-	7
Copper ore	5	-	5
Garnet	-	1	1
Gold	6	-	6
Lead & Zinc	9	1	10
Manganese ore	11	7	18
Rock Salt	-	1	1
Total	**38**	**10**	**48**

Review of literature and current practices indicates application of Road Headers(RH), Tunnel Boring Machines (TBM) and Raise Boring Machines(RBM) in hard rock drivages. Two most successful applications of TBM technology in mining have been in the San Manual copper mine and the Stillwater platinum mine in USA. The excavation of Küçüksu tunnel with a shielded roadheader of 90 kW of cutter power, showed an instantaneous cutting rate of 5m^3/h, machine utilization time of 47%, tool consumption up to 0.7 cutter/m^3 in rock having compressive strength of 100MPa and RQD of 80%. Typical advance per month achieved with the best drilling and blasting system may not exceed 100 m. Whereas this can be safely elevated to at least double (200 m) deploying roadheader and four times(400 m) deploying tunnel boring machines. Indian experiences with these technologies is also good particularly with roadheaders in coal mines achieving an average monthly drivage rates in the order of 300 m(Murthy, 1995). TBMs too are being used in tunnelling extensively (Murthy et al., 2011). In this light it is necessary to understand the issues namely, the advantages and limitations of mechanized cutting technology, equipment suitable to metal mines, rock characterization for developing appropriate machine specifications vis-à-vis selection for introducing these innovative technologies for realizing rapid mine development.

2.0 MECHANIZED DEVELOPMENT

Of late use of mechanical cutting systems are gaining popularity due to stringent production needs, environmental and health concerns of workers employed below ground. Some of the major gains achieved through mechanization are as follows:

- Reduced costs
- Faster development
- Faster mining
- Safer mining
- Mining with a smaller crew underground

- Smaller capital expenditure
- Development of a more productive crew
- Automation possible

Needless to say that the above-mentioned advantages go a long way in meeting the increased production targets of underground metal mining more so for deep mines. Rock cuttability assessment is an interactive and iterative processes. The key factors in cuttability assessment are depicted in Fig.1.

Fig.1 – Rock excavatability factors and need for rock characterization

Higher focus on underground productivity can only be achieved by automated cutting operation, cutting depth control, loading and evacuation processes. Superior ergonomically designed operator's cabin allows a good view of cutting drums, track units and conveyor discharge zone. Safety features typically include comprehensive lighting package, non-slip walkways and accesses, standardized railings, accessible stop-switches and wide range cameras including proximity sensors. Wider drums in soft rocks (as the rocks vary in their strength widely say from 20 MPa to 150 MPa) have been put in place for higher production in different underground mines apart from developing standard performance charts for machine applications in varied rock mass conditions. Design of indigenous cutting drum is in progress at IIT(ISM) in a joint project with L&T as Technology Partner. DST funds this project under clean mining and Made in India initiative. Thus, the prominent and well accepted technologies suited for mine development are roadheader and tunnel boring machine (TBM) manufactured by Robbins, Alpine Miner, Dosco, Paurat, Eickhoff etc to name a few. The tertiary development in the stopes is being accomplished by raise boring machines manufactured by Sandvik and Terratec. A brief review of these systems is given against the backdrop of metal mine development needed for understanding and applying these technologies (Table 1).

Table 1 – Mechanized mine development technologies- Roadheader vs. TBM

Roadheader	Tunnel Boring Machine
Roadheaders were first developed for mechanical excavation of coal in the early 50s. The major improvements achieved in the last 50 years consist of : 1. Machine weight - Machine weight have reached upto 120 tons providing more stable and stiffer (lees vibration, less maintenance) platform from which thrust can be generated for attacking harder	1. Tunnel Boring Machine (TBM) is a full face excavator which cuts rock by means of disc cutters mounted on a circular revolving cutting head. 2. Its design features enable it to cut stronger rock than any other type of mechanical excavator. Today

rock formations. 2. Cutter head power - The cutter head power has increased significantly, approaching 500 kW to allow for higher torque capacities. 3. Size - Modern machines have the ability to cut cross-section over 100 m^2 from a stationary point. 4. Cutter head design - Computer aided cutter head lacing design has developed to a stage to enable the design of optimal bit layout to achieve the maximum efficiency in rock and geological condition to be encountered. 5. Muck pick up and loading system - The muck collection and transport system have also undergone major improvements, increasing attainable production rates. The loading apron can now be manufactured as an extensible piece providing for more mobility and flexibility. 6. Cutting bits – The cutting bits have evolved from simple chisel to robust conical bits. There has been also improvement in the metallurgy of picks. 7. Other developments – The machine can be equipped with- Rock bolting equipment. Dust suppression equipment. Laser guided alignment control systems. Computer profile controlling and remote control systems allowing for reduced operator sensitivity coupled with increased efficiency and productivity. Some important features of roadheader – Offer flexibility, mobility and versatility Capability to excavate almost any profile of opening Low capital cost than other mechanical excavators	tunnel with a range of diameters can be excavated by TBM. The MTBM (micro tunnel boring machine) is an economical and reliable solution for constructing small diameter underground networks by trenchless method. The range of micro tunnel boring machines available today enables service main networks to be constructed whose working diameters vary from 500 mm to 2500 mm. 3. Rocks having an UCS upto 250 MPa can be cut. 4. Use of CCS(constant cross section) cutters maintain uniform wear and thus performance of the machine. 5. Some important features of TBM – Applicable for a large variety of rock i.e., soft to very hard Very high penetration rate can be achieved Flexibility is less than roadheader and D&B method. Capital cost is high.
More suited to underground metal mines	Relatively less suited unless an economic drivage length of 4 to 5 km in one setup is available. Multiple lenses developed on a horizon method are more readily suited.

3.0 ROCK EXCAVATION TESTS FOR MECHANICAL CUTTING

It is now an established fact that Roadheader, TBM and Raise Boring Machine performance prediction models require several rock parameters to be used as input parameters which are essentially obtained from both laboratory and field investigations. The following sections present the rock excavation tests required to be carried out for machine selection, design and operation (Murthy et al, 2020).

3.1 Cerchar Abrasivity Index (CAI)

Abrasiveness is one of the properties of rocks that is measured in order to assess their suitability for mechanical excavation. One of the most popular test procedures is the Cerchar abrasivity index, which is widely used in the machine tunnelling industry due to the advanced mechanization of excavation methods(Fig.2 and Fig.3).

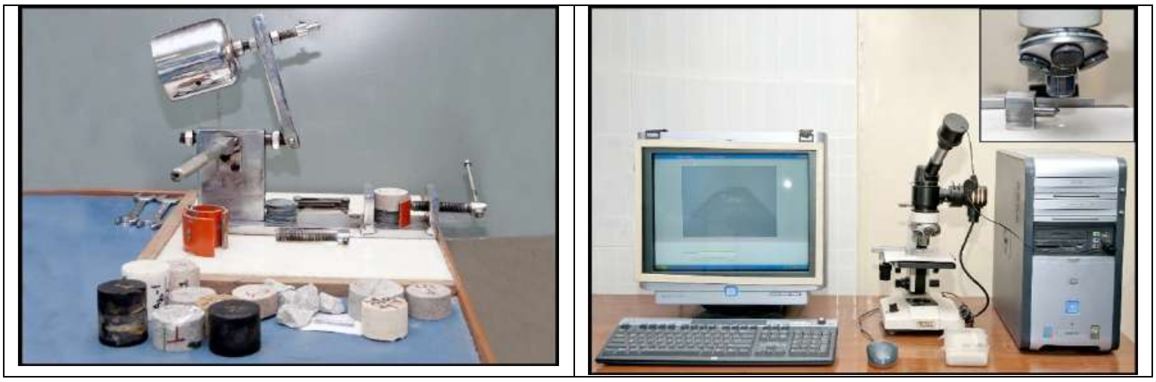
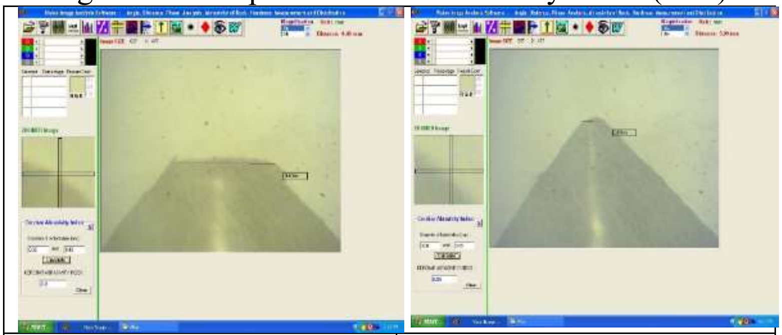


Fig.2: Test setup for Cerchar Abrasivity Index (CAI)



Quartzite/Sandstone	Quartzitic phyllite

Fig.3: Typical abrasivity pin wears in different rocks

Typical rock classification as suggested Cerchar 1986 is given in Table 1.

Table1: Classification of abrasiveness of rock

Classification	CAI	Rock type
Extremely abrasive	>4.5	Hornblende gneiss, pegmatite, pennant grit, granite
Highly abrasive	4.25-4.5	Amphibolite, granite, Quartzite
Abrasive	4.0-4.25	Granite, gneiss, schist, Darley dale, sandstone, pyroxene
Moderately abrasive	3.5-4.0	Sandstone and siltstone
Medium abrasivity	2.5-3.5	Gneiss, Californian granite, dolerite
Low abrasivity	1.2-2.5	Portland sandstone
Very low abrasivity	<1.2	Limestone

3.2 Brittleness Index (BI)

The brittleness test gives a good measure for the ability of the rock to resist crushing by repeated impacts. Density for each sample is calculated by dividing the mass (measured on an electronic balance) by the volume (length and the diameter are both measured by caliper). The test setup is hown in Fig.4.

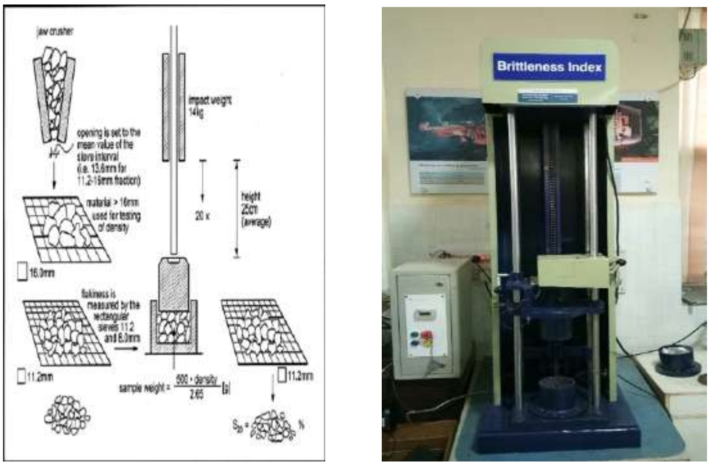
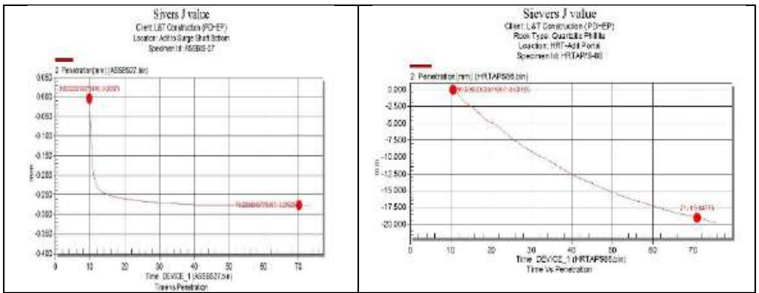


Fig.4 Schematic of brittleness test (Dahl, 2003) and Brittleness test apparatus

3.3 Siever's J Value

The hole depth measured in 10^{-1} mm units after 200 revolutions by the miniature drill with thrust of 20 kg is known as Sj value. It is determined as the mean value of 3 to 4 parallel tests. The drill bit used is 8.5 mm in dia with 110^{g} bevel angle (99^{0}). The Seiver's J value expresses indirectly the surface hardness of the rock. The test setup is shown in Fig.5 and rock samples tested in Fig.6. A combination of the Brittleness Index value and the Seiver's J value was developed empirically in order to give the best possible correlation between the DRI and penetration rates.

Fig.5: Test setup for Siever's J value determination

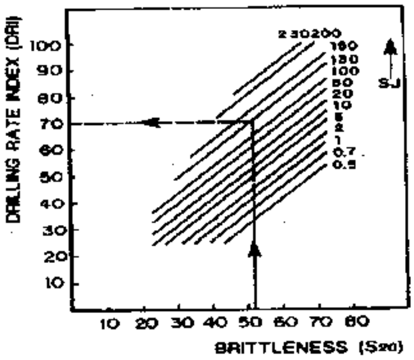


Quartzite	Quartzitic phyllite

Fig.6 – Drill bit penetration signatures

3.4 Drilling Rate Index

DRI tests on the cored samples are performed in the laboratory as per the standard procedures suggested in NTH method (NTNU, Norway). The Brittleness Index (BI) and Siever's J Values (Sj) are taken and are used to read DRI. The DRI values are determined using a nomogram developed as shown in Fig.7. Typical DRI values reported in literature are provided in Fig.8.



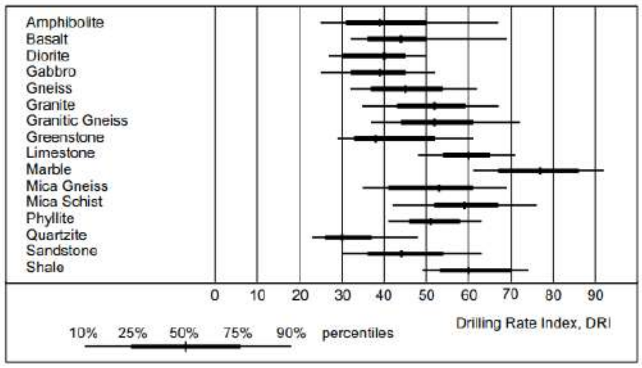


Fig.7: Nomogram for estimation of DRI   Fig.8: Typical DRI values reported (Bruland, 1998)

DRI values are determined from the nomogram from the determined Brittleness Index and Sj values. The classes into which the rock suits fall from drillability viewpoint are shown in Table 2.

Table 2:Category intervals for drillability (Bruland A., 1998)

Category	DRI
Extremely low	<25
Very low	25-32
Low	33-42
Medium	43-57
High	58-69
Very High	70-82
Extremely High	>82

3.5 Punch Penetration Index Test

The punch penetration test, originally intended to provide a direct method for estimating the normal load on disc cutters was developed in late 1960s to provide direct laboratory method to investigate rock behavior under the indenter (Handewith, 1970). Yagiz (2002) used the test results as a brittleness index, one of the input parameters for Modified CSM model, to estimate the TBM penetration. Yagiz (2009) also stated that the punch penetration test that could be directly used for measuring rock brittleness has a great potential to estimate the penetration rate of tunneling machines. The test setup and samples prepared are shown in Fig.9 and Fig.10 respectively. The slope of the best fit line (kN/mm or lb/in) was named as penetration index (PI) employed for predicting the expected cutter force and corresponding penetration for mechanical excavation (Hamilton and Handewith, 1971).

Fig.9: Punch penetration cell with indenter in PPI Test

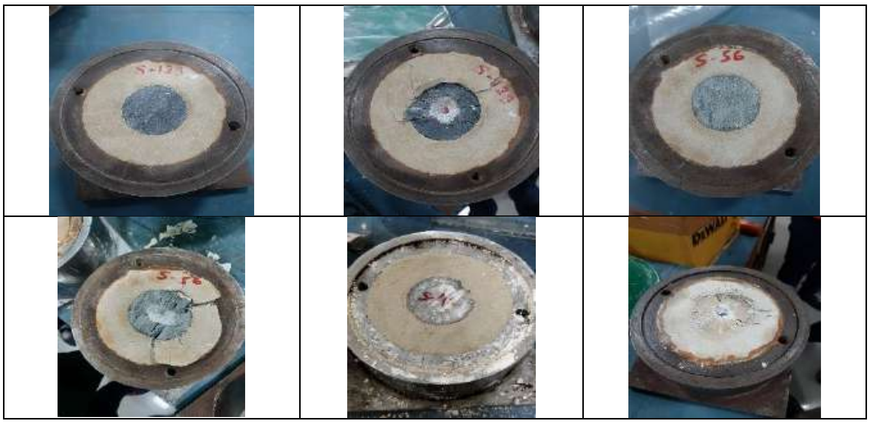


Fig 10: Photographs showing the test specimen for PPI test

The force-penetration graph that determines the PPI is shown in Fig.11.

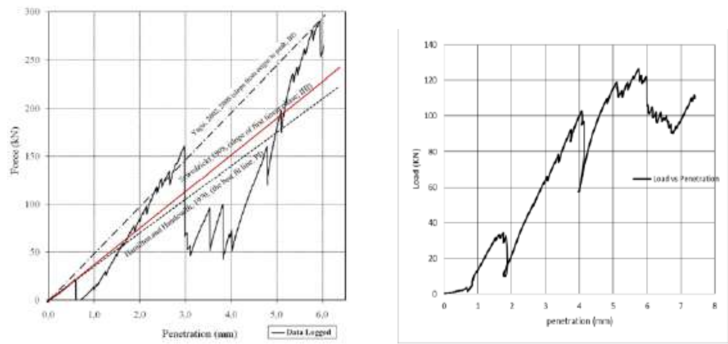


Fig. 11: Force-Penetration Graph of PPI Test (eg. Quartzite)

The slope of the best fit line (kN/mm or lb/in) was named as penetration index (PI) employed for predicting the expected cutter force and corresponding penetration for mechanical excavation (Hamilton and Handewith, 1971).In the first phase, there is elastic deformation and very fine crushing of rock surface. In the second phase, there is crushing of rock fabric and in the third phase chips of rock are formed. A linear relation represents elastic deformation and very fine crushing in the beginning of loading. Crushing is represented by “steps” on the profile and chipping of the rock fragments is represented by peaks (Fig. 11). Consequently, the brittleness index (BI) in kN/mm is computed using the slope of whole phase of force-penetration profile, obtained by drawing line from origin of the chart to the maximum applied force that rock absorbs till the test ended (Yagiz, 2009). As result, the brittleness may be computed as follows;

$$BI = \frac{F_{max}}{p}$$

Where, F_{max} is maximum applied force on a sample in kN, and P is corresponding penetration in mm.

Table 3: Rock Brittleness from The Punch Penetration Test (Yagiz, 2009)

Brittleness index (kN/mm)	Brittleness class
≥ 40	Very high brittle
35- 39	High brittle
30 -34	Medium brittle
25-29	Moderate brittle
20 - 24	Low brittle
≤19	No-brittle (ductile)

3.6 Abrasion Value Steel (AVS) and Cutter Life Index (CLI)

AV_S and CLI measure the time dependent abrasion on cutter steel in the presence of crushed rock powder. The test method was developed at the Department of Geology at NTNU in the years 1958 – 61 (Reidar Lien, Rolf Selmer-Olsen). It estimates the abrasivity of rock. This test is used to calculate the Bit wear index (BWI), Abrasion Value Steel and Cutter life index (CLI) for drilling bits and disc cutters respectively. Thus, it helps in estimating the cutting life of tools during excavation. BWI is calculated by Abrasion value (AV) test which requires testing with tungsten carbide bit for 5 min at a speed of 20 rpm. CLI is estimated using Abrasion value steel (AVs) test, which is calculated by testing of cutter ring steel bits for 1 min at 20 rpm speed. The test setup and size fractions, prepared cutting tools, mineralogical variations are shown in Fig.12. Values of CLI reported from literature (Bruland 1998) are also shown in Fig.12. Relation established between AV_S and cutter life index is also shown in Fig.13.

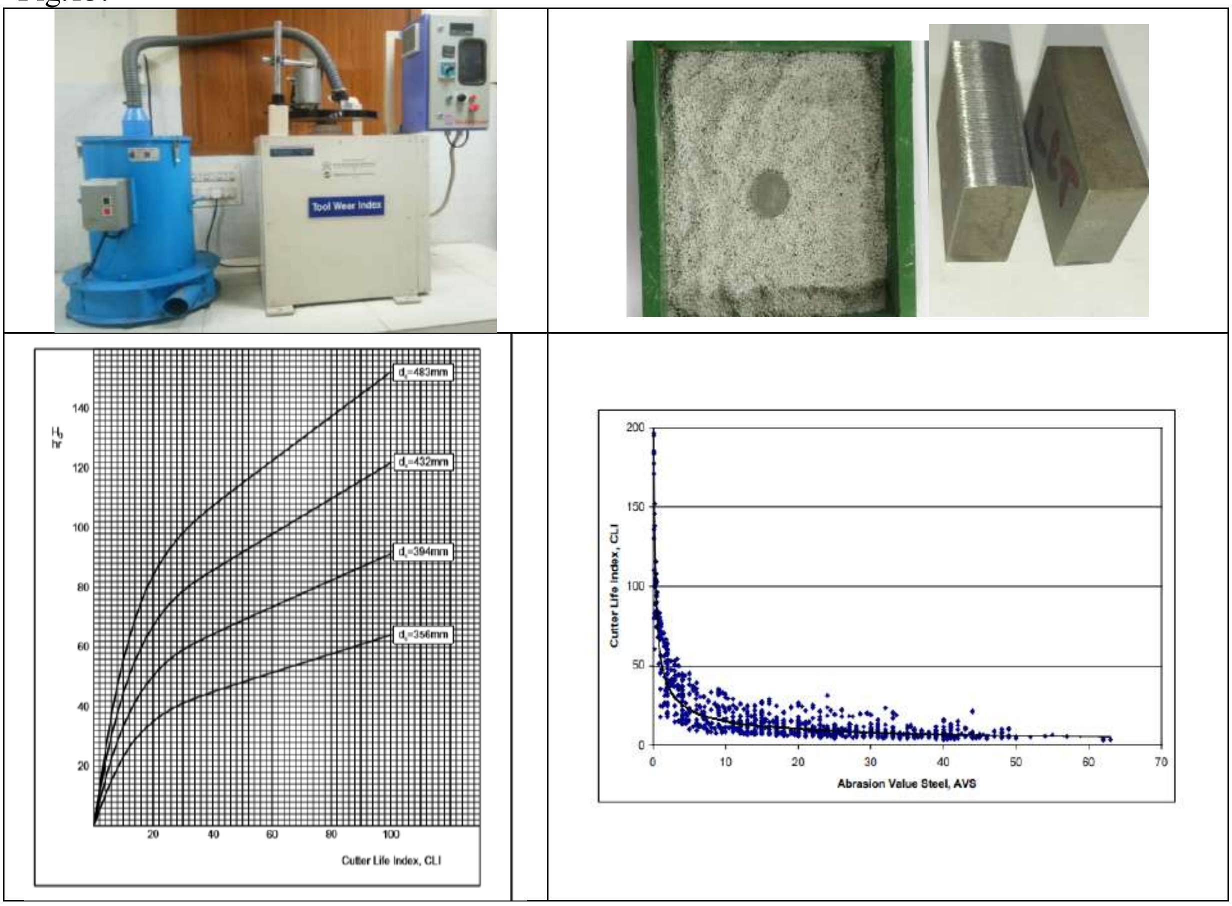


Fig.12: Abrasion Value Steel (AVS) apparatus, cutter ring samples and relation between AVS and CLI for some rocks (Bruland 1998)

The Abrasion Value is the weight loss in milligrams of the test bit after 100 revolutions of the steel disc. 100 revolutions equal 5 minutes test time. Abrasion Value Steel is the weight loss after 20 revolutions of steel disc.

$$\mathbf{AV\ or\ AVs = W_1 - W_2}$$

Cutter Life Index

CLI is determined from the following equation suggested by NTNU (A.Bruland, 1998) and presented in Table 10.

$$\mathbf{CLI = 13.84\ (Sj/AVS)^{0.3847}}$$

3.7 Linear Cutting Rig –Specific Energy Estimation

Disc cutters are used in TBM for cutting hard rock in tunneling and mining. They cut concentric groves on the tunnel face and the breakage is effected predominantly by tensile fracturing and chipping. The mechanism of cutting and test setup are shown in Fig.14. Determination of cutting forces on disc cutter using liner cutting rig and arriving at specific energy for cutting a given rock is vital for cutting performance assessment of TBMs. The equipment involves linear cutting rig, Triaxial force transducers, thrust and linear hydraulic rams, instrumentation, data acquisition system etc. This is also useful to arrive at the optimum spacing to depth ratio that yields lowest specific energy. Load up to 40 tons in vertical direction(Z-axis), 20 tons in X direction can be applied. It is clamped below the hydraulic press by nut and bolt arrangement and below this the disc cutter is fitted with the help of a fixture. The specifications of triaxial transducer and disc cutter arrangement is shown in Fig.13.

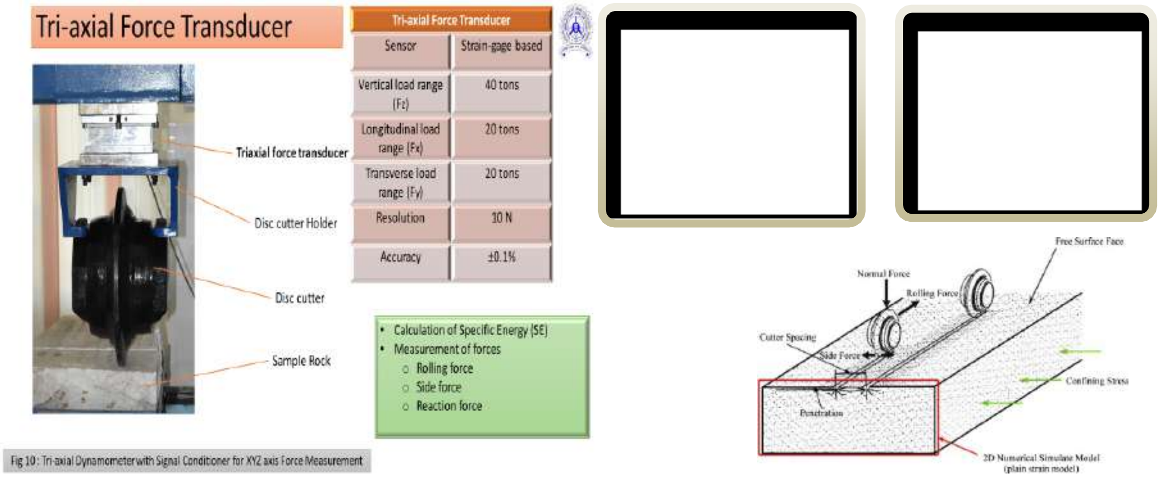


Fig.13: Linear cutting rig with triaxial force transducer and the specifications of the testing

After applying required thrust the disc cutter starts its movement from one point to another point on the pre-drawn line with the applied thrust. The tray moves from one end of the machine to the other end generating a cut on the rock. Sensors are fitted on both the ends of the machine to limit the movement of the trolley within the safe operating distance. The experiments need to be carried out with varied spacing to depth ration and the specific energy are computed. A plot relating s/d ratio and specific energy is shown in Fig.15. The specific energy is calculated by the following expression:

$$SE=FR/Q$$

Where, SE is the specific energy in MJ / m^3, FR is the force acting on the cutting disc in kN and Q is the volume per unit length of cut in m3 /m. It is also possible to determine the instantaneous cutting rate as:

$$ICR = k \cdot P * SE_{opt}$$

Where, ICR is the instantaneous speed of the rock cutting in place in m^3 / h, P is the power in kW, SE_{opt} is the optimum specific energy obtained from Rock Cutting Test in kWh / m^3 and k is a constant depending on the efficiency of the system, expressed as a ratio of the energy transferred from the excavating head to the surface of the front and between 0.85 and 0.9.

3.8 Petrographic Analysis

Petrographic studies aim to assess the rock characteristics to evaluate the mineralogical composition in the supplied rocks from their work sites. Core samples from different locations are collected and tested. Thin section samples, covering various aspects such as colour, alternation, weathering, macro features, compositional variations, were cut and prepared (Fig.16). Accordingly, thin sections were prepared for describing mineralogy, texture, approximate mineral percentages, hard mineral etc. Representative thin sections have been studied using Olympus make trinocular polarizing microscope (Fig.14).

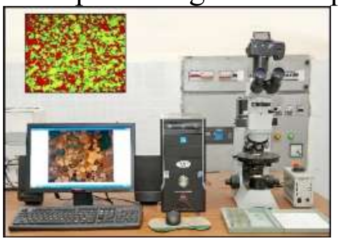


Fig 14: Petrological microscope

Megascopic Characters: Core, weathered quartzite, highly fractured and jointed, coarse grained and white in colour.

Microscopic properties- The samples are medium to fine grained with predominantly comprising of hard mineral assemblages. The grains are euhedral to subhedral in nature (Figure 2a-d). The section shows fractures and deformed minerals thereby giving the impression of a high scale deformation. The volumetric percentages of different minerals are quartz (90%), muscovite (5%) and opaque minerals (5%).

Inference- with 90% quartz observed in thin section, the rock is a quartzite. The rock is hard rock interspersed with mica grains/flakes.(Fig.15)

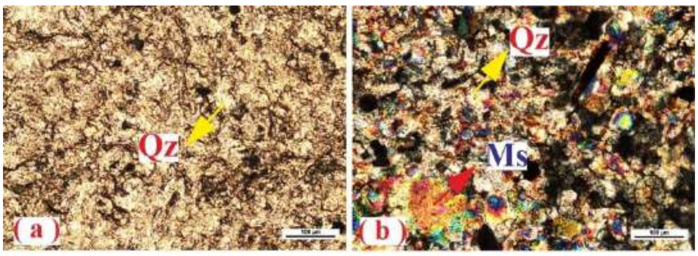


Fig.15:- Quartz (Qz) and Muscovite (Ms) grains along with minor amounts of altered minerals and opaques (Plane Polarised Light (PPL)-Cross Nicols(CPL)

4.0 PERFORMANCE PREDICTION MODELS

The development rate (primary, secondary and tertiary) covering both capital and replacement development drivage works for an annual production of 2 Million Tonnes works out to be 100 m to 150 per day. This will depend on the strike length and the location of the primary openings with respect to the ore body. Considering the thickness variations the replacement drivage length may vary. Thicker the deposit lesser will be the length. From the above discussion it is evident that the advance rate required is very high. This level of advance is very difficult or sometimes impossible to achieve using drilling and blasting. These values further increase when the production increases as expected in near future. Thus, mechanization with new technologies is the only way to meet this escalating demand. Choosing mechanized cutting technologies require the assessment of performance and some of the popular models were discussed by Murthy etal 2011 for TBM and Murthy et al 2008 for roadheader based on the actual applications of these technologies in tunnelling. A brief over view of the performance prediction models is provided in the following sections.

4.1 Roadheader

For the selection of suitable roadheader for a particular ground condition some models have been developed. One of the best prediction models is suggested by Bilgin in 2005. This involves determination of rock mass cuttability index (RMCI), instantaneous and operational cutting rate, the net advance rate per day and bit consumption rate as discussed below in Table 4.

Table 4 : Performance prediction model for roadheader (Bilgin et al., 2005)

PARAMETERS	FORMULA
Rock Mass Cuttability Index (RMCI in MPa)	$RMCI = UCS * (RQD/100)^{2/3}$
Instantaneous Cutting Rate (ICR)	$ICR = 0.28 * P * (0.974)^{RMCI}$ Where; P= Cutter head Power (HP)
Operational Cutting Rate (OCR)	OCR=ICR*CTF Where, CTF=Cutting Time Factor
Advance Rate (AR)	AR = (OCR / Face Area) * Utilization
Roadheader cutter consumption Index (RCI)	RCI=UCS/(P*W*CHD) Where, CHD - Cutter head dia, P-power, W-weight of roadheader
Bit consumption rate	$BCR=897.06(RCI)^2+6.1769*(RCI)$

Designer often would be interested to compute the machine performance for these two technologies for facilitating decision making. Typical performance assessment procedure is depicted in Fig.16.

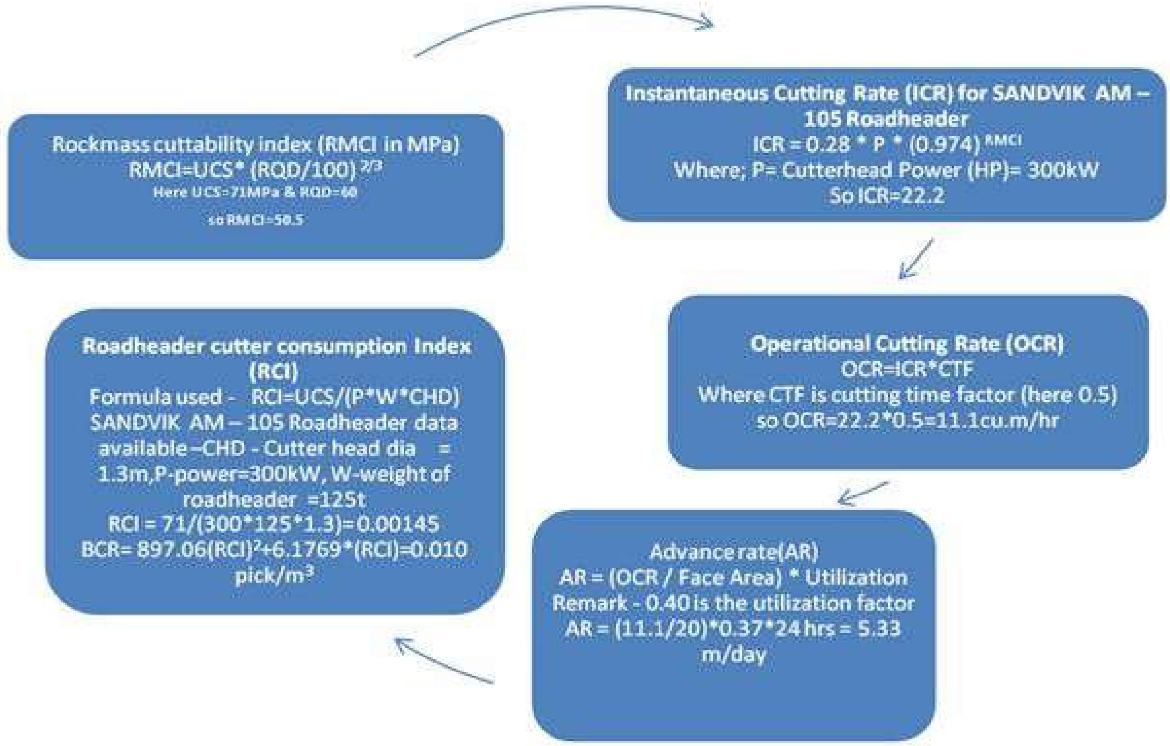


Fig.16: Performance prediction for roadheader

4.2 Tunnel Boring Machine

Performance of the machine has also been analyzed from the established procedure suggested by **Bilgin 2005**. This involves determination of rock mass cuttability index (RMCI), instantaneous and operational cutting rate. The net advance rate per day and bit consumption has also been worked out. Application of some of the models of Roadheader applicable to above conditions are presented in Table 5.

Table 5: Typical roadheader models

MODEL (ROADHEADER)	**SPECIFICATIONS**			**ADVANCE RATE (m/hr)**	**BIT CONSUMPTION RATE (bit/m^3)**
	CUTTER DIA(mm)	**WEIGHT (tonne)**	**CUTTER POWER (kW)**		
SANDVIK AM-105	1300	125	300	5.33	0.0100
EICKHOFF ET-450-L ALPINE	1320	110	300	5.33	0.0124
VOEST ALPINE AM85	1250	102	325	5.34	0.0132

The exact specifications, however, needs to be worked out based on the rock mechanics studies as mentioned above coupled with field assessment of the rockmass properties and rock structure. Selection of TBM is often made based on the specific energy required for cutting the rock. There are standard test procedures recommended for both roadheader and TBMs which involve determination of rock parameters namely, specific energy, drilling rate index, bit wear index, Cerchar hardness and abrasivity indices, punch penetration index. A typical performance assessment procedure for TBM is given in Fig.17.

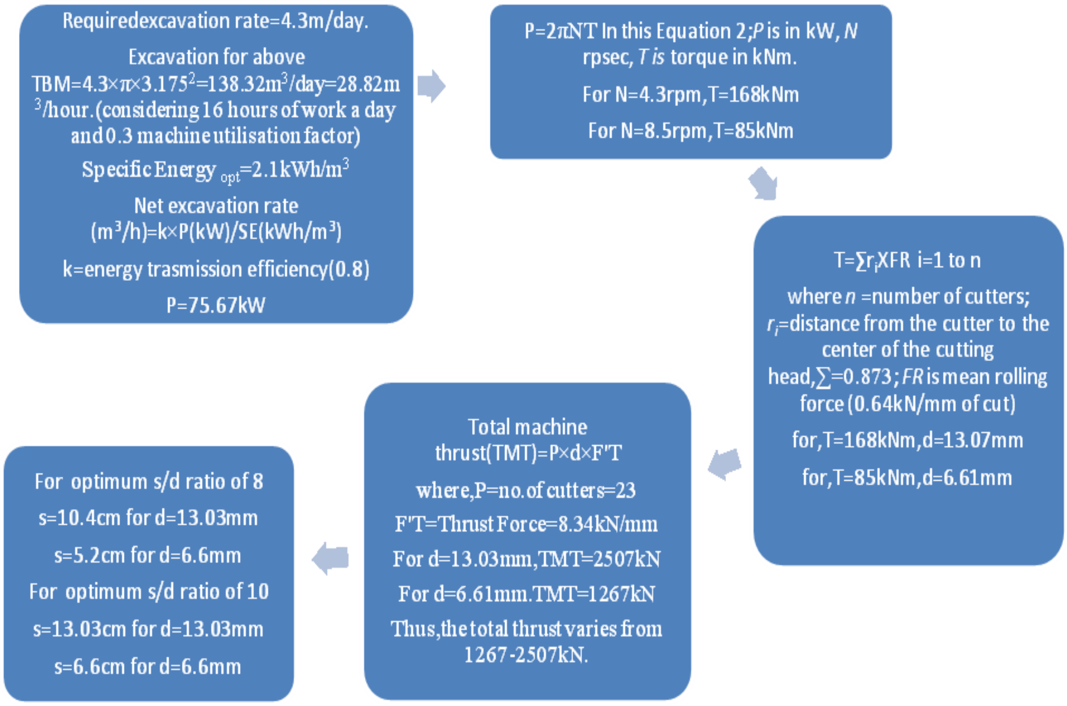


Fig.17: Performance prediction for TBM

A few typical TBMs that can be considered for metal mining perspective are provided in Table 6.

Table 6: TBM models

TYPE(TBM)	TBM diameter (m)	Max Cutterhead torque (N-m)	Thrust (kN)	Disc cutter size(mm)
Double shield	2.4	194172	4372	17
Main beam	3.3	455738	4893	17
Main beam	3.5	1056546	6005	17
Main beam	4.6	2969911	8558	17

4.3 Raise Borer Machine

For faster mine development especially deep underground mines, deployment of raise borer, which is a capital intensive and geology sensitive machine is an apt alternative. Its integration in mining needs proper planning and assessment. In the mine development phase, raise is considered to be a crucial opening that contributes for comfortable working conditions in stopes as well as facilitates passage of ore to meet the production requirements of the mine. Considering the ease and economic excavation of raise, use of Raise Borer Machine (RBM) has assumed significant importance as compare to drilling and blasting (D&B). Typical specs of a RBM are provided in Table 7. To achieve the goal of mechanisation in the formation of raises, Raise Borer Machine (as shown in Fig.18) is a better solution as it not only provides enhanced safety but also reduces raise driving time duration significantly. In a study of performance analysis of raise borer machine in Rampura Agucha mines, Hindustan Zinc Limited, India, two types of rock i.e. Amphibolite (AMP) and Garnet-Biotite-Sillimanite-Gneiss (GBSG) were considered for raise drivage using RBM. The diameter and length of Raise was 3.5 m and 255 m respectively.

Fig.18 – Deployment of raise boring machine

The different operational parameters, namely, thrust to the head, thrust per cutter, torque, penetration rate, rotation speed and power consumption of raise borer machine during reaming process were studied and were collected. The variation in operational parameters such as thrust per cutter and torque to cutter head on penetration rate was analysed. The advancement with the D&B technique has been also studied in the same study. The maximum advancement of raise achieved in D&B technique was around 5.5- 6.0 m/day. Meanwhile, keeping all the dimensions of raise unaltered, the recorded advance rate due to raise borer machine (RBM) was 16-20 m/day. The advancement rate achieved with the RBM is 3-4 times as compared with advancement achieved by D&B method. This facts and figures shows that the use of RBM must be appreciated for faster and safer drivage of raises.

Table 7 – Typical specifications of raise boring machine

Parameters/ model name	**RD-05**
Manufacturer	Master Drilling
Extended height(m)	7.4
Total Weight (kg)	39500
Max reaming force(kN)	7100
Motor Power (kW)	380
Pilot RPM	0 - 40
Reaming RPM	0 - 7
Makeup Torque (kN-m)	620
Raise Angle Range	90°-73°
Pilot Hole Diameter(mm)	350-400
Reaming Diameter(m)	3.1 - 5.1

5.0 CONCLUSIONS

Mine development needs are growing at a rapid pace owing to the stiffer ore production targets. Change in commodity prices are also forcing planners to step up the production for better profitability of operations. Owing to the slow development rate realised in general with drilling and blasting technique(even with mechanized drilling) it is time to think about the application of fully mechanized cutting technologies owing to the rapid strides made in Roadheader, TBM and Raise Borer Machines. The paper discusses these technological options for meeting the typical ore production targets, their advantages and production assessment methodologies. Need for proper intact rock and rockmass characterization for the successful application of these technologies is stressed. Capabilities of IIT(ISM) for providing needful support in selecting these machines as well predicting their performance in varied rockmass conditions is also presented. A close Industry-Academia interaction with assured market for such machines can pave way for indigenous development and their application in a accelerated way. One such collaborative research with L&T for indigenous cutting drum design and fabrication is in progress at IIT(ISM) Dhanbad, strengthening the Govt. of India's missions of Atma Nirbhar Bharat and Made in India.

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ISRM Suggested Methods (CAI)

CSM Method (PPI)

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Asymmetrical mini-disk tools as the possibility of using in mining heads of roadheaders

In underground mines, one of the most commonly used methods of hard rocks mining, in the process of row minerals excavation and drilling of exploratory and opening-out headings or tunnels is the mechanical method. There are use different types of machines - with milling head and cutting tools but also the special machines which use disk cutters - symmetrical and asymmetrical. Using cutting tools allows you to obtain large mining capacity or drilling speed, but also generates a number of hazards or restrictions, depending on used mining tools. The roadways, especially opening-out headings, are currently excavated in rocks with very unfavorable parameters – very high compressive strength and a homogeneous structure. No less important factor is the content of minerals and inclusions in the rocks, causing rapid abrasion and wear of mining tools and in the case of inclusions, for example, spherosiderites, the occurrence of sparks during the mining process.

The other of the most commonly used methods in the process of mechanical mining of hard rocks is mining by means of static crushing, carried out with the help of symmetrical disk tools. This method consists of pushing the disc edge into a rock massive with the normal force perpendicular to its surface. As a result of this force, the uniaxial compressive strength of the rock is locally exceeded, rock massive is crushed and disk penetrates into the depth p. The ability to rotate the tool in the head reduces the friction forces, which reduces energy loss and generates less toll edge wear and dustiness, compared to cutting tools. In addition, the rotation of the cutting disc causes short contact of the edge section with the rock, which ensures the very long durability of the tool. There are three types of symmetric disk tools: smooth disks, disks armed with carbide insert and toothed discs, in one and double or even triple blades versions. Their diameters can be even up to 500 mm.

The disadvantage of mining by static crushing is the need to ensure a huge pressure force of the tool. The value of the pressure force per disk tool can be as high as 300 kN the total pressure force, depending on the diameter of the body can be up to 25,000 kN and many times more value of side expanded force to ensure the stability of TBM work. The occurrence of large values of reaction forces leads to large mass (up to 3,500 Mg) and dimensions of the machine (the length of the TBM reaching up to 400 meters).

Another solution of a mining machine, which uses the principle of mining by static discs is a continuous miner made by ROBBINS. The mining head is constructed in a form of a larger diameter disc with mining discs mounted around the perimeter. The head had the possibility to turn left and right, lift up and leave down. We obtain in this case the cross-section shape of the gallery with a flat roof and floor and arched side walls as for the example the gallery obtained on Broken Hill mine in granite rock.

A clear drawback of the static crumpling method is a necessity to provide large pressure forces to the disks. Whereas, asymmetrical disk tools have been used as mining tools for longwall shearers to increase the output of a large size grain. Conducted industrial tests demonstrated the usefulness of such equipment for obtaining higher product graining. Asymmetrical disk tools are applied in the technique of mechanical mining not only as crushing devices but also in the undercutting method. The principle of the undercutting method is mining a rock by its cutting off towards a free space . A disk tool affects the rock tangentially to the surface of the mined body, similarly as for cutting tools, but the difference is that here it uses the disk rolling movement which efficiently eliminates sliding friction in favor of rolling friction. Application of disk tools in that way lowers energy consumption and pressure forces. It allows receiving much bigger grains of output.

That is why the idea of the undercutting method was used in AGH UST, in order to design an innovative construction of a mining head, equipped with mini asymmetrical disk tools. Special test stands were developed, which allow testing of the asymmetrical mini-disk tools and the parts of the mining head. The first tests carried out on the laboratory test stand using a single asymmetrical mini-disk tool for artificial rock sample mining from the side allowed us to conclude that this method of mining generates lower tool loads and bigger output grains.

The primary research for replacing cutting tools in mining head with disk tools carried out in Colorado School of Mines and in AGH UST did not allow to obtain satisfactory results. The disk tools were mounted directly on the head body. It was generated large reaction during mining, which had a great influence on durability and effectiveness.

Based on the received results of own tests of rocks mining with asymmetrical disk tools (of diameter up to 160 mm), the Department started tests to elaborate a new conception of a mining head. In this design motion of tools will be forced, and will cause mining of a rock body with tools along complex movement trajectory. It allows the crossing of mining lines of individual disk tools and facilitates mining compact rocks through breaking off rock furrows. Disk tools were mounted on separate plates that could rotate on the mining head body, and are propelled independently from it. It should decrease the energy consumption of the process. Taking that into consideration, there was elaborated a conception of a head with asymmetrical disc tools of a complex trajectory, mounted on three plates rotating in relation to the unit. The eccentric location of the plates axes with tools should enable their easy slotting into the rock body at the unit motion both vertical and horizontal one.

It was necessary to determine the values of many parameters essential for proper designing the new head solution such as e.g. the number and direction of rotation of plates with tools, required value of torques for plates and the unit body, etc. Estimating the values through theoretical simulation was very complicated or in some cases even impossible, that is why stand tests of mining compact rocks with disc tools on a specially constructed lab stand were suggested. The spatial model and the kinematic possibilities of the first stand are shown in this slide. It allowed for the mining of a rock sample with a rotating plate with 6 asymmetrical mini-disc tools in a vertical or horizontal plane. It was possible to regulate the direction and number of rotations as well as the cutting depth.

Mining tests conducted in a horizontal plane gave unsatisfactory results - for bigger mining depth the significant vibrations of the plate with disks were observed. Much better results were obtained when mining in the vertical plane. In this case, was possible mining with a depth up to 40 mm. Very important was the way of mining - in direction of the flat or inclined surface of the disk. A significantly lower dynamics of the mining process and bigger grains of output was observed for attacking the sample with the flat surface of the disc. For this mining mode, the tests of natural rock block mining (granite and sandstone) were performed. For both types of rock, the full spalling of the cut for the depth of 30 mm has occurred.

On the next laboratory stand the confirmation tests were performed. On this stand, it was possible to carry out the mining of artificial rock sample with the same plate with disk tools, but in the complex motion trajectory of the disk tools. The rotating plate with disk mined the ring sample, which also rotated, from the side. In dependence on mining depth and the mining speed, it was possible to obtain the large grains of the output. Remarkably interesting was the surface of mined rock sample - cyclic chipping is clearly visible. The results allowed to a selection of the basic parameters of the head operation - number and direction of plate and body head rotation, diameter and angle of disk tool, the needed torque value etc.

The works of the mining head project were performed in cooperation with the REMAG Company using the new mining head solution dedicated for KR150 roadheader. The mining head consists of the body driven by an external shaft and three plates with disk tools, driven by an internal shaft. The preliminary tests were performed on an artificial large size concrete block of uniaxial compressive strength up to 40 MPa. The best effects of the work – large graining of the output, low engines load, and limited vibrations were obtained for the head body rotations at the counterclockwise direction of value 20 rpm, and the plates rotations at the clockwise direction of value 60 rpm. The change of direction of the head body or plates with disk tools rotation onto the opposite had a highly negative influence on the engines load and disk tools wear.

To check the influence of the deflection angle of the rotational axis of the disk tool, new exchangeable holders of these tools were made which allow disk tools mounting at an angle of -5°, 45° and 90° relative to the surface of the plate. Only the disk tools mounted at an angle of -5° allowed for proper work, without significant wear. Another value of the angle caused the broken disk tool wedge. There were also tested the disk tools with disk wedge reinforced by carbide inserts. This solution caused the breaking of carbide inserts during mining.

To check the effect of the type of material and the method of making the tool, three types of disc tools were tested. Disk tools had the same diameter - 170 mm and wedge angle of 45°. They were made of tool steel, low-alloyed cast steel and ADI spheroidal cast iron. The tools manufactured from tool steel type NZ3 were full-hardened, to a hardness of over 55 HRC. The tools manufactured from tool steel type 36HNM were surface hardened and tempered. Tools made of cast steel were machined after casting. After this mechanical treatment, it was noticed that tools made of cast steel had numerous castings defects - blisters and pores. These tools have been disqualified.

The tests were carried out using medium type FR250 roadheader, mining the big dimension concrete block of compressive strength up to 60 MPa. The best results were obtained for tools made from tool steel type 36HNM. After one hour of operation, there were not significant traces of wear observed. In the case of disk tolls made from tool steel NZ3, already after very short work numerous edge breaks as well as cracking and breakage of the part of tools were noticed. However, in the case of disk tools made of ADI cast iron, no breakage of the tool edge but its systematic abrasive wear was observed. The outside diameter of cast iron tools after about 30 minutes of work was decreased to a value of about 135-140 mm. This diameter value did not allow further work.

Conclusions.

Based on the obtained results of laboratory and field tests it can assume that the proposed solution of mining head with mini-disk tools of complex motion trajectory is an alternative for standard cutting tools. But important for durability, mining efficiency and energy consumption is a correct assembly of disk cutters - the inclination 5° relative to the plate surface, the choice of needed working parameters - number and direction of plate and head body rotations and correct selection of material for tools - tool steel hardened and tempered. This should be confirmed by industrial research for example in one of the rock open pits.

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Increasing the technological possibilities of the vibrating mill through a change in the construction of the chamber

Summary:

The presentation will be presented the issues related to the grinding process in the vibration mills with low vibration frequency. These mills are rated among devices with high energy of impacts with much wider potential of industrial use than the classic gravitation mills. In vibratory mills there is an unfavorable decrease in the intensity of the grinding process along with the increase in the chamber diameter, which makes it impossible to achieve high performance of such devices. One of the ways to reduce or eliminate this occurrence is to intensify the load movement inside the chamber - this is the subject of this article.

In the presentation will be shown that in a vibrating mill of periodic action it is possible to increase its technological capabilities by application of an appropriate cylindrical component permanently installed inside the milling chamber.

Vibratory mills grind almost all materials with hardness down to the whole Mohs scale, including air-blasting materials and flake-shaped or bar-shaped materials. The only limitation in dry grinding is the material moisture content, which should be below 3%. In these mills, it is possible to grind all materials with a hardness of the entire Mhosa scale, including materials with grains in the shape of flakes or bars.The simplicity of connecting chambers of vibrating mills with the feeding and receiving device allows for various grinding variants (dry, wet, with reduced and increased pressure or temperature). The grain size of the feed depends on the grinding process and can reach up to 40 mm with fine grinding up to 50 micrometers to obtain materials with nano-grains. The possibility of grinding materials with such different grain sizes makes vibratory mills devices with a wide range of applications.

The chamber diameter of the tubular vibratory mill is the main design parameter influencing the efficiency of the grinding process and the mill efficiency and has the following influence:

$$Q_j = k_m \, D^c$$

where:

Q_j – efficiency per $1m^3$, ,

k_m – factor of the influence of all relevant parameters on the grinding process ,

$k=f(A, f, b, d_m, \rho_m, ...,)$, -,

D – chamber diameter, *m*,

c – exponent taking into account the basic parameters of the mill,-1 < c < 1 ,- .

The need to increase the efficiency of vibratory mills determines the need to increase their chamber diameter. Unfortunately, the increase in the diameter of the chamber causes a decrease in the effectiveness of the grinding process, i.e. (that is) obtaining worse grain size parameters of the grinding product. This is due to:

– in the vibratory mill, the grinding media receive energy from the vibrating chamber,
– as is known, the grinding media in contact with the chamber liner have the biggest energy,
– the energy of the subsequent grinding media layers decreases as they approach the chamber center,

  this causes the formation of zones of reduced energy of grinding media.,
– increasing the chamber diameter increases the size of these zones, resulting in a decrease in grinding efficiency.

The decrease in grinding efficiency in large-diameter chambers means that in order to obtain the high efficiency of vibrating mills while maintaining their high technological capabilities, the only solution was to produce multi-chamber mills with relatively small diameter chambers.

The negative impact of increasing the chamber diameter on the increase in the size of the low activity zones of grinding media can be eliminated by using:

- the elliptical trajectory of the chamber movement,
- the use of complex chamber movement (for example, combination of rotation of the chamber around its axis and vibration movement),
- **by changing the structure of the chamber.**

The experimental tests were conducted in a laboratory vibratory mill with kinematic excitation of a vibrating motion with a circular vibration trajectory

The tests were carried out in steel chambers with an internal diameter of 210 mm. These were chambers: Classical vibratory mill - designated as the S chamber and chambers equipped with an additional element intensifying the milling process in the shape of a cylinder, rigidly fixed in the geometric center of the chamber with different diameters.

S Chamber	**A** Chamber	**B** Chamber	**C** Chamber

In the beginning, using a high-speed video camera, visualization tests were carried out, consisting in observing the movement of grinding media in the presented chambers of the vibrating mill.

These tests were carried out at the set operating parameters of the mill and the speed of photo recording, and the purpose of these tests was verification location and size of zones of reduced activity of grinding media and verification of the benefits of changing the chamber construction.

The main aim of changing the construction of the chamber was to increase the intensity of the grinding process. Therefore, **the determination** of the influence of these constructional changes on the quality of the grinding process required experimental research. So, tests of grinding the model material were carried out - for which quartz sand with a grain size of almost 100% below 0.5 mm was selected.

The following parameters were adopted as the established parameters of the grinding process and the vibrating mill:

- chamber filling degree 0.80 [-], the most favorable for the classic chamber – S calculated for the working (active) chamber volume,
- vibration frequency 12 Hz,
- vibration amplitude 10 mm

The research program was divided into 3 stages.

The first one concerns the influence of 5 sets of grinding media on the grain size parameters of the grinding product, for grinding times from 2.5 to 20 minutes - for the first 4 sets of grinding media and up to 40 minutes for a set of 17.5 mm - for two chambers - "S" (classic) and with the smallest element, chamber "A". After analyzing the particle size distribution results (in the laser diffraction particle size analyzer), it was observed that using an intensifying element improved the particle size distribution parameters of the ground material for each set of grinding media. Nevertheless, the worst results were obtained for a set of grinding media with a diameter of 10.0 mm.

Therefore, in the subsequent stages of the research, the testing of this set was abandoned. Due to the labor-consuming research and the known nature of the grinding kinetic curve, two grinding times were adopted in the subsequent stages of the research: 10 and 20 minutes. (in total it was over 120 regrinds and over 500 grain size analysis). The obtained results clearly show that much finer graining is obtained in the chambers equipped with intensifying elements during the same grinding times.

The use of a cylindrical element inside the chamber reduces its working volume - which may result in a decrease in total efficiency. But the correct selection of the intensifier diameter, besides improving the graining parameters, can significantly improve the yield.

The fourth series of tests concerned the experiment in a chamber with a larger diameter.

The research aimed to determine the influence of the selected intensifying element on the particle size distribution parameters. These were chambers: standard - "D310S" (internal diameter 310 mm) and with the additional feature "D310B".

Also for the tests of a chamber with a larger diameter, an intensifying element gave very good results.

As expected, finer graining was obtained in the smaller chamber, but it is important how the obtained results affect the mill's efficiency for the yield of grain of a specific size. Those tests indicated that using an additional element in chamber B provides higher throughput of about 29% for the same specific grain size.

Conclusions:

1. The visualization of load movement by using a high-speed digital camera has shown that the use of the additional cylindrical element within the chamber reduces the zone of grinding media lower activity (location of the lower kinetic energy of the grinding media).
2. The results of quartz sand grinding tests showed that changing the chamber construction for each of the analyzed variants significantly improves the grain size parameters of the milling product.
3. The advantageous effect of such an additional element inside the chamber is more significant in a chamber with a larger diameter (310 mm).
4. The aim of the work was achieved.

DUMP SLOPE, HIGH WALL AND BENCH MONITORING USING MOTION TRACKING ALGORITHM AND PARICLE IMAGE VELOCIMETRY

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ABSTRACT

An accurate measurement of movement/ deformation in dump slopes, high walls or benches is fundamental to a safe mining operation. Motion tracking algorithm is effective in geotechnical modelling domain. Particle Image Velocimetry (PIV) is a velocity-measuring technique in which image space i.e. patches of texture are tracked through an image sequence and converted to object space using a transformation matrix. Image processing algorithms have been written to apply the PIV principle to images of rock movement. This system can measure deformation, associated velocity and acceleration more precisely than the existing radar based systems.

1.0 INTRODUCTION

Motion tracking and analysis algorithm based on the principle of particle image velocimetry (PIV) and close-range photogrammetry is useful to investigate the stability of dump slopes, high walls or benches. Using PIV, the movement of a fine mesh of soil/rock mass patches is measured precisely. Automatic tracking of unlimited number of objects without markers can provide a management tool to predict early detection of any failure in dumps, high walls or benches. Since PIV operates on the image texture, intrusive target markers need not be installed in the observed soil/rock mass. The resulting displacement vectors are converted from image space to object space using a photogrammetric transformation. This paper presents an application of motion tracking and analysis algorithm in a large surface mines using all weather NIR camera which can be used under rain, fog, mist or dust. The motion tracking algorithm, which has been patented, integrates various technologies viz. Artificial Intelligence, deep learning, neural network, synergetic computing, advanced data analytics, machine learning, pattern recognition, discriminant analysis and classification techniques.

2.0 MOTION TRACKING AND ANALYSIS ALGORITHM

The algorithm takes video file (AVI, raw) as an input and undertakes 3D calibration. In order to track the moving objects automatically, the algorithm tracks object positions (called “trajectories”) covering following variables.

- x, y, z over time
- Angles and distances
- First and second derivatives over time
- Angle projections onto all planes
- Center of mass
- Impulse

- Force
- Moment of momentum
- Moment of torsion

2.1 Key Characteristics of Motion Analysis Software

The tracking system allows the followings

- the necessary Graphical user interface(GUI) to connect all inputs required and collect video streams from camera
- monitoring the tracked objects features of movement in all directions
- necessary masking tool to define area of interest
- necessary communication to issue an alarm
- necessary licensing mechanism to protect the software
- triggering an alarm/alert as soon as movement exceeds the threshold limit as set up by the mine management

2.2 Major Hardware Requirement

The list of major hardware details is enumerated below:

- Industrial server with dual monitors: fan less, 25^{o}C ~ 60^{o}C, Intel Core i7, 32 GB, 1 TB SSD, 2TB HDD with RS 485
- Server rack: low with power supply
- WiFi radio with directional antenna (IP 67)
- Network switches with PoE
- Lightening surge protection
- Env. Box (IP 67)
- NIP camera with mounting accessories
- Alarm and notifications system with software
- Windows server with Presentation tool
- Power supply system

3.0 FIELD EXPERIMENTATION

The field study was carried out at a large surface mine, where an NIR camera was mounted on a pole as shown in Figure 1 (a). The control system containing data storage and NAS is shown in Figure 1 (b). The camera was equipped with auto switch facility to activate night lense whenever the illumination fell to less than 10 lux. During day time, the colour lense was activated and all video streams were saved in the internal memory of the control system. The 6 MP camera used had a resolution of 3072x2048 pixels. At a distance of 500m, the camera had field of view (FOV) of 575m (width) x 415m (height). The horizontal accuracy was configured as 18.72 cm/pixel and vertical accuracy as 20.26 cm/pixel.

Figure 1(a): NIR camera mounted on the pole

Figure 1(b): Control system along with storage device

A typical tracking picture showcasing the BioID framework in case of movement in the dump is depicted in Figure 2(a), (b) & (c) where green color arrows show the movement of particles in the dump picked up by the BioID tracker software.

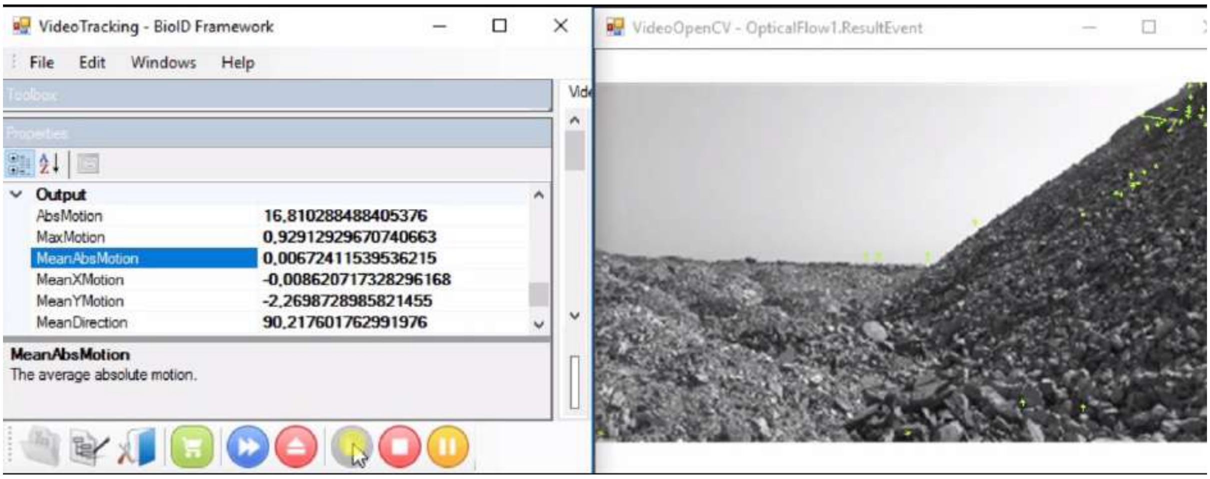

Figure 2(a) : Movement in the dump captured by BioID Tracker

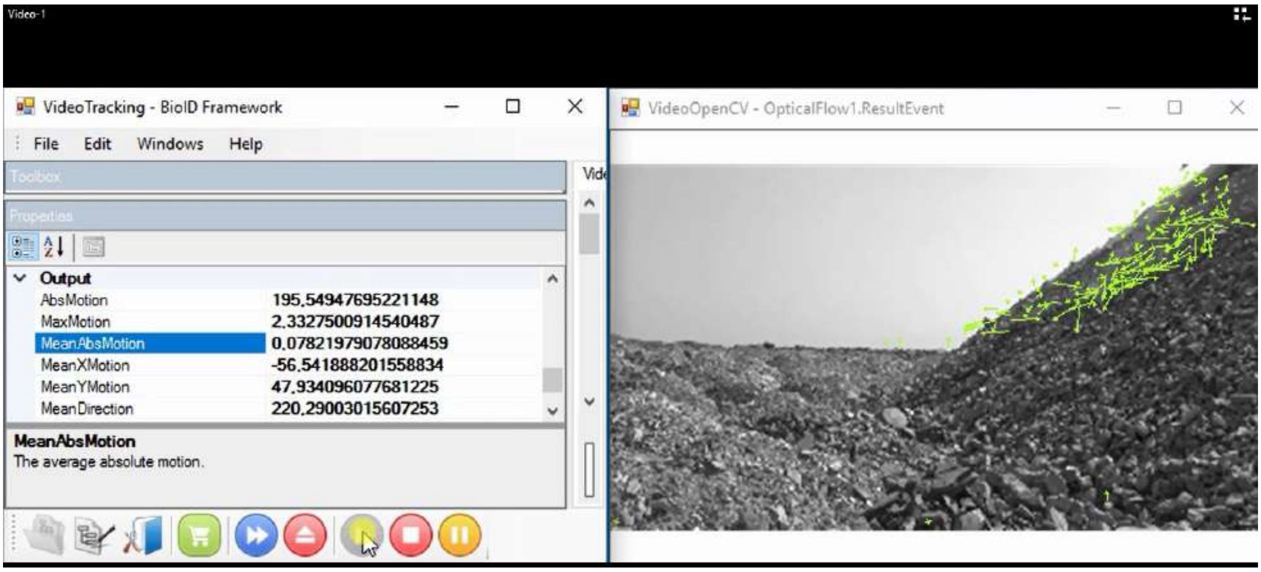

Figure 2(b) : Movement in the dump captured by BioID Tracker

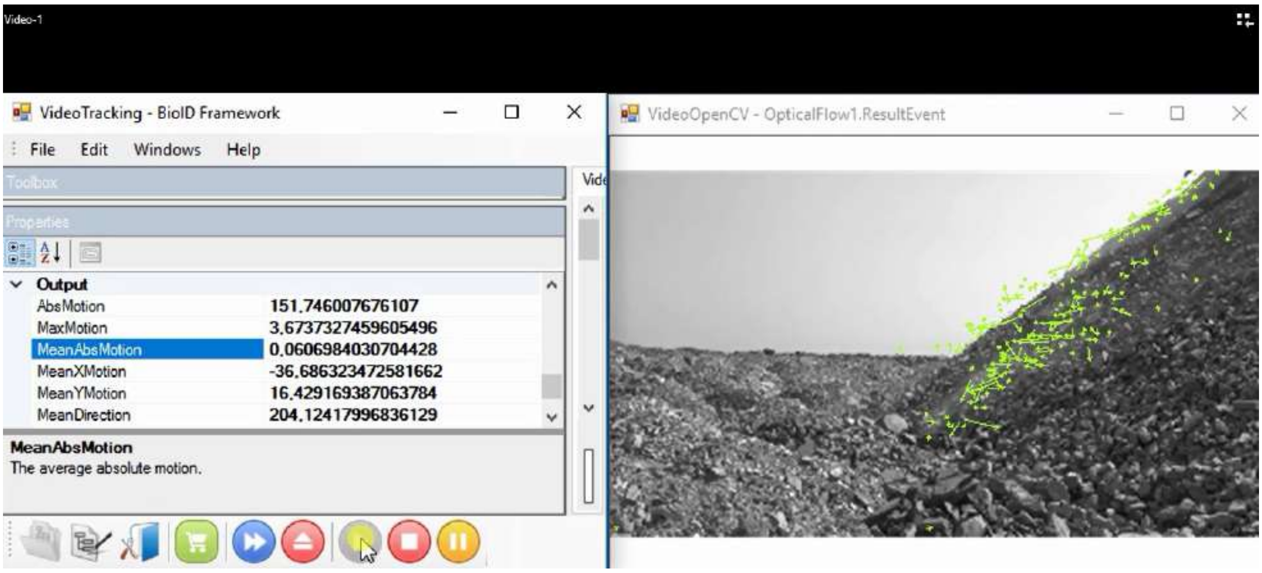

Figure 2(c) : Movement in the dump captured by BioID Tracker

4.0 INTERPRETATION OF RESULTS

The analysed output derived from the motion tracking algorithm was compared with radar output by fixing identical field of view (FOV). The signature of average enhanced deformation average, minimum and maximum is shown in Figure 3(a), (b) & (c).

Figure 3(a) : Plot showing average enhanced deformation (mm) of moving particles

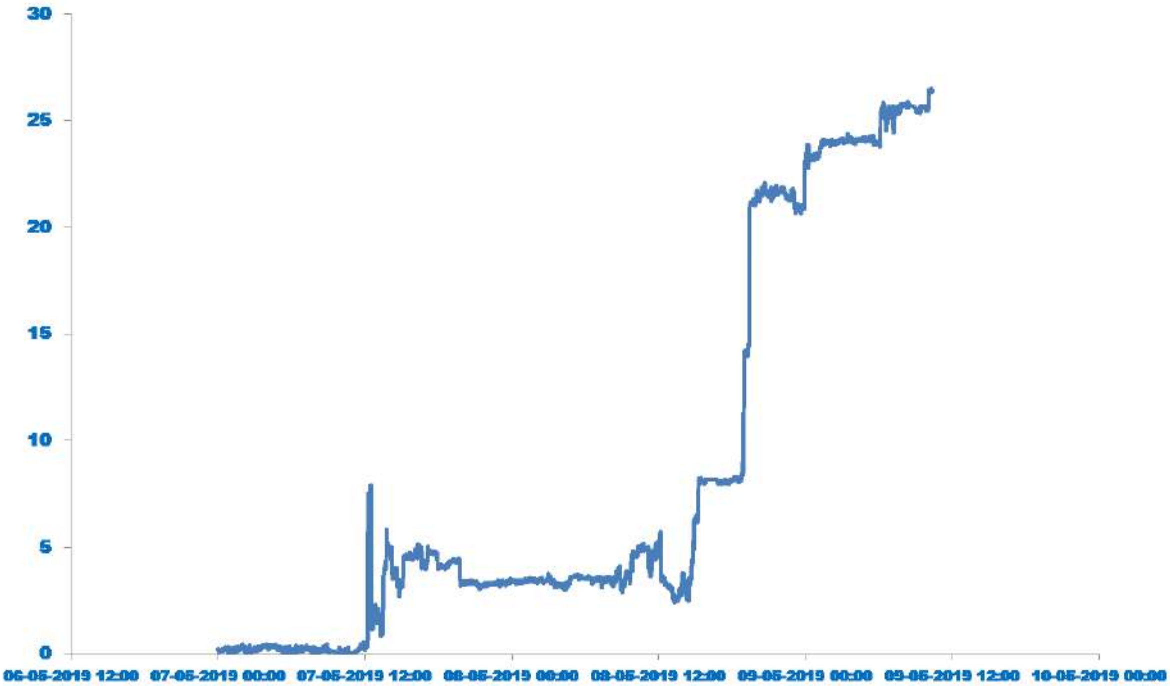

Figure 3(b) : Plot showing maximum enhanced deformation (mm) of moving particles

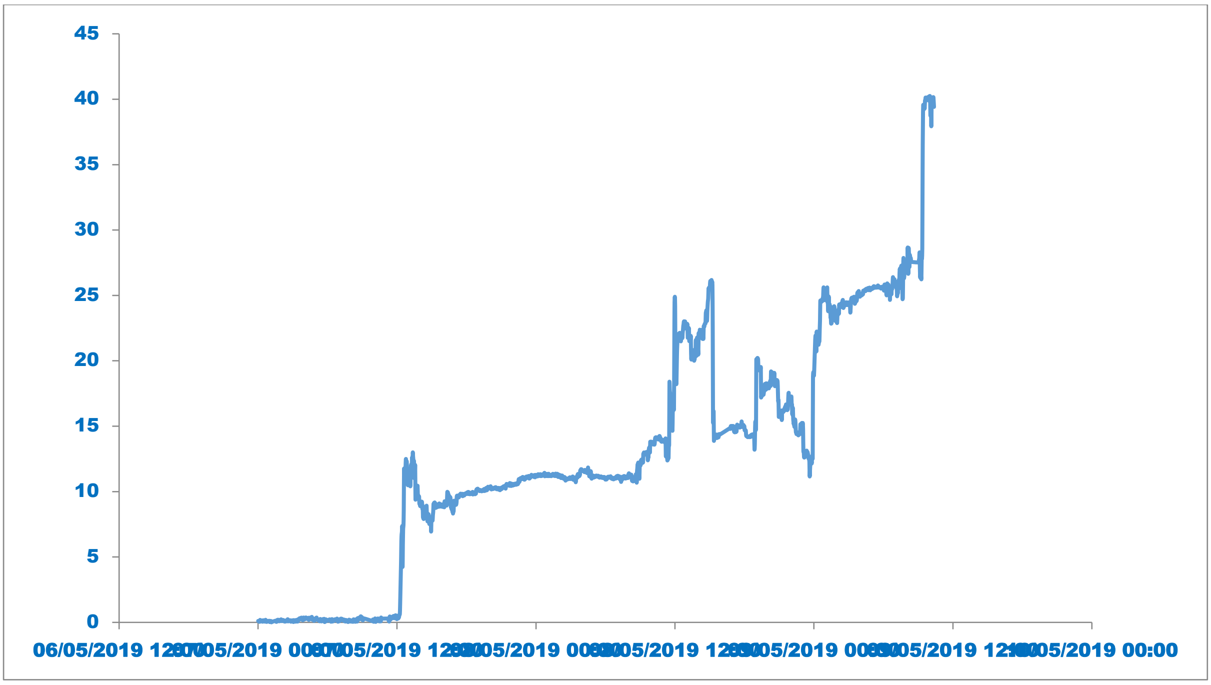

Figure 3(c) : Plot showing minimum enhanced deformation (mm) of moving particles

5.0 CONCLUSIONS

Motion tracking and analysis algorithm using NIR camera would be a cost effective and technically superior solution to monitor the movement in various kinds of slopes. As camera system converts the image space to object space, all movement in real world scenario i.e. inward or outward of plane, vertical downward or sideways movement can be detected accurately and enhanced deformation trajectory can be obtained for detailed geo-technical investigations. The camera system does not require any WPC license unlike the radar system. The camera system has no health hazard whereas a long exposure of radio waves can create health hazards viz. distress, insomnia, depression etc. In terms of tracking accuracy per pixel, the camera system at a distance of 850 m from field of view would be 7.5 times more accurate than the radar system as camera system can track at a pixel size of 1mx1m with sub pixel accuracy whereas the radar based system has pixel tracking accuracy of 7.5mx7.5m at a distance of 850 m from field of view and 15m x 15m at a distance of 1.7 km from the field of view. The farther one proceeds, the tracking accuracy of camera system increases as compared to the existing radar based systems. The camera system does not face any atmospheric refractivity like the radar system which incorporates a fixed error during tracking movement.

The motion tracking algorithm along with PIV technique can be gainfully used to investigate the stability of dump slopes, high walls stability or benches.

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FLYASH AS A MINE VOID FILL MATERIAL

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Abstract

Generation of fly ash at high volume is a major challenge for its bulk utilization. Filling of mine void through fly ash generated is a way toward the solution with a concept of full recycle. Moreover it needs proper investigation towards negative implication to environment and practical difficulties associated with.. Sand and Mill Tailings are conventionally used by mining industry to fill voids created due to mining.. Present chapter is attempt towards compile all information available for use of fly ash in mining industry as a fill material, so that one can plan for effective and bulk utilization of fly ash with a concept of full recycle.

Introduction

Stowing by incombustible material is conventional practice to fill voids created by mining activity, once the process is completed or in operation as per approved plan. The stowing materials which are being widely used from a very long time for the particular purpose are sand and mill tailings (Mishra and Karanam , 2006). Sand obtained from the river beds possess apt physical properties to justify its use in mine back filling. Due to increase in mining activity, more quantity of sand is required which in turn is increasing the pressure on the river beds. Due to the massive utilization of sand in the construction sector and its non-replenishment in the rivers because of the construction of dams on the upstream side, the availability of the sand has become limited or scarce. Thus, the use of alternate stowing materials are being emphasized (Gupta and Paul, 2017).

Fly ash generation is abundant in our country and its utilization in the field of mine back filling could be fostered. Moreover, the power plants are located mostly in the vicinity of coal mining area and thus transportation of fly ash would be easy as compared to sand from the river beds which are 50-80 kilometers away from the mining sites (Bijon *et al.*, 2016) . The physical properties such as bulk density, porosity, permeability, specific gravity, Atterberg's limits, water holding capacity and particle size distribution suggest that fly ash is suitable as a stowing material (Skousen *et al.*, 2017). The use of fly ash could replace sand with increased benefits.

Potential of fly ash as fill material

Fly ash is basic in nature having pH value ranging from 7-10. The filling up of mine sites and mine pits with fly ash has proved to be beneficial where Acid Mine Drainage is prominent (Skousen *et al.*, 2017). The basic property of fly ash neutralizes the acidic waters present at the mine site and further restricts the generation of AMD by cutting off the contact between pyrites and oxygen. The filling up of fly ash with proper compaction also reduces the risk of subsidence at the mining sites Ahmaruzzaman (2010),. Fly ash has high water holding capacity and absolutely no plasticity.

Since the fly ash is very fine in nature, during its handling, storage and transportation, huge amount of dust is produced in the surroundings which could lead to irritation of eyes, skin, nose, throat and respiratory tract (Yao *et al.,* 2015) Their storage also requires a huge amount of space. Previously, the fly ash was dumped on to the barren lands which could lead to soil degradation and could possibly be a threat to both humans and environment. Besides, fly ash when comes in contact with the surface water or rain water for a long time, it starts leaching heavy metals along with the water. This has potential of further contaminating our ground water reserves with the heavy metals. And, this leaching of heavy metals is more prominent in acidic medium (Dutta *et al.,* 2009). Further studies have revealed that when fly ash is hydraulically transported to the fill site, they tend to clog the pipes as they try to settle down (Rani and Jain, 2017). This increases the pressure on the pumps which are being used for the particular purpose and also consumes a lot of water.

Fly ash is one of the suitable materials for mine back filling. It is lightweight, granular and non-plastic material which behaves like a non-cohesive soil. These geotechnical properties make it excellent fill material for mine reclamation and use in active mines (Singh, 2010). Mine back filling with fly ash has potential to be an attractive option for those power plants located near the coal mining region. Back filling of underground mines with fly ash is technically feasible and holds good potentials for those areas where sand is scarce. Open cast mine filling may also be considered as land reclamation (Ahmaruzzaman, 2010). Presently the utilization of fly ash in mining sector is generally restricted to abandoned mines. With the change in technology, life of mines is also getting extended, thus delaying the availability of the area of ash filling purposes-one of the main reason for limited fly ash utilization in this sector (Singh, 2010).

According to Ahmaruzzaman (2010), fly ash mine void filling has been carried out in lab scale as well as actual field applications. Mine void filling is undertaken for numerous causes which are mainly control of Acid Mine Drainage (AMD) and control of mine fire.

Due to the above mentioned reasons, the use of fly ash composites are gaining acquaintance. Previous studies have engrossed the mixing of fly ash with lime, gypsum, cement, powdered coal, etc. to overcome the potential problems associated with the use of fly ash alone (Mishra and Karanam , 2006, Rani and Jain, 2017, Jain and Sastry, 2003 & Das *et al.,*2012). Water alone cannot bind the fly ash particles since they are hygroscopic in nature, thus, lime has been used (Forsmo *et al.,* 2006). Small spherical granules can be prepared in a rotating Disc Pelletizer by varying the disc parameters such as disc speed and its inclination with the horizontal (Harikrishnan and Ramamurthy,2006). The granules possessed sufficient strength to be handled, transported and stored. This was ensured by studying the help of granule properties such as Drop number and Green Compressive Strength of the green granules (Anamika *et al.,* 2019).

The concept of granulation of fly ash could help the industries as well as the thermal power plants to store and use the granules when required. The granules could be stock pilled and this would require less space as compared to that with the fine, powdery fly ash. Also, their hydraulic transportation would improve in the form of spherical granules. Due to the spherical particles obtained, the packing of the granules would be better and permeability will reduce. And, because of the presence of lime along with the fly ash, the leaching of the heavy metals would reduce. The solution of lime with water is considered basic in nature. Thus, it would restrict the leaching of heavy metals from the fly ash into the ground water reserves.

The procedures for conducting underground mine void filling with fly ash are same irrespective of purpose such as subsidence control, AMD control, or fire abatement. (Magnuson and Malenka, 1970). This can be done by two methods either dry fly ash injection or wet slurry injection. Dry fly ash injection is done through placing steel casing through drilling of 6 inch diameter boreholes into the mine void to that level. The dry fly ash is then injected at 12-30 psi (relatively low pressure) into the mine void. On the other hand, wet slurry injection is conducted in much the same manner as dry ash injection at slightly larger 10 inch borehole at higher injection pressures (up to 100 psi). (Magnuson and Malenka, 1970).

Filed Studies

In underground coal mines, typical sand is being used for stowing purposes. Coarse fly ash particles behave similar to sand and in order to explore possibility of its use in underground mines (Singh, 2010). During 1999-2000, Backfilling of 60,000 tonnes flyash demonstrated by the National Thermal Power Corporation Limited (NTPC), India in underground mines of Singareni Colliery Company Limited, Southern India, with collaboration with Central Institute of Mining and Fuel Research, India (Mathur, 2000).

Utilization of fly ash in mining sector as stowing material in the underground mines or as fill material for reclamation of land in the abandoned mines has been proven and needs to be pursued aggressively. There is also a possibility of filling ash along with overburden dumps in the operating mines. This will open a new field for fly ash utilization in the mining sector (Singh, 2010). In India, fly ash stowing was first tried at Lodna Colliery of BCCL in 1987. SCCL (Singareni Cllieries Company Limited) has been experimenting fly ash stowing since 1995 (Sahay, 2010). MoEF has already notified a frame work regarding the utilization of fly ash in the mines. Power utilities and mining companies need to work together in association with various regulatory authorities for utilization of fly ash, reclamation of mines and thus protection of environment (Singh, 2010).

Case study 1: In the year of 1999, NTPC in association with CMRI, Dhanbad, carried out a lab scale study to determine the suitability of ash filling in open cast mine. This study was conducted on ash from Korba, Kahalgaon, and Talcher Thermal Power Stations and was found to be appropriate for mine back filling. (Source: Singh, 2010).

Case study 2: CMRI, Dhanbad (Presently known as CIMFR) and FAM (Fly Ash Mission), New Delhi has conducted extensive research work for utilization of fly ash as a stowing material for underground coal mines. For this purpose two sites were chosen for field trial such as Durgapur Rayatwari Colliery, WCL and PK-1 Mine of SCCL. At Durgapur Rayatwari Colliery ash was used for stowing from Chandrapur Super Thermal Power Station, MSEB and approximately 8000 cu.m of ash could be stowed effectively. At PK1 Mine of SCCL ash was used from the captive power plant of HWP, Manuguru and about 10000 cu.m of ash could be stowed successfully in this mine. (Source: Ghosh *et al*., 2005).

Case study 3: A research cum pilot scale study was jointly conducted by NTPC and CMRI, Dhanbad in underground mine of GDK-6A of Singareni Collieries Company Limited at Ramagundam in 1994-95. Initially about 10000 tonnes of bottom ash was successfully stowed in experimental stage. Later about 80000 tonne bottom ash was further stowed successfully in the mine. (Source: Singh, 2010).

Conclusion

Number of researches are still going on towards utilization of fly ash and its derived product for application in the mining area. Number of regulatory provisions were also announced by Government of India. Mining industry still prefer use of fly ash in abandoned mines only. Due to which still utilization level of fly ash in mining is not satisfactory.

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Addressing the constraints of Overburden dump accommodation in an Opencast mine, at the design level, through a model defining relation between stripping ratio and strike length of coal mining block area.

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Abstract: **B**urgeoning coal demand has necessitated corresponding increase in the size and depth of the opencast mines in the country. The deeper coal deposits have necessitated the handling of large volume of Overburden, resulting in formation of huge overburden dumps. Accommodation of huge overburden dumps have become a matter of important concern for mines with higher stripping ratio. Restriction in availability of land area, for accommodating overburden in the external dumps, on account of socio-economic & environmental factors aggravates the issue. Planning for Coal extraction from a mine block area of given stripping ratio, necessarily requires to address the issue of overburden dump accommodation, while complying the extant stipulations regarding safety & environment.

This paper deals with an effort to find a solution for determining the optimum strike length of mine block area, for a given stripping ratio, while addressing the issue of overburden dump accommodation, within the proviso of extant conditions regarding safety and environment.

Introduction: The coal vision 2030 estimates that the domestic coal demand will go to 900-1,000 MTPA by 2020 and 1,300 - 1,900 MTPA by 2030 [1]. In 2019-20, around 95.64% of coal was produced from opencast mines. On account of upcoming high demand of coal, it is incumbent upon the mine operators, to extract coal from deep lying seams which have higher stripping ratio. According to coal directory of India 2017-18, MCL reported the minimum stripping ratio of 0.97 whereas NEC reported the highest stripping ratio of 10.09. Higher stripping ratio means handling of huge amount of overburden for extraction of coal, which creates a problem of overburden dump accommodation, on account of limited space within the mine precincts and the extant stipulations from the regulatory bodies.

It is always better to have proper planning & design, rather than performing remedial measures to compensate for design deficiencies, with due consideration to the stipulations given by regulatory affairs. The cost of the compliance may be reduced when taken into account in the design or planning process, in a proactive manner, rather than being addressed on an ad hoc basis as problems develop or enforced actions occurs [2].

Problem statement: The seams which were left unworkable due to high stripping ratio in the past are being extracted now profitably, on account of cost effective technology available globally. However, limited space being provided for mining, in the current scenario of high environmental concern, the problem of over burden dump accommodation thereof, have posed another challenge, that need immediate attention [3]. Overburden generated at the start of excavation is required to be accommodated in external dumps (additional land area in the no-coal zone, until sufficient space is generated for internal dump (de-coaled area). In the light of above, it is felt necessary to determine an optimum strike length of a coal mining block area, for a given stripping ratio, while addressing the issue of overburden dump accommodation.

Assumptions: Coal seams are always found in undulated terrain, which means the ratio between thickness of coal seams and over laying over burden always varies. For calculating stripping ratio and depth of the mine, we consider coal block as rectangular block having average thickness of coal seams and over laying strata throughoutthe mine life.

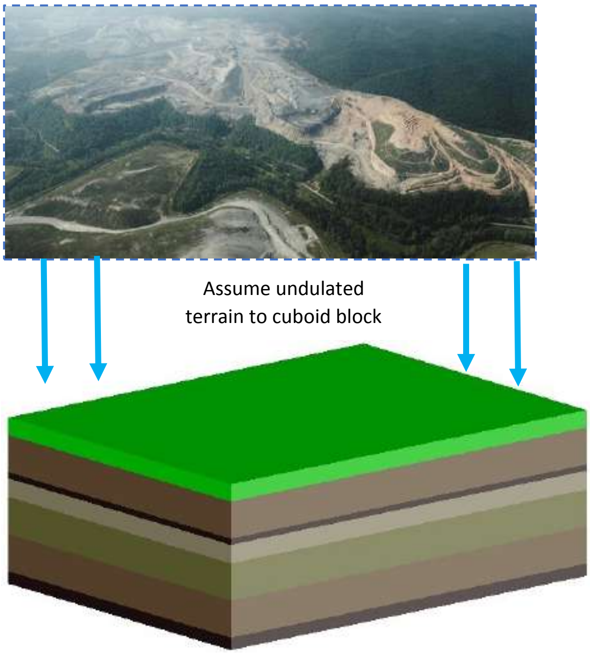

Fig: 1

1. Evaluation of volume of external Dump:

For any green field project, i.e starting of mining in any virgin land area, we have to start excavation from no coal zone, so as to reach the in-crop of the bottom most coal seam, upto its floor. However, Formation of benches, for the purpose is exhibited in the most simplecross-section (dip direction),as shown in fig: 2.

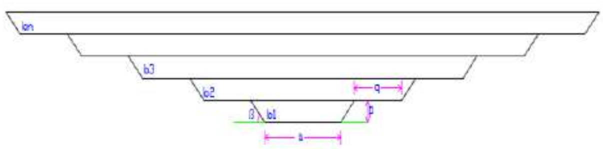

Fig: 2: Cross-sectional view (Perpendicular to strike)

Assuming the height, width and angle of the benches as**p, q** and **β** respectively and the minimum distance between dump and lower most bench as "**a**", minimum Cross-sectional area($A_{ñ}$)of solid material which need to be accommodated in the external dump, will be the sum of b1, b2, … bn (as shown is fig: 2)

$$\boldsymbol{A_{ñ} = ñp[a + ñp\cot\beta + (ñ - 1)q]} \quad \textbf{……(1)}$$

Detail derivation:

$$b1 = \{a + a + 2p\cot\beta\}\frac{p}{2}$$

$$= \{a + p\cot\beta\}p$$

$$b2 = \{a + 2p\cot\beta + 2q + a + 4p\cot\beta + 2q\}\frac{p}{2}$$

$$= \{a + 3p\cot\beta + 2q\}p$$

$$b3 = \{a + 4p\cot\beta + 4q + a + 6p\cot\beta + 4q\}\frac{p}{2}$$

$$= \{a + 5p\cot\beta + 4q\}p$$

.

.

$$b_{ñ} = \{a + (2ñ - 1)\,p\cot\beta + 2(ñ - 1)q\}p$$

$$A_{ñ} = \sum_{ñ=1}^{ñ}\{a + (2ñ - 1)p\cot\beta + 2(ñ - 1)q\}p$$

$$= [añ + \{2\frac{ñ(ñ+1)}{2} - n\}p\cot\beta + 2\{\frac{ñ(ñ+1)}{2} - ñ\}q]p$$

$$= [añ + \{ñ^2 + ñ - ñ\}p\cot\beta + \{ñ^2 + ñ - 2ñ\}q]p$$

$$A_{ñ} = ñp[a + ñp\cot\beta + (ñ - 1)q] \quad ……(1)$$

Where number of benches $ñ = \frac{h}{p}$

(*Where h is avg. weighted depth of mine*)

Putting value of "ñ" in equation (1)

$$An = \frac{h}{p}p[a + \frac{h}{p}p\cot\beta + (\frac{h}{p} - 1)q]$$

$$An = h[a + h\cot\beta + (\frac{h}{p} - 1)q]$$

Solid Volume to be excavated for accommodation in external Dump=S x $A_{\tilde{n}}$

(Where S is strike length of mine, which will be evaluated at later stage of this model)

$$\mathbf{V = Sh[a + h\cot\beta + (\frac{h}{p} - 1)q]}$$

Although, the volume of external dump may vary depending on method of mining and equipment deployed, the above model is expressive of the approximate volume of solid over burden material that is required to be accommodated in external dump.

2. **Evaluation of Sectional Area of internal OB Dump:** Considering deck height of individual OB dump benches formed by shovel-dumper system is "d" and slope of individual dump benches is "θ". Width of the deck between two benches is "l" and base length of one dump is "A" as shown in fig-3. Considering maximum allowed number of decks is "n".

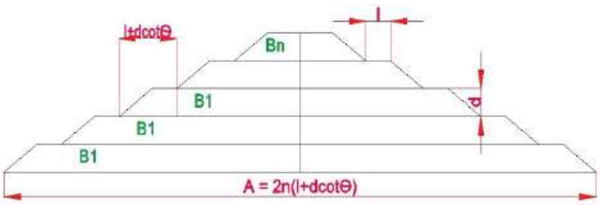

Fig: 3: Sectional View of one Dump

(Along strike)

Required Sectional area of one dump (S_d) for creating "n" decks

$$\mathbf{S_d = nd[A - (n-1)l - nd\cot\theta] \ .... (2)}$$

Detail derivation:

Cross-sectional Area of first deck (B1):

$$B1 = (A + A - 2\,d\cot\theta)\frac{d}{2}$$

$$=(A - d\cot\theta)\,d$$

Cross-sectional Area of second deck (B2):

$$B2 = \{A - 2(l + d\cot\theta) + A - 2(l + d\cot\theta) - 2d\cot\theta\}\frac{d}{2}$$

$$= \{A - 2(l + d\cot\theta) - d\cot\theta\}d$$

Cross-sectional Area of third deck (B3):

$$B3 = (A - 2x2(l + d\cot\theta) + A - 2x2(l + d\cot\theta) - 2x2d\cot\theta\}\frac{d}{2}$$

$$= \{A - 2x2(l + d\cot\theta) - d\cot\theta\}d$$

Cross-sectional Area of Nth deck (Bn):

$$Bn = \{A - 2(n-1)(l + d\cot\theta) - d\cot\theta\}d$$

Total Sectional Area of n decks

$$S_d = \sum_{n=1}^{n} Bn = B1 + B2 + B3 + \ldots\ldots + Bn$$

$$S_d = \sum_{n=1}^{n}\{A - 2(n-1)(l + d\cot\theta) - d\cot\theta\}d$$

$$= [nA - 2\{\frac{n(n+1)}{2} - n\}(l + d\cot\theta) - nd\cot\theta]d$$

$$= [nA - 2\{\frac{n(n-1)}{2}\}(l + d\cot\theta) - nd\cot\theta]d$$

$$= [nA - n\{n-1\}(l + d\cot\theta) - nd\cot\theta]d$$

$$= [nA - \{n^2 - n\}(l + d\cot\theta) - nd\cot\theta]d$$

$$= [nA - n^2 l + nl - n^2 d\cot\theta + nd\cot\theta - nd\cot\theta]d$$

$$= [A - nl + l - nd\cot\theta]dn$$

$$S_d = nd[A - (n-1)l - nd\cot\theta] \ .... (2)$$

The maximum height of the dump for creating "n" numbers of deck, is "nd" and minimum length along the strike length, is "$2n(l + d\cot\theta)$"

Minimum base length of one dump

$$\mathbf{A = 2n(l + d\cot\theta)\ldots\ldots\ldots (3)}$$

Putting the value of A in equation (2)

$$S_d = nd[2n(l + d\cot\theta) - (n-1)l - nd\cot\theta]$$

$= nd[2nl + 2ndcot\theta - nl + l - \quad nd\ cot\theta]$

$$S_d = nd[nl + ndcot\theta + l] \text{.......... (4)}$$

After reaching the maximum height, dump will expand along the strike length. Assuming that dump will expand ΔS after covering 2n(l+dcotθ) length along the strike.

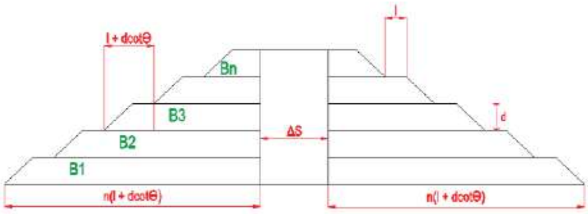

Fig: 4 Section view after ΔS expansion

(Along strike)

Sectional area of dump which is created by expansion (ΔS) of dump

$S_{\Delta S} = nd\Delta S$

Total Sectional Area of one dump

$Sn = S_d + S_{\Delta S}$

$$Sn = nd[nl + ndcot\theta + l] + nd\Delta S \text{... (5)}$$

3. **Evaluation of relation between Strike length and sectional Area of internal OB dump:**

When considered as rectangular mine block area, strike length of the mine will be the sum of base length of two dumps and width (W) of the haul roads.

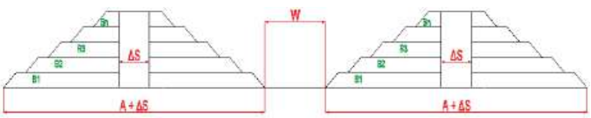

Fig: 5 Showing total strike length (Along the strike)

Strike length, $S = W + 2A + 2\Delta S$ (Where "W" is width of central haul road)

Putting the value of A from equation (3)

$S = W + 2X2n(l + dcot\theta) + 2\Delta S$

$$\Delta S = 1/2\{S - W - 4n(l + dcot\theta)\} \text{...(6)}$$

Putting value of ΔS from equation (6) in equation (5)

$$Sn = nd[nl + ndcot\theta + l] + \frac{nd}{2}\{S - W - 4n(l + dcot\theta)\}$$

$$= \frac{nd}{2}[2nl + 2ndcot\theta + 2l + S - W - 4nl - 4ncot\theta]$$

$$Sn = \frac{nd}{2}[S + 2l - W - 2nl - 2ndcot\theta] \text{..(7)}$$

"Sn" is expressed as total sectional Area of one dump

4. **Relation between Mine movement and Production:**

For smooth functioning of a mine, it is considered necessary that, apart from the OB accommodated in the external dump, whatever overburden removed must be accommodated simultaneously in internal dump.

Assuming that, for producing P tonnes of coal, mine will advance in the dip direction for distance = M mtrs (*refer fig. 6*).

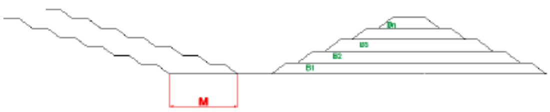

Fig-6 Section showing advancement of mine(Perpendicular to strike)

Total volume to be handled for M movement of mine = MhS ….. (8)

(*Where "h" is av. weighted depth of the mine*)

Total volume handled for movement upto M distance in the mine is same as the sum of volume of coal produced and volume of OB removed for producing P tonnes of coal.

Total volume handled $= \frac{P}{g} + rp$ **........ (9)**

(*Where "g" is specific gravity of coal and r is stripping ratio of mine*)

Hence, from equation (8) & (9)

$MhS = (P/g + rP)$

$$M = \frac{P}{hgS}(1 + gr) \text{................. (10)}$$

5. Volume of Internal Dump :

For producing P tonnes of coal, total OB required to be removed = rP cum

Swell volume of OB = μrP cum
(*Where μ is swelling factor of OB*)

It is considered that OB dump will advance at the same pace as the advancement of mine benches. Hence the maximum volume which can be accommodated in two internal OB dumps will be equal to:**Mx2Sn**

Since the OB removed for producing P Tonnes of coal, must be accommodated within the two nos. internal OB dumps, with due consideration to its swell volume and the extant statutory provisions of dump profile :

Swell volume of OB removed = available space in two dumps

$\mu rP = Mx2\ x(sectional\ area\ of\ one\ dump)$

i.e. $\mu rP = Mx2xSn$ ……… **(11)**

6. Evaluation of relation between Strike length and Stripping ratio:

A) MODEL-1: *One Central entry and two peripheral entry to the bottommost seam floor* :
Putting the value of Sn and M from equation (7) & (10) in equation (11), optimum strike length, S_{ma} considering one central entry and two peripheral entry to the bottom most seam floor is determined as:

$$S_{ma} = \frac{nd(1+gr)(W+2nl+2ndcot\theta-2l)}{nd(1+gr)-\mu rhg}$$

…… **(12)**

Detail derivation:

- $\mu rP = \frac{P}{hgS}(1+gr)2\frac{nd}{2}[S+2l-W-2nl-2ndcot\theta]$
- $\mu rhgS = nd(1+gr)[S+2l-W-2nl-2ndcot\theta]$
- $\mu rhgS = nd(1+gr)S + nd(1+gr)(2l-W-2nl-2ndcot\theta)]$
- $nd(1+gr)S - \mu rhgS = nd(1+gr)(W+2nl+2ndcot\theta-2l)$
- $\{nd(1+gr) - \mu rhg\}S = nd(1+gr)(W+2nl+2ndcot\theta-2l)$

$$S = \frac{nd(1+gr)(W+2nl+2ndcot\theta-2l)}{nd(1+gr)-\mu rhg}$$

…… (12)

B) MODEL-2: *One Central entry to the bottommost seam floor and two peripheral entry to the middle seam floor or OB benches* :

Assuming that two flank roads of width W/2 is developed on outer side of both the internal dumps at the height of two decks (2d).

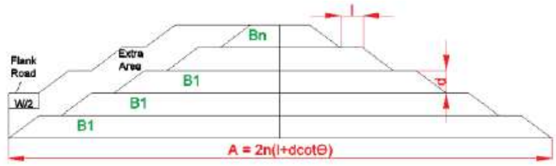

Fig: 7 Showing sectional area of one dump including flank road

Total cross-sectional area of the internal dumps including extra area developed by creation of flank road

$$\hat{S}n = \frac{d}{2}[nS + 6nl - 2nW - 2n^2l - 2n^2dcot\theta + 4ndcot\theta - 6l - 4dcot\theta + 2W]$$

……….**13**

Detail Calculation:

Extra cross-sectional area created due to development of flank roads.

$$S_f = \left\{2(l+dcot\theta) - \frac{W}{2}\right\}(n-2)d + \frac{1}{2}d^2cot\theta + (l + d\,cot\theta + l + d\,cot\theta + d\,cot\theta)\frac{d}{2}$$

$$S_f = \left\{2l + 2dcot\theta - \frac{W}{2}\right\}(n-2)d + \frac{1}{2}d^2cot\theta + \frac{d}{2}(2l + 3d\,cot\theta)$$

$S_f = \frac{d}{2}\{(4l + 4dcot\theta - W)(n-2) + dcot\theta + 2l + 3d\, cot\theta\}$

$S_f = \frac{d}{2}\{4nl + 4ndcot\theta - nW - 8l - 8dcot\theta + 2W + 4dcot\theta + 2l\}$

$S_f = \frac{d}{2}\{4nl + 4ndcot\theta - nW - 6l - 4dcot\theta + 2W\}$……… *(i)*

Now the total cross-sectional area will increase by Sf

New sectional area of one dump

$\hat{S}n = Sn + S_f$

Putting value of S_n & Sf from eq(7) &eq(i)

$\hat{S}n = \frac{nd}{2}[S + 2l - W - 2nl - 2ndcot\theta\,] + \frac{d}{2}\{4nl + 4ndcot\theta - nW - 6l - 4dcot\theta + 2W\}$

$\hat{S}n = \frac{d}{2}[nS + 2nl - nW - 2n^2l - 2n^2dcot\theta + 4nl + 4ndcot\theta - nW - 6l - 4dcot\theta + 2W\,]$

$\hat{S}n = \frac{d}{2}[nS + 6nl - 2nW - 2n^2l - 2n^2dcot\theta + 4ndcot\theta - 6l - 4dcot\theta + 2W\,]$ ………13

Putting the value of area (Ŝn) (derived above) from equation (13) in equation (11), Strike length "S_{mb}" in case of model 2 is determined as follows:

$$S_{mb} = \frac{d(1+gr)2nW - 6nl + 2n^2l + 2n^2dcot\theta - 4ndcot\theta + 6l + 4dcot\theta - 2W}{nd(1+gr) - \mu rhg}$$

…….. (14)

Detail derivation:

Putting the value of cross section area in equation (11)

$\mu rP = \frac{P}{hgS}(1 + gr)2\frac{d}{2}[nS + 6nl - 2nW - 2n^2l - 2n^2dcot\theta + 4ndcot\theta - 6l - 4dcot\theta + 2W\,]$

$$S = \frac{d(1+gr)\{2nW - 6nl + 2n^2l + 2n^2dcot\theta - 4ndcot\theta + 6l + 4dcot\theta - 2W\}}{nd(1+gr) - \mu rhg}$$

…….. (14)

RESULTS : Analysis of the calculation table, with varying parameters is expressed in the graphs as below:

Chart Title : Variation of Strike length of the mining block w.r.t varied depth for a given stripping ratio of 2.99

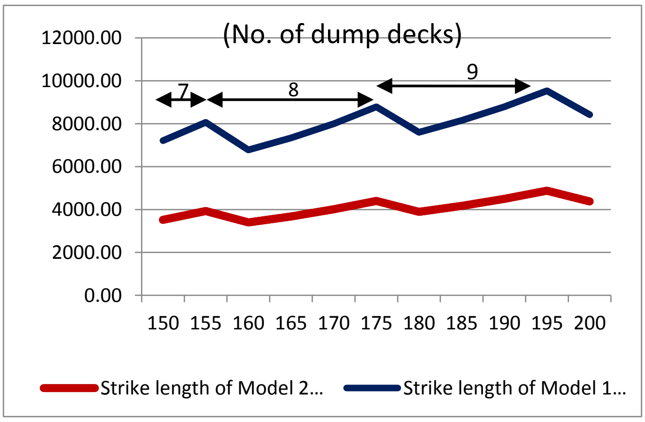

Chart Title : Variation of Strike length of the mining block w.r.t varied Stripping ratio for a given av. mine depth of 150m

Evaluation of model for existing OCP of Coal Idia Ltd.:

Actual parameters of Jayant OCP of NCL, was put up in the model derived above, to evaluate and verify the strike length of the mining block as below:

Parameters	**Symbols**	**Value**
No of decks	n	7
Deck height (m)	d	30
Deck width (m)	l	30
Avg. Weighted depth of mine (m)	h	150
Specific gravity of Coal (te/Cum)	g	1.5
Swelling factor	μ	1.3
Central haul road width (m)	W	120
Angle of repose θ=37 deg	$cot\theta$	1.327
Current Stripping Ratio	r	2.99
Strike length evaluated from the derived model (mtrs)	**S**	**3518**

Actual strike length of the mine is 3.5 km.

Conclusion:

1. Average weighted depth of the mine, for a given stripping ratio, is an important parameter for determining the optimum strike length of a mining block, in the light of overburden dump accommodation.
2. For a given depth of mine, strike length of the mining block area is proportional to the stripping ratio of the mine block, in the light of overburden dump accommodation.
3. Increasing the no. of mine entries at the floor of bottom most seam restricts the overburden dump accommodation, which consequently, requires higher strike length, for a given stripping ratio of the mining block
4. Strike length of the mining block area can also be optimized by regulating the no. of deck or the deck height in the overburden dumps.
5. The model derived for determination of strike length for a given stripping ratio appears to be conformity with the actual scenario of the existing OCPs lf CIL.

Hence it can be concluded that the above model can be used as an effective tool to find a solution for determining the optimum strike length of a mine block, for a given stripping ratio and average weighted depth of the mine. The model can successfully address the burning issue of overburden dump accommodation, within the provisions of extant stipulations regarding safety and environment.

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GREEN MINE CLOSURE PLANNING INTEGRATED WITH FLOATING SOLAR PROJECT AT FINAL MINE VOID WATER BODY

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ABSTRACT

Floating solar *is solar panels mounted on a structure that floats on water body like water reservoir or a lake. The mine void left at the end of mine life is filled with water and act as water body. This water body may be utilized for installation of floating solar power project. The floating solar power project can be integrated with green mine closure planning to maximise the capacity of floating solar plant and to implement it with minimum time. After the closure of mine, Floating solar PV project at mine void water body would produce renewable energy without using land resources and also provide source of alternate employment generation for local people that will serve livelihood for surrounding people.*

1.0 INTRODUCTION

In 2020-21 Coal India produced 596.22 Mt of coal and major coal produced from opencast mining about 569.77 Mt. Coal India produces about 94 to 95% of its production from opencast mining. During the working in opencast mine, the mine void is created to keep safety distances between working face to the toe of internal OB dumping benches. As the mine advances towards dip side this mine void is also moves towards dip side. Finally, the mine void left at the end of mine life is filled with water and act as water body. The creation of mine void is inevitable at the end of

Figure 1- Showing Laying of floating Solar panels

mine life. Generally the area of mine void is 20% to 30% of total quarry area, or even more for steep seam working. This mine void water body act as water reservoir to recharge ground water table. The surface of this water body may be utilized for installation of floating solar plant to create more value addition for society.

Floating solar has ability to capitalize the unused water surfaces to produce renewable energy without sterilizing country's land resources. Floating solar is solar panels mounted on a structure that floats on water body like water reservoir etc. Floating solar PV has gained its popularity due to its huge potentiality of energy generation with minimum use of land resources.

The floating solar PV also has some other benefits for water reservoirs. The placement of floating solar panels over water surface reduces the amount of water evaporation. In some cases floating solar PV coverage reduces the growth of algae also. Besides that floating solar PV has some more benefits than ground mounted solar PV.

2.0 ADVANTAGES OF FLOATING SOLAR

The main benefit of solar PV is that it does not produce any pollution. It is one of the cleanest source of energy. All these benefits of solar PV are applicable for floating solar PV plants also. In addition to that floating solar PV plants has some additional benefits which is making floating solar PV plants more popular. The additional benefits are as given below.

1. ***No land Requirement*:** the main advantage of floating solar PV plants is that they do not take up any land, except the limited land required for electrical infrastructure for grid connections.
2. **Less cleaning required due to less dust**: The dust generation over floating solar PV is less due to water surface surrounding the panel area. So less cleaning is required and solar panel energy generation is increased.
3. **Easier Cleaning** : The floating solar PV is placed over water surface, so water is easily available surrounding the panel area. So cleaning of floating solar PV is easier.

4. ***Easier Installation and decommissioning***: The floating solar PV plants are more compact than land-based solar plants. The management is simpler and their construction and decommissioning straightforward. The main advantages during installations is that no fixed structures exist like the foundations used for a land-based solar plant.
5. ***Conservation of Water and water quality**:* The partial coverage of water surface can reduce the water evaporation. This result depends on climate conditions and on the percentage of the covered surface. In arid climates this is an important advantage because about 25 to 30% of the evaporation of the covered surface is saved. This is very useful feature if the water reservoir is used for irrigation purposes.
6. ***Solar PV Naturally Cooled :*** The floating structure is naturally cooled as part of the structure is submerged under water surface. Due to this cooling effect solar PV modules efficiency rises with a gain in energy harvesting.
7. ***Easier for Tracking of solar Panel:*** Large floating platform can be easily turned and can perform a vertical tracking. It can be done without wasting energy and without the need for a complex mechanical apparatus as it is required for land-based solar PV plants. Equipping a floating PV plant with a tracking system costs little extra while the energy gain is much more.
8. ***Gravity Energy Storage opportunity**:* The presence of water may have additional advantages to store energy using gravity energy storage by pumping water to a height during day hours. During night hours electricity may be generated again with hydroelectric system.
9. ***Support Environmental control:*** *The algal blooms is* a serious problem for water in industrialized area and it may be reduced. The partial coverage of the water surface and the reduction of light on biological fouling just below the surface, together with active systems can solve this problem.
10. **Solar Panel Efficiency improvement**: Many studies claim that solar panels over water are more efficient. The energy gain reported range from 5 to 15%.

3.0 TYPES OF FLOATING SOLAR INSTALLATION

The floating solar panels are little bit costly as system needs to have a high corrosion resistance, good load capacity and a long life span for holding the panels in water for more than 25 years. The floating solar modules should have ability to handle water and wind corrosion as well as operational maintenance like anchoring etc.

Most of the installations can be classified into three categories:

1. PV plants designed by modules which is mounted on pontoons to float the structure over water surface.

Figure 2- Showing floating Solar panels mounted on galvanized steel

2. PV modules mounted on rafts built in plastic and galvanized steel and it is floated over water surface

3.PV modules mounted on rafts, fully in plastic to float the structure over water surface.

Figure 3- Showing floating Solar panels mounted fully in plastic

4.0 FLOATING SOLAR PROJECTS IN INDIA

India's largest Floating Solar PV plant has successfully commissioned at NTPC Simhadri in Andhra Pradesh. The capacity of project is 25 MW and it covers an area of 100 acres. The project has been designed with an innovative floating array to meet the unique requirement of anchoring the support structures without touching the reservoir floor. The module array has been designed to withstand gusts of wind up to 180 km/hr. In view of the coastal location of the project site that leads to severe corrosion, all the platform structures and other equipment have been made corrosion resistant.

Figure 4- Showing Laying of floating Solar panels at NTPC Simhadri

The Jharkhand government has approved a 100 MW floating solar plant in Getalsud dam near Ranchi. Another plant of 100 MW capacity is expected to become operational in the reservoir of Ramagundam thermal power plant in Telangana's Peddapalli district. It is being developed by the NTPC.

5.0 SOLAR RESOURCES IN COALFIELD AREA

The generation of solar energy depends on solar irradiation of that area. Direct Normal Irradiation (DNI) is beam radiation measured on the earth surface directly from sun excluding diffuse solar radiation. DNI depends on solar elevation angle, cloud cover, moistures etc. Diffuse Horizontal Irradiation (DHI) is the radiation at surface of Earth from light scattered

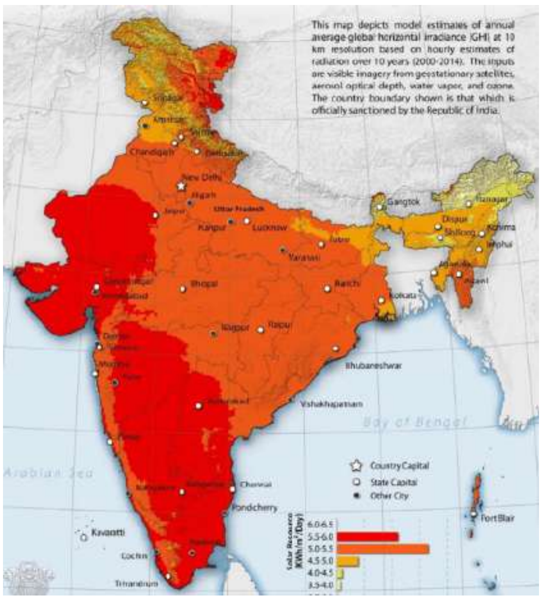

Figure5- Estimate of Annual average global horizontal irradiance

by atmosphere excluding radiation coming directly from sun. Global Horizontal Irradiation (GHI) is the total irradiation received on horizontal surface of Earth considering both Direct Normal Irradiation (after accounting solar zenith angle) and Diffuse Horizontal Irradiation. Solar Resource assessment is carried out using Global Horizontal Irradiation (GHI) receiving at the proposed sites.

GHI = DHI + DNI Cos(Z),   Z= solar zenith angle of the sun

NASA's Solar resource dataset is a monthly averaged values generated globally through satellite over the time span from July 1983 to Dec 2018 and contains monthly averaged values for each month in kWh/m2. It holds satellite derived monthly data for a global coverage on a 0.5° latitude by 0.5° longitude grid. The data set is freely available on the website.

Indian solar resource map created using Global Horizontal Irradiation (GHI) and it is helpful to assess the approximate potentiality of solar power generation in any location in India. For commercial use, site specific more detailed day wise, month wise solar irradiation data, sun path diagram, climatic parameters including temperature, wind and precipitation etc are analysed through computer software with different tilted angle of solar panel to assess generation of solar electricity.

The solar resources are different in different parts of India as shown in the Indian solar resource map. From the map it may be noted that Western, Southern and Central part of India is receiving higher solar irradiation in comparison to Northern and North Eastern part. The area which are receiving higher solar irradiation, it will generate more solar electricity with same number of solar panel.

Most of the coalfields are located in the eastern central part of our country. From solar resource map, it may be noticed that most of the coalfields are receiving comparatively higher solar irradiation (Average about 5.0 to 5.5kwh/m2/day). So, our coalfields areas are quite potential for installation of solar power projects.

6.0 POTENTIAL SITE OF FLOATING SOLAR PROJECT IN MINE AREA

During the working in opencast mine, the mine void is created to keep safety distances between working face benches to the toe of internal OB dumping benches. As the mine advances towards dip side this mine void is also moves towards dip side. Finally, the mine void left at the end of mine life is filled with water and act as water body. The haul road utilized during working of the mine, finally left as mine void also filled with water and act as water body. Thus large mine void water bodies are created at the end of mine life. These water bodies may be utilized for installation of floating solar power project.

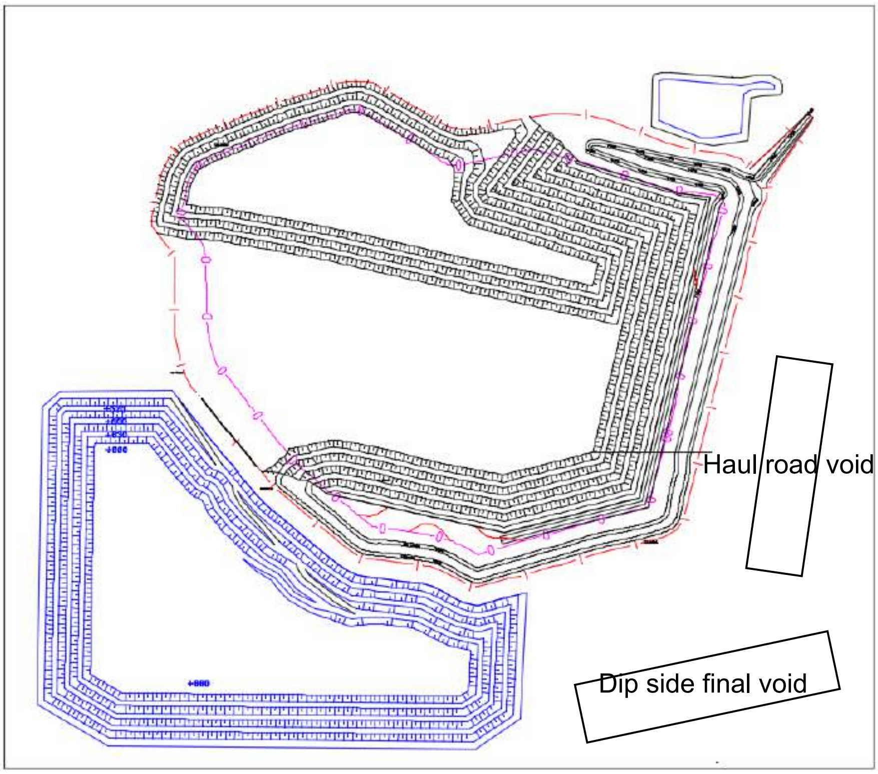

Figure 6- showing proposed site in opencast mine for floating solar panels

The large area mine void water bodies can be converted to potential site for floating solar project in following locations.

1. **Dip side final void** water body after closure of mine activities.
2. **Haul road final void** water body after closure of mine activities

Around 1.6 to 1.8 Ha of water surface is required for setting up of 1 MW floating solar plant with crystalline Silicon technology. The generation of solar energy may vary from location to location depending on solar irradiation.

7.0 POTENTIAL CAPACITY OF FLOATING SOLAR

The mine plan shows area of dip side final void is about 124 Ha.and area of Haul road final void is about 146 Ha. Total surface area of mine void is 260Ha.

Considering 50% of mine void area as surface area of water body. Surface area of water body is about 130 Ha. Considering 50% of water surface area for installation of floating solar PV, Surface area of floating solar PV is about 65 Ha.

Considering 1.70 Ha water surface area required for installation of 1MW floating solar PV. Capacity of floating solar PV is 38MW.

8.0 FINANCIAL STUDY OF FLOATING SOLAR

The cost of installation of 38 MW floating solar power plant is 171.00 Crores (Considering cost Rs 4.50 Crore/MW). The average operation and maintenance (O&M) expenses of the project are about ₹ 5.5 lakhs/MW/annum. As per the experience and warranty commitments of manufacturers, crystalline silicon modules degrades annually at 0.7% p.a. to 0.8% p.a. i.e., an average degradation of 0.75% p.a.

Considering Industrial Energy charge for mining is Rs 6.40/Kwh, 60% generation in first year and escalation of O&M cost 5.5%, tentative average annual cost saving from solar power generation and tentative annual cash flows are given in table and shown in figure.

YEAR	INITIAL CAPITAL (In Crores)	ANNUAL O&M COST (Crores)	TOTAL OUT FLOW (Crores)	POWER GENERATION (Kwh)	ENERGY COST SAVING (Crores)	ESTIMATED CASH IN FLOW (Crores)	NET CASH FLOW (Crores)	NET CASH FLOW(CUM) (Crores)
1	171.00		171.00	35951040	23.01	23.01	-147.99	-147.99
2		2.09	2.09	59918400	38.35	38.35	36.26	-111.73
3		2.19	2.19	59469012	38.06	38.06	35.87	-75.87
4		2.30	2.30	59022994	37.77	37.77	35.47	-40.40
5		2.42	2.42	58580322	37.49	37.49	35.07	-5.33
6		2.54	2.54	58140970	37.21	37.21	34.67	29.34
7		2.67	2.67	57704912	36.93	36.93	34.26	63.61
8		2.80	2.80	57272125	36.65	36.65	33.85	97.46
9		2.94	2.94	56842584	36.38	36.38	33.44	130.90
10		3.09	3.09	56416265	36.11	36.11	33.02	163.92
11		3.24	3.24	55993143	35.84	35.84	32.59	196.51
12		3.40	3.40	55573195	35.57	35.57	32.16	228.67
13		3.57	3.57	55156396	35.30	35.30	31.73	260.40
14		3.75	3.75	54742723	35.04	35.04	31.28	291.68
15		3.94	3.94	54332152	34.77	34.77	30.83	322.51
16		4.14	4.14	53924661	34.51	34.51	30.37	352.89
17		4.34	4.34	53520226	34.25	34.25	29.91	382.79
18		4.56	4.56	53118824	34.00	34.00	29.43	412.23

YEAR	INITIAL CAPITAL (In Crores)	ANNUAL O&M COST (Crores)	TOTAL OUT FLOW (Crores)	POWER GENERATION (Kwh)	ENERGY COST SAVING (Crores)	ESTIMATED CASH IN FLOW (Crores)	NET CASH FLOW (Crores)	NET CASH FLOW(CUM) (Crores)
19		4.79	4.79	52720433	33.74	33.74	28.95	441.18
20		5.03	5.03	52325030	33.49	33.49	28.46	469.64
21		5.28	5.28	51932592	33.24	33.24	27.96	497.59
22		5.55	5.55	51543098	32.99	32.99	27.44	525.04
23		5.82	5.82	51156525	32.74	32.74	26.92	551.95
24		6.11	6.11	50772851	32.49	32.49	26.38	578.33
25		6.42	6.42	50392054	32.25	32.25	25.83	604.17
TOTAL	**171.00**	**93.01**	**264.01**	**1356522527**	**868.17**	**868.17**	**604.17**	

The life of floating solar PV project is 25 years. So cash flow analysis has been done for 25 years. The total capital for installation is invested in the first year itself. After that only annual operation and maintenance cost is required for smooth generation of solar electricity. The financial data analysis shows that payback period is about 5 to 6 years.

The graphical cash flow for 25 years are as follows.

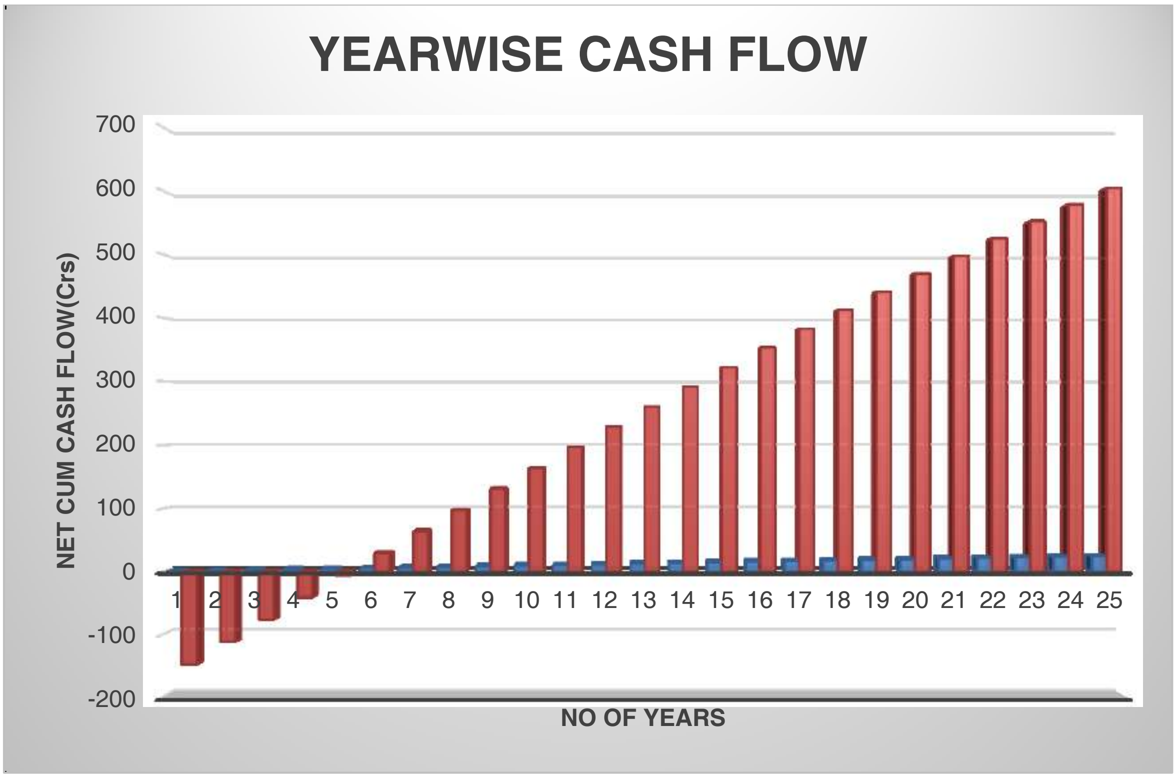

Figure 7- Showing Graphical Cashflow of floating Solar panels

8.0 CONCLUSION

The mine void left at the end of mine life may take 2/3 years or more to be filled with water depending on annual rain fall. Once the mine void is filled with water, it will act as water body. After creation of water body in mine void, the process for installation of floating solar PV may be undertaken. The floating solar PV project may integrated in the mine closure report during the planning stage, it can be implemented with minimum time and minimum effort during closure of mine. After the closure of mine, it would provide source of alternate employment generation for local people that will serve livelihood for surrounding people. It will also provide financial gain to mine authority after the closure of mine. The floating solar PV plant will generate pollution free energy for the country. It will also help in conservation of water resource by reducing water evaporation. Thus, floating solar PV will create a win-win situation for mine authority, local people, and environmental protection.

9.0 ACKNOWLEDGEMENTS:

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Quality is What We Pursue
WE KNOW WHAT WE DO

Hydrocarbon Economy: Practical & sustainable future of India

Dr. Shambhu Jha* & A.K. Mishra **

Hydrogen Vs Hydrocarbon:

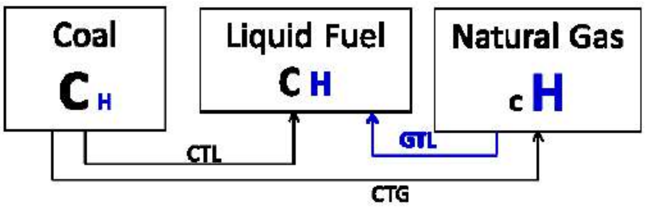
There is a hype for the hydrogen fuel however due to it's very less density hydrogen economy may not be feasible. Hydrogen is an excellent gas but its molecules are so sparsely packed that it's density is very less. At room temperature it is not feasible to pack it in a bottle. It will require cryogenic temperature i.e. (-) 256^0 Celsius or very high pressure of 700 psi to pack it in a bottle. Even then, 1 liter of kerosene bottle, which can be easily packed in a bottle at room temperature, is 11 times more powerful than 1 liter of hydrogen.

Thus hydrocarbon is much better source of energy for all practical purposes than hydrogen. In addition hydrocarbon can be a source of not only energy but many more excellent products can be prepared by the use of hydrocarbon.

Hydrocarbon Economy:

Hydrocarbon is an excellent source of energy. Carbon & hydrogen are packed in molecular arrangement to give gaseous hydrocarbon, liquid hydrocarbon and solid hydrocarbon i.e. Coal.

Basically hydrogen is the main source of energy but density is balanced by the carbon. The simplest hydrocarbon is methane gas (CH_4), where 4 hydrogen atoms are attached with 1 carbon atom. Here, ratio of hydrogen w.r.t. carbon is maximum. Then if we increase the ratio of carbon atoms and decrease the hydrogen atoms we get Butane, Propene, etc., which are gases used in LPG, CNG, etc. Then further if we increase the ratio of carbon atoms it will come in liquid form and we will get liquid fuel like **methanol, diesel, petrol, kerosene, jet fuel,** etc. If we further increase the number of carbon atoms we will get solid fuel i.e. **Coal**.



CTL : Add Hydrogen or Reject Carbon

GTL : Reject Hydrogen or Add Carbon

CTG : Add more Hydrogen or Reject more Carbon

*** Dr. Shambhu Jha, TS to CMD, MCL***
***** A.K. Mishra, Manager (Mining), TS to CMD Secretariat, MCL.***

There are established chemical processes through which we can convert the form of hydrocarbon i.e. from **Coal to diesel, petrol, etc.**, **coal to methanol, coal to different gases**

like methane, LPG, CNG, etc. It may be noted that 1.4 kg of coal can give 1 m^3 of gas. Also, using coal we can prepare many excellent and useable materials like **polythene, plastic** and **high end plastics**, which are used in **Car, Airplane, Thermos flask, Refrigerator** and what not.

Plastic is a wonder material. It has changed our life. Average life without plastic was around 30 years, which is now increased to about 70 years. This is because of the use of plastic in delivering medicines, drinking water, and other essential material in a clean and hygienic manner. Plastic has increased the mileage of our Cars, which was nearly 5 km/liter and now it has increased to 20 km/liter. Polythene bag has much less carbon footprint than paper or jute / cloth bag. Life & usability of paper / jute / cloth bags is very less compared to the polythene bag. Thus, without plastic we cannot think of surviving and **plastic is nothing but hydrocarbon**. It can be used as a fuel; it can be used for preparation of methanol, diesel, petrol, jet fuel, etc. Once the reserves of coal available diminishes or there is a restriction on the use of coal, this plastic will play a major role in providing source of energy and source of other hydrocarbon materials. The entire economy can be sustained for next 500 to 1000 years by the use of present volume of plastic available with us and in future plastic can also be prepared through biomass, algae, etc. and then it will be cyclic and those plastic will be **green plastic**.

Hydrocarbon fuel cell will be the most practical energy conversion system, which can give up to **80% efficiency**, which is far more compared to the present diesel engine which has efficiency of 12 to 20%, thermal power plants with an efficiency of maximum 40%.

Moreover, this can be used with the present system & infrastructure available with us.

In view of the above scientific considerations it can be easily understood that hydrocarbon economy can prove to be a much more practicable and sustainable rather than creating hydrogen economy.

Coal: The king of all hydrocarbon.

Contrary to the present bad image of coal created by the media and the unfounded thoughts and myths, coal is the king of all hydrocarbons. It has maximum carbon atom ratio and hydrogen can be added because it is abundant in the nature and almost free and just by adding hydrogen and another atoms innumerable materials used in present day to day life can be prepared from coal. There are simple chemical processes involved for converting coal in to different materials. However, clean coal technology has not gained any importance in the Indian scenario and **coal is only and only used for thermal power plants** for generating electricity. However, this is the **wastage of such a huge potential material**.

There are mainly two uses of coal, first for generating electricity/energy, second for gasifying it and then converting it to different gases like methane, ethane, propane, butane, LPG, CNG, etc. or converting it to liquid fuel like petrol, diesel, jet fuel, etc. or converting it to polythene, plastic, high end plastic, etc. or converting it to ammonia, ammonium nitrate, fertilizer, explosive, di-methyl ether (DME) and so many products.

There can be alternative source for generating electricity like solar, wind, nuclear, hydro, biomass, etc. but jumbo jet/boing engines can only depend on diesel/liquid (hydrocarbon) fuel.

Presently, **6 to 8 lakh crores** foreign exchange is wasted in importing diesel, petrol, methanol, natural gas, etc., which can be easily produced through coal. This is a fallacy that we are purchasing petrol @ 110 rupees/litre, wherein we have world's third largest coal reserve in our country, world's largest source of biomass, world's largest source of solid waste, etc. and by properly creating hydrocarbon economy we can not only completely stop importing liquid and gaseous fuel but we can provide it at much cheaper rate (Rs.20 to Rs.30/litre). Further, we can also give great relief to our environment by utilizing the polythene / plastic waste. Micro plastic is a much bigger issue and it is available in the salt, in the drinking water, in the fish, etc. and it is cancerous and it can create many medical issues and there is only one solution i.e. use / management of plastic.

Coal in India is of drift origin, wherein ash material is from **35% to 45%**. With such huge ash content reject generation is much more and also GCV is very less compared to the coal of US, Australia, Indonesia, etc. By use of washery the ash content can be reduced by only 7-8% and still there will be 34% ash in the washed coal. This is because of presence of near gravity material because of inherent composition and origin of coal. Oil agglomeration can reduce the ash up to 20% and GCV can also be increased up to 6,000 K.Cal/kg but the process requires use of oil and considering cost of oil @ Rs.90/liter, presently this method is not viable, although proven. If the cost of the oil can be reduced to Rs.30-Rs.40/liter then this method can become viable.

Process of conversion of Coal to Gas/Chemical:

There are three basic proven processes for conversion of Coal into Gas/Chemicals

- **Indirect Coal Liquefaction**
  1. **Gasification**

     Coal + O_2 + $H_2O \longrightarrow$ **SynGas** (H_2 + CO)
  2. **SynGas to Chemicals (Fischer-Tropsch process)**

     SynGas (H_2 + CO) $\xrightarrow{\text{Catalyst}}$ Hydrocarbons (C_xH_y)

- **Direct Coal Liquefaction**

  Coal + $H_2 \xrightarrow{\text{Catalyst}}$ Hydrocarbons (C_xH_y)

- **Solvent Extraction Process**

  Coal $\xrightarrow[\text{Heat, Pressure}]{\text{Catalyst}}$ Graphite, Carbon Fibers etc.

Gasification is a technological process that can convert any carbonaceous raw material such as coal into fuel gas, also known as **synthesis gas** (syngas for short).

Gasification occurs in a **gasifier**, generally a high temperature/pressure (700^0 C) vessel where **oxygen and steam** are directly contacted with the coal causing a series of chemical reactions to occur that convert the coal to syngas and ash/slag (mineral residues). Chemical reaction involved is given below:

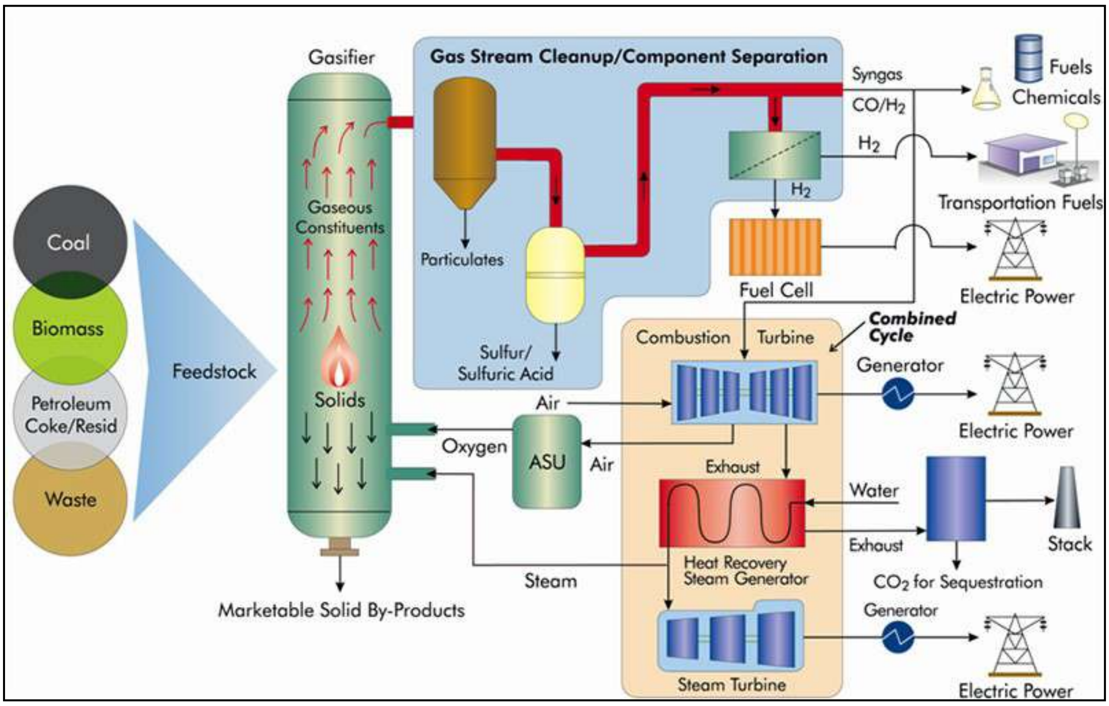
3C (i.e., coal) + O_2 + H_2O → H_2 + 3CO {Synthesis gas}

Syngas is so called because of its history as an intermediate in the production of synthetic natural gas.

Composed primarily of the colorless, odorless, highly flammable gases carbon monoxide (CO) and hydrogen (H_2), **syngas has a variety of uses**. The syngas can be further converted (or shifted) to nothing but hydrogen (H_2) and carbon dioxide (CO_2) by adding steam and reacting over a catalyst in a water-gas-shift reactor. When hydrogen is burned, it creates nothing but heat and water, resulting in the ability to create electricity with no carbon dioxide in the exhaust gases.

Furthermore, hydrogen made from coal or other solid fuels can be used to refine oil, or to make products such as ammonia and fertilizer. More importantly, hydrogen enriched syngas can be used to make gasoline and diesel fuel. Polygeneration plants that produce multiple products are uniquely possible with gasification technologies.

Carbon dioxide can be efficiently captured from syngas, preventing its greenhouse gas emission to the atmosphere and enabling its utilization (such as for Enhanced Oil Recovery) or safe storage.



The graphic representation of a gasification process

During burning or combustion organic matter (consisting of C, H & O_2) is converted into CO_2 & H_2O and heat is generated. Because plenty of O_2 is available for reaction, **two** oxygen molecules are combined with carbon with double bond to form CO_2 and **two** oxygen molecules are combined with hydrogen to form H_2O.

On the other hand during **Gassification**, because of less air or oxygen in the gassifier, only **one** oxygen molecule is combined with carbon with triple bond to form CO and no oxygen molecule is available for hydrogen hence H_2 is formed and oxygen molecule in the steam (H_2**O**) combines with Carbon to form CO and thus another H_2 is released, thus finally we get **more volume of H_2 and CO** instead of CO_2 and H_2O as in case of Combustion process.

Concept of creating hydrocarbon economy in India:

- **Use of coal for power generation only to support the base load requirement** i.e. primary source of energy will be solar, wind, hydro, biomass, nuclear, etc. and only for ensuring 24 x 7 power supply thermal coal to be used. Clean coal technology like gas based power plant should be used so that **requirement of coal will reduce to half**.

- There should be maximum number of coal based gasification plant, which should be designed in such a way that very high ash content coal can be used directly and in addition the same plant can use biomass, algae, organic solid waste, etc. to produce syngas (CO&H_2) and from this syngas many different products can be prepared as explained above.

- This will result in proper use of plastic and other domestic solid/liquid waste. With raw material free i.e. plastic waste, cow dung, human latrine, biomass, etc. and only transportation cost involves, and with systematic collection and transportation arrangement (like sewerage pipeline, etc.) the cost of liquid fuels like petrol, diesel, jet fuel can be drastically reduced. Cost of domestic fuels like LPG, CNG, etc. can be drastically reduced and cost of other useful materials like methanol, polythene, plastic, high quality plastic, etc. can be drastically reduced. **This will create a revolution** in all sector economy like transportation, food industry, medicine, tourism, etc.

- Even very poor quality coal can generate very high volume of syngas (1.4 kg = 1 m^3 of syngas). There is limited reserve of petroleum and natural gas in our country but the reserve of coal is very high, **346 billion tonne**.

- In addition we can **get rid of the micro plastic**, which is a very sensitive and critical environmental issue of present times.

- **Plastic exchange** formula in the community: Collection/segregation/transportation/ storage – huge potential of employment.

- Existing thermal power plants can be converted to use biomass / plastic, etc. – 50% should be converted. Balance 50% as gasification plant for energy.

- EV – Electric vehicle – huge requirement of electricity – solar can recharge these EV batteries during day time.

- Petrol / diesel consumption will reduce by 50% or more after use of EV and this will be produced by coal – no import.

- EV / Consumer articles / Aeroplanes, etc. will use high end plastic material – very less weight & very strong – air traffic is going to increase tremendously in India – all these material to be prepared by coal and not by natural gas as per present practice.

Why Coal Companies should diversify in creating hydrocarbon economy?

Big coal companies should come forward because of the following:

- Hydrocarbon economy is the future, it is sustainable, it is profitable, it can generate huge employment opportunities, it is environment friendly and so on as explained above.
- It has money
- It has manpower of different disciplines like Mining, Electrical, Mechanical, Chemical, MBAs, Human Resource Professionals, Environmental Engineers, Security, System, Materials Management, etc.
- It has to be generated employment/skill so as to be socially acceptable.
- As a responsible corporate it will have to think for the future of 22,000 direct manpower, 22,000 contractual manpower and other indirect businesses, which are earning livelihood from coal business.
- It is necessary for overall development of the region of the State.
- It has to sustain the business.
- It has to think that after replacement of coal for energy generation, what will be the future of coal industry?

Tentative economics of pilot scale Syngas production:

Syngas production	2,25,000 Nm^3/hr
Syngas production/yr @ 8000 hr	1.8 billion Cum
GCV of seam-II of Bhubaneswari (G11)	4200 Kcal/Kg
Cost of Coal/Te (G-11-Power)	Rs.1713/Te
Cost excluding the GST compensation	Rs.1313/Te
Specific consumption of Coal/Nm^3	1.4 kg
Input to Gasification Plant of MCL (Rs./Nm^3)	1.84

Cost of Raw Material/Nm^3	Unit	Rate	Specific Consumption	Cost/Nm^3
Coal	Rs./Te	1313	1.4	1.84
Power	Unit/hr	3.181	0.147	0.47
HP Steam 40 Kg/Cm^2	Rs./Te	786.115	1.25	0.98
MP Steam 12 Kg/Cm^2	Rs./Te	786.115	0.156	0.12
Oxygen	Rs./Nm^3	1.189	0.25	0.30
Nitrogen	Rs./Nm^3	1.189	0.138	0.16
DM Water	Rs./m^3	40	0.001	0.04
Total	**Rs./Nm^3**			**3.91**

Byproduct credit/Nm^3	Unit	Rate	Specific Generation	Credit/Nm^3
Clear Tar	Rs./Te	15000	-0.032	-0.48
Gasification Oil	Rs./Te	20000	-0.022	-0.44
Benzol	Rs./Te	14500	-0.008	-0.12
Ammonia	Rs./Te	32800	-0.01	-0.33
Crude Phenol	Rs./Te	24000	-0.005	-0.12
Phenolic pltch	Rs./Te	8000	-0.001	-0.01
Sulphur	Rs./Te	8000	-0.004	-0.03
LP Steam	Rs./Te	786	-0.169	-0.13
Total credit	Rs./Nm^3			**-1.66**
Net cost of Syngas Generation (3.91-1.66)	Rs./Nm^3			**2.26**
Stores & spares	Rs./Nm^3			0.30
Out sourcing	Rs./Nm^3			0.08
Salary, admn & other fixed cost	Rs./Nm^3			0.24
Total variable cost (2.26+0.3+0.08+0.24)	Rs./Nm^3			**2.88**
Interest	Rs./Nm^3			0.78
Depreciation	Rs./Nm^3			0.63
Total Cost (2.88+0.78+0.63)	Rs./Nm^3			**4.29**

GCV in 1 Cum of Syngas	Kcal			3600
1 Kcal	BTU			3.96
BTU in 1 Cum of Syngas	BTU			**14256**
Syngas required for 1 million BTU (10,00,000/14256)	Nm^3			**70.15**
Cost of Syngas having 1 MMBTU (70.15 x 4.29)	Rs.			**300.62**
Conversion rate	Rs./$			75
Cost per MMBTU (300.62/75)	$/MMBTU			**4.01**

Innovation and Technology in the Mining Industry: A Whole Mine Approach

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Abstract

This paper discusses a vision of the mine of the future – one that is innovative and leverages core technologies – and how to build it today. This vision is based on a premise that there is a need to drive a transformation of the mining industry with solutions that address the key issues in the industry. These issues and main challenges are clearly known to mining – we are dealing with declining grades, deeper deposits, stricter legislation, more complex metallurgy, and ever-increasing expectations of companies to continuously earn and maintain their licence to operate. Indeed, solutions are needed to address the growing demand for responsible, effective operations with zero harm to people, mines, processing plants, communities, and the environment. Many of the solutions to bring about responsible mining are technical in nature. The products are being developed at an ever-increasing rate given the advent of the Internet of Things (IoT) with wireless devices and software, and the uptake is increasing too, with a savvy workforce who readily embrace and harness the power of the digital age. There is also an interesting weaving of solutions – migrating across industries and available globally.

Introduction

This paper has been prepared in line with the requirements of the ICMSO 2022. The area of study is the use of technology and innovation to support a responsible mining industry and using a Whole Mine Approach (Espley, 2019) and described with 10 core elements, as shown below (Fig. 1).

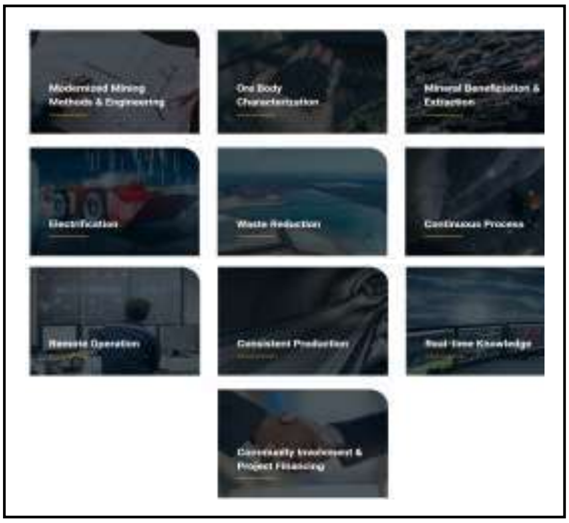

Fig. 1 The Whole Mine Approach: 10 Core Elements

Context: Why is a Transformation Underway?

The mining industry's risks and opportunities are well documented through technical reports and surveys including those of Ernst & Young[0] (Fig. 2) with the top 10 opportunities and risks in 2021 with the highest risk being the license to operate followed by high impact risks, the rising cost of doing business, and the growing need for decarbonization in a green agenda. Interestingly, the risk and opportunity with innovation is in the top 10 position. The dichotomy of this element is clear as both a risk and an opportunity to the industry.

The industry needs to transform itself and build the mines of the future today, to solve many of the risks inherent in the business. The drive for innovation in or itself requires experienced and trained personnel in the application and use, which also requires the change in the workforce and how the technology is leverage. Much of the challenge with innovation is social, requiring strong change management plans to engage with stakeholders.

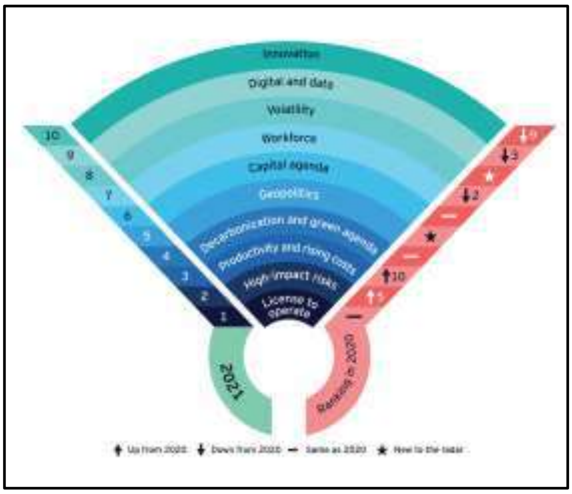

Fig. 2 Opportunities and Risks in the Mining Industry[1]

Mining industry advocacy groups, regulatory bodies, think tanks, and governments around the world recognize the importance of critical minerals as the building blocks of a clean and digitized economy[0,3] and there's scientific evidence of an evolving 6th Wave of Innovation[4] supporting the emerging sustainability imperatives. Specific net zero targets are being set and are used to drive efforts to move toward reductions of scope 1 and 2 carbon emissions, and to then focus on the scope 3 areas for improvement. Business leaders, such as CEO Elon Musk of Tesla, are driving a change through strong messaging and agreements to only buy metals from mining companies with progressive carbon emission reductions and solid ESG commitments[5].

A visionary outlook by the World Economic Forum[6] further corroborates these viewpoints. There is an underlying agreement that minerals and metals remain an essential contributor to society, and with an estimated 9.6 billion people living on the planet by 2050, with a higher percentage of society enjoying a higher quality of life compared to today, the emphasis is on consuming less, not more.

Investors are driving a transformative change in mining too[7]. They are outspoken in their preferential funding of mining companies who demonstrate responsible and sustainable actions, using a new environment social governance (ESG) index or set of sustainability criteria such as those set up with S&P 500 ESG Index[8] to rate businesses.

Investors are increasingly seeking to align their values with their investments - putting their money into businesses who fulfil their commitments to people, communities, and the environment.

Finally, society at large is shining an intense spotlight on mining, insisting on zero harm, insisting on engagement and involvement in mining projects “in the back yard”, and insisting on the workforces becoming more diverse and inclusive.

Overall, the drive for mining transformation is real and it is coming from all angles.

1. Environmental – climate change, growing concerns with waste and damage from mining activities
2. Society – expectations on fairness, equity, inclusivity, diversity
3. Political – jobs, wealth distribution, legislation
4. Geography – lower grades, deeper deposits, remote locations, logistics challenges
5. Technology – rapid developments, speed of change

Given the risks and pressures, mining companies are actively adjusting. Most are embracing the imperatives of change for the betterment of the business and the eco-system. Barrick, for example, is using a partner-centric perspective to challenge traditional views of mining and head toward their 21st century sustainability vision for the organization[9].

While the global community of investors, political leaders, regulators, and society itself raised the bar for mining, the technology innovators and engineering providers are answering the challenge. This is a win-win with the tremendous impetus for transformational change and the solutions are ready and are being developed to be implemented. The time for dreaming and waiting is over. The industry must move quickly to discover, assess, and implement leading-edge solutions in their mines, processing plants, and all the ancillary infrastructure systems and processes, while upping the outreach and engagement of Indigenous groups, communities, and society about the absolute critical necessity of the mineral and metals industry and the commitment to operating responsibly.

This transformation imperative is fully supported by industry with the new-age concept of fail fast. This means we safely learn and adjust quickly, with our scouting, demonstrations, and implementations of new solutions to get us to the future-state of mining, sooner rather than later. This is much more attractive, and needed, compared to a conservative and risky tactic of being first to be last to implement. Companies who are slow to transform may be the first ones to be out of business.

The businesses who embrace this journey and move ahead with their implementation plans in parallel with their improved social processes are destined to be the winners in the competitive business landscape and they will be the ones honoured for contributing to the sustainability of our planet.

Of course, this is a complex dance as solutions must be innovative and technically viable and must also address social responsibility, environmental responsibility, governance, and human resources requirements to satisfy key stakeholder expectations:

1. Investors and shareholders receive a threshold return on investment.
2. Mine owners achieve reduced costs, guaranteed safety, and improved productivity.
3. Communities enjoy clean water, air, and soil.
4. Workers are paid well, are kept safe from harm to body and mind, and are fully engaged in their work.

A transformational shift in mining is possible today with engineering services, technology solutions, and the deep-thinking to make this a reality. There are 10 elements to The Whole Mine™ approach where we see the greatest opportunity for transformation.

Modern Mining Methods

This element is geared to maximizing mechanization with a step change in productivity by re-designing mining methods. This means taking advantage of the latest in technology, equipment, and social considerations to yield production improvements and to guarantee safety. Some key solutions include:

- control centres with diagnostics tools
- extensive process automation with trouble-shooting teams,
- geographically distributed business centres compiling enterprise metrics

- IT networks linking people, processes, equipment, instrumentation for real-time oversight and response
- monitoring of assets and sites in terms of health, diagnostics, and algorithms for assurance of critical controls
- tracking of supplies

Ore Body Characterization

This element is focused on data, in knowing ore body geometries and the value distribution across the zones. This means taking advantage of the latest technology and equipment with new software tools to yield improved understanding of the ore body characteristics. Some key solutions include:

- real time assaying,
- ground penetrating sensors,
- downhole probes and mapping technologies,
- geo-structural and stress orientation measurements,
- algorithms to produce mineral and geotechnical domain outlines,
- data integration tools and 3D visualizers,
- diamond drill hole location optimization,
- value distribution based on mineral content and mining constraints,
- geological data linked to mine design tools,
- cutoff determination and hill of value computations with rapid trade-offs including economic evaluations,
- schedule impacts using probability and likelihood estimates for core processes
- geometallurgical estimates based on mill processing recoveries and impact of deleterious elements, grades, and tonnages
- 3D geospatial database to feed to mine design alternatives and optimization

Minerals and Metals Extraction

This element is geared to maximize recoveries from mine to market. Geometallurgical models and grade-recovery curves are tuned to real time performance to link mine design software to drive optimal stope sequencing, ore deliveries and blends. Processing plants are designs with zero emissions as a target and new markets are explored to deliver critical minerals for batteries, renewables, and clean energy materials. This means taking advantage of equipment, processes, and control systems. Some key solutions include:

- blast fragmentation optimization to replace crushing,
- sizers paired with screening to separate high-grade and/or reactive fines and prioritizing delivery to the concentrator,
- ore and waste sorting to improve head grades and shuttle waste into nearby voids or surface waste piles,
- on-line analyzers to automatically adjust grinding, flotation, hydrometallurgical processes, and refinery circuits,
- green, eco-friendly reagents,
- recycling loops to reduce freshwater intake and minimizing waste effluent discharge,
- in-line treatment and removal of select or deleterious elements,
- off-gases and effluents are captured and processed into value-added products,
- digital twins used to assess opportunities and calibrate to the operational performance,
- new ionized and similar technologies are used to recover metal from old tailings sites,
- re-design processing to create new critical mineral products and market products

Electrification

This element is focused on powering a site with clean, green energy, and reducing energy use. A transformation in energy for mobile and fixed infrastructure is underway, with a move away from carbon intensive equipment and processes. This means taking advantage of new technology and equipment, and smart control systems. Some key solutions include:

- electrified mobile equipment with high-capacity batteries or trolley-assist,
- off-gas filters and higher-tier engines are used with diesel engines to capture and reduced harmful emissions, respectively,
- hydrogen fuel cell engines and fuel replenishment processes,
- simulation suites to optimize a fleet including GHGe estimates and total power needs,
- renewable energy via wind, tidal, solar, and hydro-electric generation,
- battery storage used as a buffer in storage vs supply in high demand peaks,
- re-cycle and re-use exhausted battery packs,
- underground ventilation controls systems with fit-for-heading supply of air using wireless tracking systems and automated controls of fans, doors, louvres to direct air in real time, allowing increased production and clearing of blast gases,
- micro and small modular reactors with options to build, float, and operate on a barge in safe, engineered locations, in a harbour or underground, and depleted units are safely removed by the owner/operator,
- scalable micro grids to transmit power to site,
- multi-use reactors offer support to mining operations and local communities.

Continuous Processes

This element is based on transforming how we move material, without delays and with no inventories. There is a recognition of the traditional mining's inefficiencies in terms of low face utilization and multi-handling of waste and ore. There is an opportunity to re-design the material movement systems and core mining activities with an aim to eliminate value destructive activities. This means taking advantage of equipment, processes, and control systems. Some key solutions include:

- mechanical rock excavation and remote-controlled processes for development access, vent raises and vertical shafts, and for ore production, particularly in high stress and challenging ground,
- precision-cut profiles for excavation stability, minimizing support requirements and eliminating over/underbreak,
- cuttings allow for continuous transport with conveyor systems and opportunity for sorting,
- automated rail-veyors, high angle conveyances, and tandem shuttle cars, with continuous loaders, rapidly and effectively move material in small headings,
- Maglev replaces drum and rope style hoisting plants,
- automated material handling systems deliver just in time supplies and are stored and secured in modular containers eliminating warehouses and storage bays,
- operations are managed and monitored from strategic locations,
- cemented tailings from the mill is recirculated directly to underground voids for tight fill.

Real-Time Knowledge

This element is geared to leveraging of the power of Industry 4.0 technologies. This means taking advantage of the latest communication, storage, and artificial intelligence systems with automation and process control systems. Some key solutions include:

- next generation backbone networking infrastructure and cloud platforms,
- wireless communications and edge computing,
- artificial intelligence and robotics,
- real-time data to anywhere and to anyone with authority allows optimization, analytics, and autonomous decisions,
- plug-and-play capabilities transform how devices like fans, pumps, controllers, etc. are controlled over a standard platform,
- short-interval control with integrated planning and scheduling to pivot operations with available resources for maximum safety and productivity,
- virtual data is accessible and digital transformation to perform work and capture new routines for continuous improvement,
- ground response data is integrated with mining activity and analyzed with feedback to designs for optimization,
- real-time performance data, used with simulators and digital twins, assess bottlenecks and design improvements
- safety and health information are monitored for rapid or emergence response, if needed.

Remote Operation

This element is all about taking control to a new level with strategy centres. This means taking advantage of the latest in data collection, distribution, storage, and computations to benefit a range of equipment, processes, and control systems. Some key solutions include:

- cloud technologies to host business data and process control platforms,
- geographically distributed operations centres for remote control, strategic oversight, decision-making,
- product-to-customer interactions and interfacing including supply chain logistics, inventory management, and autonomous deliveries from mega-fulfillment centres
- distributed experts to support global operations with maximum use of virtual connections
- use of avatars for tech support and troubleshooting on the job
- local control centres are replaced with mobile devices and apps carried by every worker
- full coordination of key processes and control of top risks
- augmented reality technology for the design stage, commissioning, and operations support
- monitoring of all processes and support facilities, from mine to port, with control and assessment in real time and escalation protocols embedded in software systems.

Consistent Products

This element is about generating optimal activities with end-to-end coordination. Total visibility is achieved for predictable, reliable, safe operations, and optimal value to the business. This element leverages the real-time monitoring and tracking including for high risk and top priority facilities such as dams, emissions, treatment plants, etc. Instrumentation is used to monitor of the health of critical controls and operations. This means taking advantage of design software with instrumentation and control systems. Some key solutions include:

- drill and blast designs to minimize dilution and waste,
- ore movement and processing plant designs to maximize metal recovery,

- supply chain logistics and pre-planning to deliver materials on time, to prevent down time and under-utilization,
- use of strategic replenishment and fulfillment centres for Amazon-like delivery systems, using robots,
- an integrated face to the business Enterprise Management system
- wireless tracking of all inputs and outputs to meet quantity and quality requirements,
- personnel scheduling to fit with production and maintenance activities,
- year-in-advance schedule and resource planning,
- integrated life of facility plans and schedules.

Sustainability and Responsible Mining

This element is focused on mining only ore, leaving footprints, fresh air, and clean water and soils. All waste sources are minimized in design and new sources are fully re-distributed to the working areas and original sites. Tailings are effectively managed to eliminate large storages and dams. Water is strategically used with maximum recycling to limit fresh-water intake and dirty water discharge. Some key solutions include:

- tailings delivery to underground voids for maximum placement as paste,
- surface mines use dry stacking of tailings waste,
- rehabilitation while mining to minimize the footprint,
- natural cooling and super cooling systems are maximized in underground mines with heat transfer to provide quality air on an as-required basis,
- cooling ventilation of strategic underground facilities such as maintenance shops and work areas,
- 100% recycling of water in process plants,
- 100% recycle of process water in the underground mines with treatment of excess water to discharge as fresh water or re-use this water in other areas of the plant.

Community Involvement

This element is geared to a need to work together as a responsible industry and community base. Our mining industry involves the full community with a level of engagement that is the envy of other industries. There is an engaged mining culture that is fostered and it brings out the best in people in terms of meeting business, environmental, community, and safety performance. Mining companies are leaders in responsible operations and meet and exceed the expectations of all stakeholders. There is an overall celebration and collaboration and a pride in the resulting excellence. There is economic vitality and well-being within the entire ecosystem and the mining industry is highly valued for its essential contributions to society. Some of the key solutions to create this reality include the following:

- synergies are leveraged with financial investments in terms of the infrastructure such as power generating plants to energize hospitals, schools, and the mining operation,
- industry collaborates with core associations and advocacy groups along with academia, government, supplies and service sector, NGOs, and the indigenous communities with strong partnerships on all levels,
- personnel are trained in the community with knowledge, skills, and specialty capabilities,
- next generation workers manage technically advanced processes,
- skills trades are multi-faceted with knowledge of electrical, mechanical, and IT systems to maintain the complex equipment and systems,
- shift schedules, work assignments, and workshops are tailored to meet the needs of the employees and the business,
- mental health and physical health are optimal such that the workforce and business deliver on zero harm and guaranteeing safety,
- focus groups continue to evolve and transform the industry with thriving and active communities.

Summary and Conclusions

The world is demanding responsible mining and these mines of the future can be built today. The Whole Mine Approach is a foundational guide for making a transformative change and a new reality in terms of the successful outcomes from all mining operations and the associated ecosystem of stakeholders. Solutions are driven by technology and are enabled by talented people who will ensure the financial and social requirements are also met. Community, industry, and visionary leaders are needed to bring this vision to life for the current mine designs and operations, and for those in the future. It is an imperative to engineering responsible mines using diversity of thought and collaboration as a means to get there. The Whole Mine is a comprehensive view to be trusted and relied upon to build your sustainable, responsible operation.

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Conflict of Interest

The author declares that there is no conflict of interest in the publishing of this paper.

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Sustainability in Indian Surface Coal Mining Industry – A Brief Techno-Environmental Overview

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ABSTRACT:

Exponential increase in coal production and productivity levels need over emphasis through gigantic and expansive coal project outlays, positive outlook towards adoption of rampantly evolving fore-front technologies, research, innovation and designs etc, on one hand and sustainability of mining operations vis-à-vis growing environmental concerns, as the by-product of increased coal production, on the other hand. In this light, the key sustainability issues related to environmental challenges faced by the coal industry in various stages of coal mining operation chain and the possibilities to overcome these challenges in light of emerging technologies are discussed in the present paper.

1.0 INTRODUCTION

Although India is producing over 700 Mte of coal annually and it ranks as second largest coal producer globally, there still exists a huge gap between the demand and supply of coal. The huge demand is unlikely to stop in foreseeable future. This is primarily attributable to abundance of this fossil fuel in India, availability of very limited resources and reserves of oil and natural gas and several limitations being faced by renewable and nuclear energy resources in contributing to the energy sector in our country. In addition to the power generation (almost 58%), the coal is an essential raw material for Steel, Cement, Fertilizer, Ceramics, Chemical, Paper and a plethora of MSME industries. Given this situation, coal has been and shall remain “King” in catering to the energy needs of our nation in near as well as distant future. Therefore, Coal mining in India needs to be accelerated in view of ambitious projects, such as “Make in India”, “Made in India” leading to an “Atmanirbhar” India as immaculately envisaged by our Hon’ble Prime Minister.

A noteworthy point, although India as second largest coal producer in world, with a population of about 1.39 Billion (estimated growth rate 0.91% approx.), produced almost 720 Mte (2020-21), China, the world’s largest producer with population of 1.44 Billion(estimated growth rate of below 0.5% approx), has over 5-times higher coal production. This indicates insufficient energy production, which, in turn, distinctly reveals poor per capita energy usage in industrial, commercial, manufacturing and domestic sectors of India. This state is alarming for a growing Indian economy and needs to be viewed and reviewed utmost seriously as is being done by the Govt. of India. Boost in energy sector by massive impetus on expansion of coal projects and also by enhancing the capacity utilization of the existing projects is absolutely crucial for propelling Indian economy.

Exponential increase in coal production and productivity levels need over emphasis through gigantic and expansive coal project outlays, positive outlook towards adoption of rampantly evolving fore-front technologies, research, innovation and designs etc. with proper cognizance to operator's Safety Health and Environmental (SHE) issues.

Nevertheless, the emphasis on coal production on one hand and serious concern on Net Zero for creating a Carbon Neutral environment on the other hand, has made the industry, academia and researcher very sensitive and overtly conscious about the sustainability of coal mining. In the current and evolving perspective, the ecological imbalances as the by-product of coal mining need to be addressed vociferously by adopting befitting technologies and state-of-art remediation and curative measures to protect the environment in order to make the coal mining more responsible and sustainable in the years ahead, especially in view of energy security needs of our Nation. In this light, the current paper targets the emphasis on the existing gap areas, which need to be addressed to by the Indian coal industry in its quest for sustainability, with environmentally friendly mining tools, techniques and gadgets, in the forthcoming years.

2.0 Goals and Scope of Sustainable and Responsible Mining

Sustainable and responsible Mining aims at fostering innovation, best practices and intelligent solutions to deliver acceptable results across the entire value chain of mining life cycle in its different stages, commencing from the mineral discovery and culminating to the delivery of finished products. The sustainable mining entails the preparation of pragmatic plans prepared after a rigorous internal and external engagement, in-depth understanding and critical assessment of challenges and opportunities in terms of short- and long- range perspective. It necessitates the clear understanding of long-term impacts of mining activities before, during and after the mining operations with especial thrust on environmental, economic, and social dimensions. Sustainable mining practices must accomplish the sacred goals in the different stages of the mining life cycle, as illustrated in Fig. 1.

Fig. 1: Goals of Sustainable Mining Practices Vis-à-vis the Mining Life Cycle

Furthermore, scopes of sustainable mining practices in each stage of the mining life cycle are discernible in the Fig. 2.

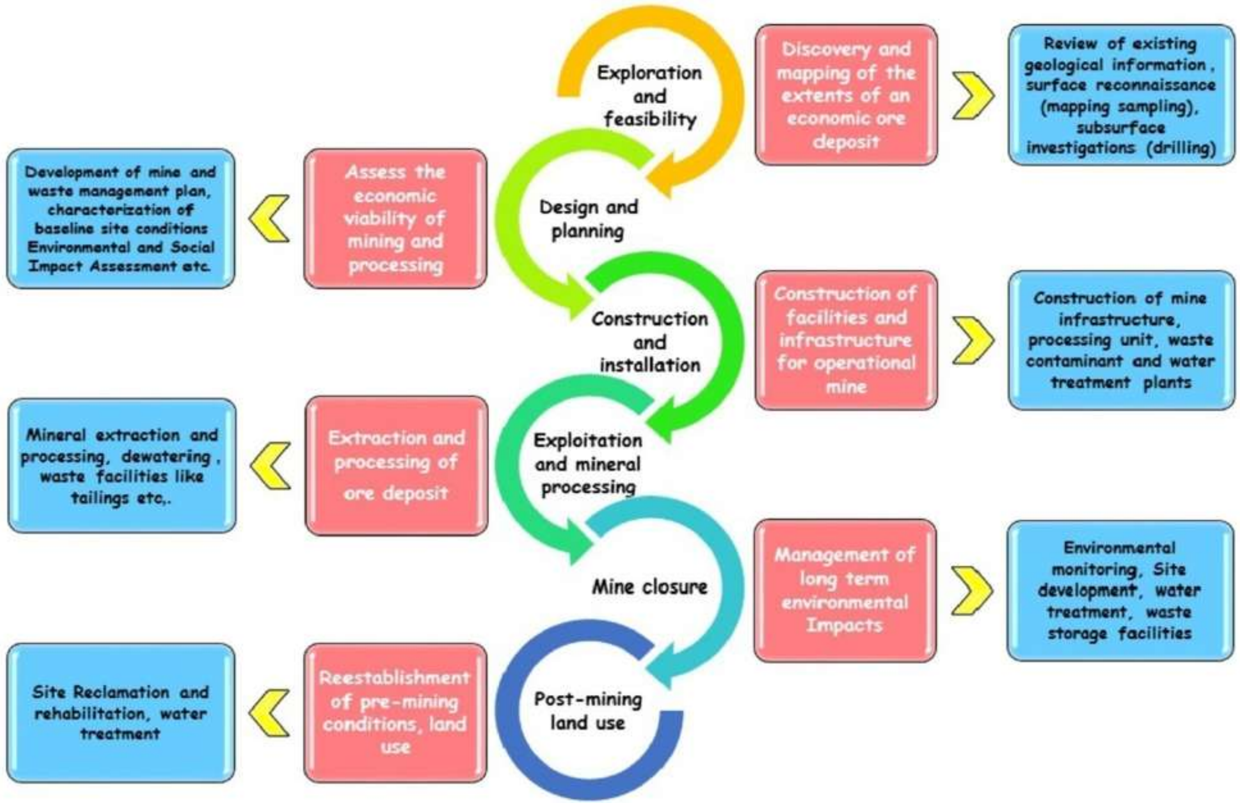

Fig. 2: Scopes of Activity in Various Stages of Mining Life Cycle

It is quite evident from the Figs. 1 and 2 that not only the exploration, feasibility, design, planning, construction, exploitation and mineral processing are important, but equally and rather, more important, are the mine closure and post-mining land use planning and its precise implementation. The scope of land use encompasses the restoration of not only the degraded land but it must also be looked into as a measure to restore the complete eco-system (inclusive of biodiversity), with due cognizance to the air, water, noise dust, waste, aesthetic and socio-cultural changes. Effective implementation of this understanding shall establish a long way not only in protecting the environment, ecosystem, public health, public perception and changing the attitude and mindset of people and government towards the mining industry.

It is very consequential to re-affirm the importance of Net Zero vis-à-vis sustainability of mining industry. The recent directive by the Ministry of Coal, Govt. of India is to boost the production and productivity from the CIL in order to reach the annual target of 1 billion tones by 2023-24. In accordance, the CIL has ambitious expansive plans with an outlay of approximately Rs. 1.25 Lac Crores to meet the slated target of coal production by 2023-24. Four Coal India subsidiaries, namely, MCL, SECL, CCL and ECL are likely to invest around Rs. 3400 crores in around 14 major projects to enhance the coal production capacity by over 100 Million tonnes per annum. This capacity expansion necessarily entails huge energy consumption, both diesel and electric, in the entire value chain of production operations. Therefore, there is an emergent need to gear up for the momentum from the beginning in order to follow an integrated and holistic approach from viewpoint of conservation of environment, especially in view of emerging concerns on carbon foot prints, their minimization and culmination to net zero in India by the year 2070, as per Glasgow summit and agreements. The Green House Gas Emissions (GHGEs), dust (especially PM 2.5 and PM 10), noise etc. again become critical components.

In this light, it is of paramount importance that the aggressively evolving technology must be seamlessly intertwined at relevant operational points in order to reap the fullest benefits for accomplishment of cherished goals of sustainable and responsible mining.

3.0 Methods, Concepts and Technological interventions for Sustainable Mining

Apart from focusing on various conventional methods, practices and techniques, to bring forth a few like; replenishing native soils and grasses, cleaning excess waste, proper waste removal, site inspections, replanting trees and restoration of natural forestry, choosing environmentally friendly mining operations and methods, implementing green mining technologies, reducing and reusing waste, re-evaluating the cut-off grades, increased use of in-pit crushing and conveying System, angle conveyors including high angle conveyors, redesigning open cast mines to reduce haul distances (wherever possible), on-line dust suppression techniques, improvements in operation and design of diesel engines, use of electric vehicles (wherever possible), deployment of large sized equipment- drills, shovels, dumpers, draglines etc., creation of impermeable tailing dams and pond, effective treatment of acid mine water, mill tailings, extraction of REE from acid mine water, effective and regulatory shut down of illegal mining etc., some of the latest technological developments are being elaborated (in view of their game changing potential and relevance in the emerging and evolving technological scenario) as follows:

(i) **Application of Surface Miners**: Surface miners have been working in Indian surface coal mines with higher productivity and environmental benefits. Their use has been attaining increased acceptance, especially in those mining areas where breakage by drilling and blasting is either operationally or cost prohibited. For instance in the Gevra project of SECL almost 66 % of the coal production is attributed to the surface miners. Currently, 135 surface miners are working deployed in 36 OCPs of CIL. The surface miners although not as versatile as the D&B , wherever they can be optimally deployed the success rate has been laudable. Besides overcoming a host of blasting nuisances in and around the blasting area, nearby habitation sites the surface miners are readily vulnerable to selective mining of coal. Furthermore contiguous and/or multiple thinner and inferior coal seams which were unworkable by conventional drilling and blasting system, get readily extractable, which, in turn, has converted the existing coal resources into reserves, thereby increasing the total coal reserves. Overall production cost by the surface miners is reduced. Nevertheless, the hardness and gradient of the coal seam are constraining factors with surface miners.

(ii) Overland Conveying Systems (OLCS) : Handling and transportation of millions of tones of broken rock and/or coal to their deposition/end use sites by fleet of trucks is a common practice in surface coal mines. The challenges posed by difficult terrains, weather conditions, road conditions, fugitive and dust emissions, down and maintenance time, idling time due to queuing at loading and disposal site, poor overall efficiency and most importantly the public distress in the mining areas due to frequent plying of trucks with their fugitive and dust emission levels, deterioration and ruining of public roads more than offset the merits of truck transportation system that are largely economical owing to the fleet of trucks being much cheaper to purchase. While the cost benefit aspect may appear to be cheaper initially, in the long range perspective on evaluating the direct and indirect cost elements and the efficiency of truck transport system, the initial hypothesis may appear much more expensive being inefficient and environmentally unsustainable. Given this the Overland Conveyor System (OLCS) besides a plethora of technical and operational merits, are much more superior in terms of their environmentally sustainable features and merits embedded therein.

The OLCS of Sasan Power Limited,Reliance, Singrauli, is India's largest Eco-friendly OLCS for transportation of coal. It is a single flight, securely covered conveyor belt without any transfer point en-route. Therefore, it minimizes fugitive, dust and noise emission during the transportation of coal from the coal mine to the power plant. As such, it does not cause social distress, which, in turn, makes it much more attractive and environmentally sustainable. This OLC System has been designed to carry coal at 4500 TPH capacity with belt speed of 5.6 m/s and belt width of 1800mm. The system is highly durable and robust for long, speedy, noiseless and continuous handling operations.

(iii) GHGEs, Environmental Considerations vis-à-vis Intelligent Technology: In light of previous description of the Net Zero vis-à-vis sustainability, the GHGEs and other environmental parameters need to be carefully monitored and analyzed by using state-of-the art techniques, tools and methods. The intelligent and smart monitoring, quantification and analysis of these key parameters shall go a long way in accomplishing the goals of production, productivity, cost economics, on one hand and sustainability of mining projects on the other hand in our quest for "Green mining". Apart from active mining faces and mining operations in the active mining areas, the haul roads, the crusher points, coal handling plants, railway sidings, waste dumps etc.

must be considered as suitable sites for monitoring and remediation by generating suitable KPIs for evaluation. Towards this, state-of- the art application of sensor based drones, digitization of data gather, high resolution cameras, dashboard systems could be effectively utilized for smart monitoring and providing the MIS. The information and data so gathered could be aptly synthesized, analyzed and interpreted by use of a number of Artificial Intelligence (AI) techniques, such as big data analytics, Machine learning, deep learning, advanced statistical techniques etc.. The results of gathered data and its analysis could be disseminated by use of sensor based IIOTs, on the Android phones, as well.

(iv) **Mine Depth Related Issues**: As the mines get deeper the ventilation, water management system and safety of operation shall be confronted. Close monitoring of operational and operator's safety and health issues is warranted thereof. Water appears to be a big deal in the future. Process technology where we use less water, reuse of water, as well as dealing with mine water may be interesting and challenging too. Also, in deeper mines static as well as dynamic loading on deep pit and dump slopes would be important. To be handled with adequate caution.

Impact assessment of blasting fumes and dust generation potential due to blasting vibrations from the active benches and loose waste dumps and their dispersion pattern need to be monitored properly, especially when the mines are going deeper and clearance of dust and fumes has been posing immense challenge from deeper horizons. On-line monitoring, water sprinkling and analysis of dust dispersion patterns need to be done by state-of-the art techniques.

(v) **Waste to wealth**: This area has recently received significant attention in view of the noble idea of reducing, reusing and recycling the waste generated in any process or technology so aptly propounded by our Hon'ble Prime Minister. The idea and motivation holds very laudable potential to provide huge revenue to the coal industry by using the waste generated in mining operations. OB waste is already being used to generate sandstone, it could also be thought of and researched properly for use (after suitably crushing and sizing) in making embankments, pavements, reinforcing mine haul roads etc. Similarly, the byproducts from coal washing plants, such as ash, tailings, burnt oil etc., could be reused within the mining industry itself in a closed loop. Waste such as ash, tar and burnt furnace oil from the nearby TPPs also offer tremendous reuse potential in mining loop itself. Additionally, very low grade coal, as a by-product in higher grade coal mining, could be converted into graphene and nano-particles for energy storage. The use of oxygen storage in graphene and nano-particles needs to be explored. REE and heavy metal extraction, acid mine water neutralization, bricks manufacturing from ash need especial mention here.

(vi) Clean Coal Technologies (CCT): Clean coal technologies need not be restricted to washing coal and concurrently harnessing the value from the washery rejects. It is now imperative to tap the deep seated and/or low grade coal resources that have merit to be become reserves. To meet this end, although lot of prospecting and exploration in underway in various coal fields, still lot more serious impetus needs to be given to tap the techno-economic and techno-commercial extraction of Abandoned Mine Methane (AMM), Coal Mine Methane (CMM), Coal Bed Methane (CBM), extraction of coal by primary/in-situ gasification methods. The resource and reserve characterization for these CCTs need to be done in a coherent and organized manner by bringing a host of agencies and institutions together on a workable platform.

Surface coal gasification is considered as cleaner option as compared to burning of coal in the TPPs. The surface gasification (aka secondary gasification) largely depends on the chemical properties of coal. Syn Gas produced from the surface coal gasification has multiple usages, namely, for producing Synthetic Natural Gas (SNG), energy fuel (methanol & ethanol), production of urea for fertilizers and production of some important chemicals etc.

4.0 Conclusion: Sustainability of mining operations in general, and surface coal mining operations, in particular gain much greater significance and have become much more imperative with exponentially rising demand of coal to meet the energy security of our nation. To increase our impetus on sustainable mining, it is essential to critically view the sustainability at each stage of the mining life cycle. Accordingly, in addition to continuing the conventional methods practices and techniques of tackling the environmental issues, it is of paramount importance that the aggressively evolving technology must be seamlessly intertwined at relevant operational points in order to reap the fullest benefits for accomplishment of cherished goals of sustainable and responsible mining. This ought to cater to the energy security needs of our nation on one hand and make our coal mining industry very contemporary, environmentally sustainable and responsible in the global perspective, on the other hand.

75 Azadi Ka Amrit Mahotsav

New INITIATIVES of Team ***WCL***

ECO-MINE TOURISM & ECO PARK

First of its kind initiative in India
Created with an aim to dispel the notion
of pollution and environmental degradation
associated with Coal Industry

COAL NEER PLANT

A significant initiative of using
Mine water and turning it into potable
& safe drinking water using
reverse osmosis water purification process.

SAND PLANT

WCL has introduced a new Green technology
to safely extract sand from
its Overburden (Earth material
removed to extract coal) dumps.

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Sustainable Development of Singrauli Coalfields, India, vis-a-vis Mining Equipment Selection & Environment and Ecology Management

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Abstract

Energy demand of India is primarily met by coal based thermal power plants spread all over the country. To make available 'electricity' to the growing population, attempts have been made to have the energy mix of hydel-thermal and non-conventional sources of green energy. Besides, energy availability, India has also laid emphasis on access to reliable and sustainable energy, energy at an affordable cost, and reduction in carbon footprint. The present 57% of electricity from coal-based power units draws major quantities of power grade coal from large opencast mines. Efforts have been made by state owned Coal India Ltd and its subsidiary companies, to mine coal with least impact on the environment, land area, contamination of surface and groundwater. With largest fleet of draglines, dragline mining has proved to be cost effective, energy efficient, safe and a very stable production unit. In this paper an attempt has been made, to highlight various environmental issues associated with surface/opencast mining and the best practices being adopted. The case study in the paper refers to the mines of Northern Coalfields Limited (NCL), Singrauli. NCL has successfully reduced total emission 1, 26,712 Tonnes of CO_2 in a single financial year.

Introduction

India possesses one of the largest coal resources in the world. As per the BP Statistical Review of World Energy, 2019, India has the world's fifth largest coal (including lignite) proved reserves with ~10% share (~101 billion tonnes). The reserve to production ratio (R/P ratio) is in excess of 100 years at the current production level. (Fig 1)

As per the existing Indian system of reserve classification, the proved reserves for coal and lignite in India are 148 billion tonnes and 6.5 billion tonnes respectively. India has invested significantly in the exploration efforts in the past and the proved reserves of non-coking and coking coal have increased by CAGR of 4% and 1% respectively over the last 5 years. The detailed break up of coal and lignite reserves in India are presented in Table 1.

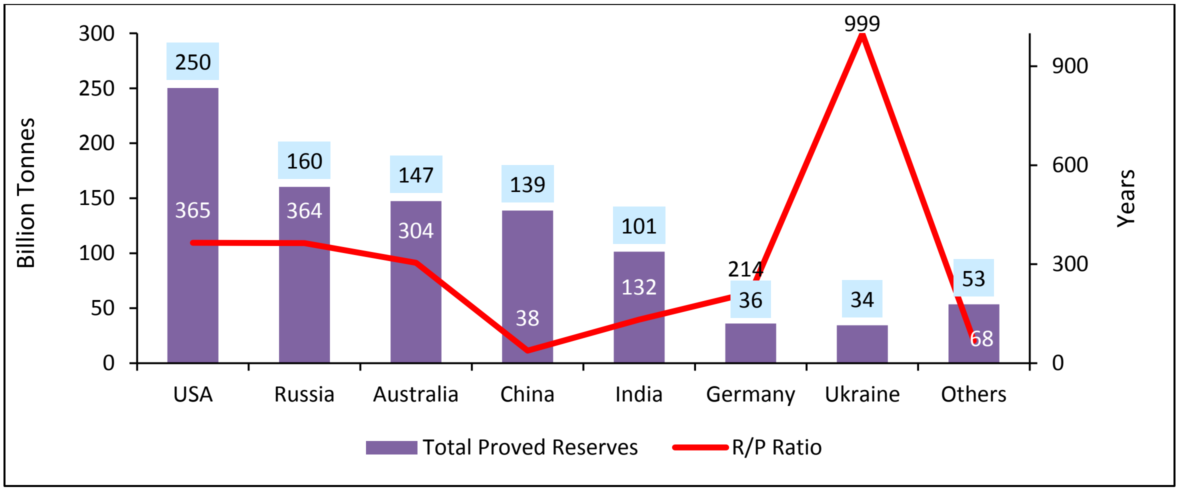


Figure 1: World coal reserves

Table 1: Coal reserves in India, in million tonnes

Type	Proved	Indicated	Inferred	Total
Coking coal				
Prime Coking	4,649	664.19	-	**5,313**
Medium Coking	13,914	11,709	1,879	**27,502**
Semi Coking	519	995	193.21	**1,708**
Total Coking coal	**19,082**	**13,368**	**2,073**	**34,522**
Non-coking coal	129,705	125,796	28,996	**284,498**
Total coal	**148,787**	**139,164**	**31,069**	**319,020**
Lignite	6,541	26,389	12,734	45,664

The present peak power demand in India is 1,71,004 MW against peak power supply of 1,70,241. Presently installed capacity of power generation in India is 3,99,497 MW (1.04.2022) consisting of coal based thermal power generation of 2,04,080 MW. The contribution of different sources in current power generation is shown in Fig. 2. In view of the increasing demand for power, the demand of coal in installed capacity of power generation is also likely to be increased. It can be analyzed from Fig. 3 that % share of coal in installed power generation capacity of India will decrease because of growth in renewable energy sector but in absolute terms it will continue to grow.

Overall coal demand is estimated to be 900 to 1,000Million Tonnes per annum by 2020 and 1,300–1,900 Million Tonnes per annum by 2030. By 2030, of the overall coal demand, thermal coal demand is estimated to be 1,150 to 1,750Million Tonnes per annum and the balance is coking coal demand. By 2032, it is expected that share of renewable source of energy will be more as compared to coal based thermal plants. With continuous increase in coal based power generation from 708.3 TWh in year 2012 to 3153.6 TWh in year 2047, the Green House Gas (GHG) Emission/capita will also increase from 1.7 tons/capita in year 2012 to 5.8 tons/capita in year 2047.

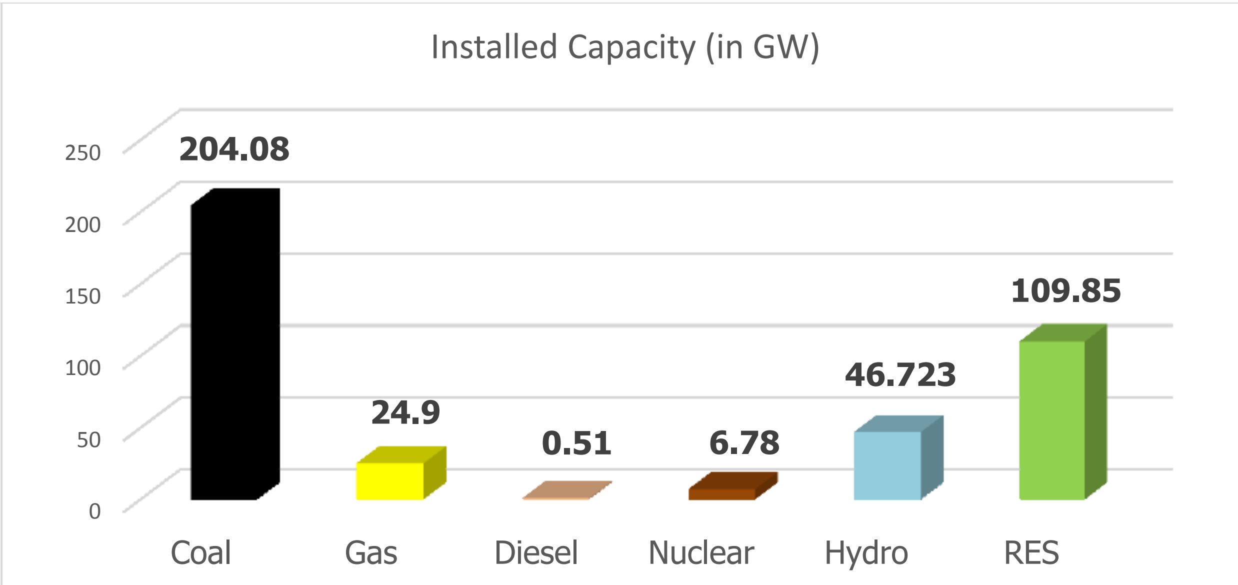


Figure2: Presently installed capacity of power generation from different sources in India (as on 01.04.2022)

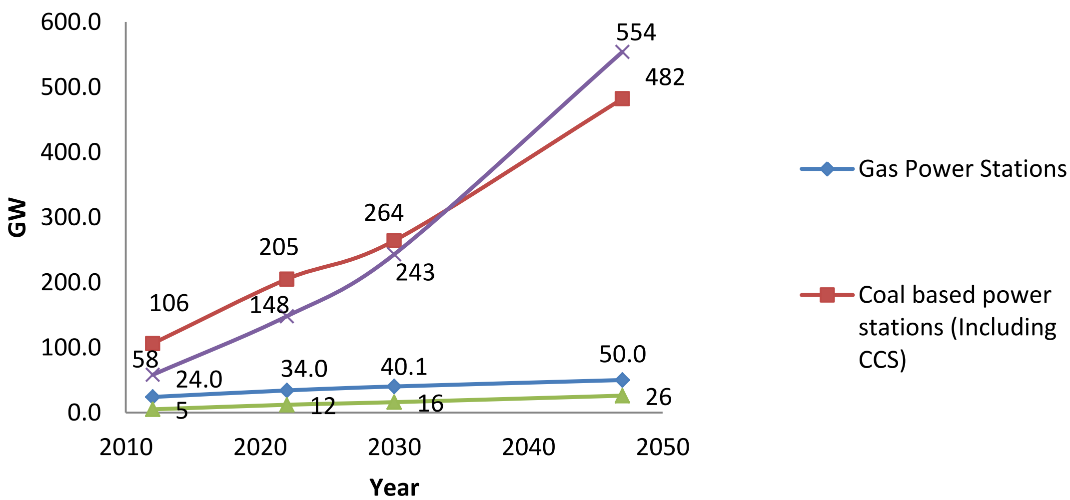


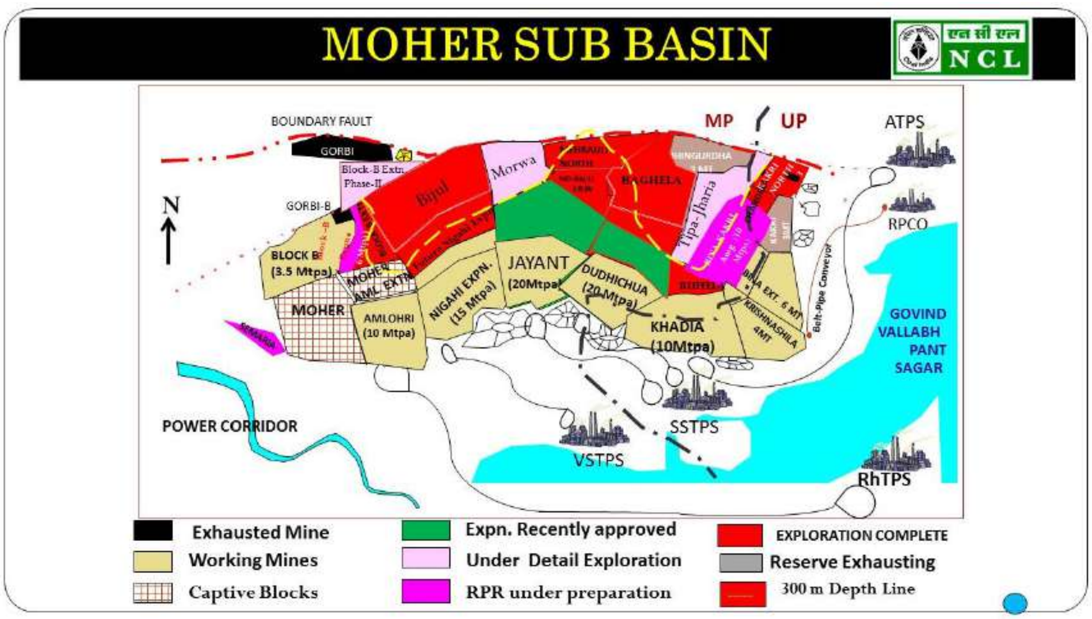
Figure3: Different sources of installed capacity of power generation till 2050

Singrauli Coalfields of India

Northern Coalfields Limited (NCL), Singrauli is a major contributor to energy requirement of the nation. NCL is a Public Sector Company (Mini Ratna-Category-I) since 2007 and is a wholly owned subsidiary of Coal India Limited, under the Ministry of Coal, Government of India. NCL is producing coal since February 1965. It is an ISO 9001:2008, ISO 14001:2004 and OHSAS 18001:2007 certified company. About 94% of the coal produced is dispatched to Power Sector. The company's gross turnover for the fiscal 2020-21 was 238229 Million Rs.

Singrauli Coalfield is spread over 2202 Km^2, comprising of two basins, viz. Moher sub-basin (312 Km^2) (Fig. 4).and Singrauli Main Basin (1890 Km^2). It has total coal reserve of 10.06 BT (6.83 BT in Moher Sub-basin and 3.23 BT in Main Basin). Major part of the Moher sub-basin lies in the Sidhi district of Madhya Pradesh and a small part lies in the Sonebhadra district of Uttar Pradesh. All the coal mining operations of NCL are at present concentrated in Moher Sub-basin through 10 numbers of highly mechanized opencast mines. Singrauli main basin lies in the western part of the coalfield and is largely unexplored.

Figure 4 : Moher Sub-Basin - Operating Mines of NCL



To meet the growing demand of coal and in keeping with the pace of economic growth, NCL has to continuously supplement / contribute to the country's growing energy demand. Thus, in the next five years it is expected that NCL will have to produce in the range of 125-130 MT and majority of all these coals will come from the existing mines. This increase in production involves the following challenges:

- i) No new area is available in the strike direction except Semaria and Kakri North Blocks.
- ii) High Stripping ratio towards the dip.
- iii) Increase in working depth.
- iv) Scarcity of Overburden dumping space.

v) Half basinal shape of the deposit, because of which mining operation will be converging towards the center, squeezing the available working area / strike length.
vi) Area on the dip side of the Mega Projects like Jayant, Dudhichua and Nigahi are densely populated and needs Resettlement and Rehabilitation.
vii) Environmental Challenges due to substantial increase in mining activity involving drilling, blasting, excavation and transportation.

Planning Initiatives

a) There are two / three major coal horizons. All the mines have been planned to optimum pit geometry with no adverse lagging of any coal horizon.
b) Thereafter to maintain a "Synchronized advance" of the pit Geometry in order to keep the catchment area minimum as well as to achieve the enhanced coal production target.
c) To supplement the progress of lower seam being exposed by Aged Draglines, bench thickness of dragline benches reduced.
d) Creation of "advance" sump in the bottom most seam.
e) Extraction of coal locked up in inter-mine boundary to create additional dumping space along with increase in ratio of extractable to mineable reserves.
f) Resorting to multiple dumping to enable dumping of material in order of their formation, i.e., top bench materials are dumped in top decks of the dumping, middle bench overburden in middle decks and bottom bench overburden in lower decks.

Equipment selection-operation and management

All the operating mines have to handle huge volumes of blasted overburden material by dragline and electric rope shovels. Table 2 presents the quantity of overburden material handled and coal produced last year and the projections for 2030. To meet the excavation and final production, NCL maintains a very large fleet of Heavy Earth Moving Machineries (Fig. 5 & Table 3).

Notable additions of HEMMs during the last few years have been 1 no. 24/96 Dragline, 6 nos. 20 CUM Electric Rope Shovels, 11nos. 11-12 cum hydraulic shovels, 103 nos 100T Dumpers, 12 nos. 850 HP Dozers, 4 nos 311 drills, 11.5 cum pay loaders, 120T cranes.

NCL has planned to procure additional 6 no. 24/96 Dragline, 12 nos. 20 CUM Electric Rope Shovels, 5nos. 11-12 cum hydraulic shovels, 92nos 190T Dumpers, 15 nos. 850 HP Dozers during this financial year and in the next fiscal.

Table2: Quantity of overburden and coal produced last year and projections for 2029-30.

Mine	Stripping Ratio	Quantity of OB		Quantity of Coal Production	
		2021-22	2029-30	2021-22	2029-30
AML	4.28	53.82	60.00	14.00	14.00
BIN	4.57	44.38	-	9.00	-
DCH	4.54	57.21	113.50	22.06	25.00
JNT	3.04	54.12	75.80	24.75	25.00
JRD	1.15	6.86	-	2.74	-
KKR	2.25	4.32	-	2.41	-
KHD	4.23	51.79	64.88	14.00	16.00
NGH	3.68	56.82	86.00	21.00	25.00
KSL	3.38	16.46	25.00	7.00	7.00
BLB	3.31	17.98	43.30	5.47	10.00
SEM	7.48	-	14.64	-	2.00
BIN-KKR Amal		-	63.24	-	14.00
JRD Bottom		-	12.36	-	2.00
KKR North		-	25.34	-	3.50
TOTAL		**363.76**	**584.06**	**122.43**	**143.50**

Figure 5: Presents list of Major Equipments deployed

Equipment	Total Working Equipment Population
Dragline	23
Shovel	113
Dumper	540
Dozer	177
Drill	143
Surface Miner	5

Table 3: List of Major Heavy Earth Moving Machinery (HEMM)/ Equipments deployed

Name of Equipment	Manufacturer	Capacity	No. of Units	Year of commissioning
Dragline	HEC*	24/96	5	1993,2014,15,16,19
	Ural mash	20/90	4	1992,1994,1995
		15/90	1	1979
	Bucyrus	24/96	11	1985 - 2003
	NKZ	10/70	2	1977-78
Rope Shovel	Bucyrus	20.0 m^3	3	2009-10
	Bucyrus / RB,BE	10.0 m^3	14	1993-2007
	TZ	20.0 m^3	6	2017-2018
	MARION /BEML*	10.0 m^3	7	2003-2011
	EKG	10.0 m^3	1	2000
	P&H	10.0 m^3	22	1987 –1999
Hydraulic Excavators	Komatsu PC2000	10 - 12.0 m^3	11	2011-2016
	TATA Hitachi*	11.0 m^3	3	2016
		3.0 m^3	2	2009
		1.2 m^3	3	2016
	BEML*	9.5 m^3	4	2006-10
		5.8 m^3	1	2009
		3.5 m^3	4	2015
	HM*	9.5 m^3	1	2005
	L&T*	3.0 m^3	4	2010-11
Dozers	KOMATSU	860 HP	12	2008-2012
	CAT	770 HP	15	2007-16
	BEML*	410 HP	105	1990-2015
Drills	Atlas Copco	311 mm	11	1999-2017
	RECP*	311 mm	4	2005-16
		250 mm	22	2002-2012
		160 mm	22	2013-17
	IDM*	250 mm	30	1998-2012
		160 mm	22	2013
	LMP*	250 mm	2	1986-87
		160 mm	1	2004
Water sprinklers	BEML*	70 KL	15	2015-19
		28 KL	25	2001-2016
	HM*	28 KL	4	1998-2000
Graders	BEML*	280 HP	51	1989-2016
	CAT	280 HP	6	2011-16
Surface Miners	L&T*	4000mm	4	2015-16

**These are Indian Manufacturing units.*

NCL has developed a well laid out maintenance and safe operating procedures for all the equipments. These equipments are also serviced by the OEMs and total spares management is done in a coordinated manner so as to ensure optimal productivity. Such large equipments are manned by trained workmen/operators and simulators have been used to train at regular intervals. Presently, NCL has two numbers of simulators, one for dumper and the other for Dragline, Shovel and Dozer.

NCL having the largest number of draglines in India and Asia, planned and designed the operations for effective side/blast casting. A system of Tandem operation is adopted in all the mines, thereby reducing number of multiple handling of the blasted material. Undertaking large blasts in dragline benches has also posed several challenges and could be overcome with the involvement of scientific bodies like CIMFR and explosive manufacturers. Very recently the concept of stratablast or combining overburden and coal benches in a single hole pattern could be successfully executed with least dilution and better fragmentation. Use of E-Det in Dragline bench blasting has also contributed in lowering air blast and ground vibrations.

Coal Evacuation (4a, 4b and 4c)

NCL supplies approx. 94 MT of coal to power plants, out of which 52 MT is supplied to Pit Head power plants. Almost all coal is dispatched to power plants in the Singrauli region from our mines through coal handling plants and merry-go-round system of Rail transportation.

Table 4 (a): Presents Coal Evacuation Infrastructure

Existing Crushing Arrangements

Project	**Crushing Capacity (Mty)**				
	CHPs	Interim CHP/ Feeder Breaker	Mobile Crusher	Surface Miner	Total
Amlohri	10.00	-	-	-	10.00
Bina	4.50	-	3.00	-	7.50
Block-B	3.50	2.50	-	-	6.00
Dudhichua	10.00	-	1.50	1.95	13.45
Jayant	10.00	-	3.00	3.85	16.85
Jhingurdah	3.00	-	1.50	-	4.50
Kakri	3.00	-	-	-	3.00
Khadia	10.00	-	6.00	-	16.00
Krishnashila	-	2.50	-	1.98	4.48
Nigahi	15.00	-	-	-	15.00
Total	**69.00**	**5.00**	**15.00**	**7.78**	**96.78**

Table 4(b) : Under Construction and Planned Crushing Arrangements

<table>
<tr><th rowspan="2">Project</th><th colspan="2">CHPs under construction</th><th colspan="5">Planned Crushing Capacity (Mty) by FY 2025</th></tr>
<tr><th>Capacity</th><th>Timeline</th><th>CHPs</th><th>Timeline</th><th>Mobile Crusher</th><th>Surface Miner</th><th>Total</th></tr>
<tr><td>Amlohri</td><td colspan="2" rowspan="8">Already equipped with CHPs</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Bina</td><td>5.50</td><td>2021-22</td><td>-</td><td>1.95</td><td>7.45</td></tr>
<tr><td>Block-B</td><td>4.50</td><td>2021-22</td><td>-</td><td>-</td><td>4.50</td></tr>
<tr><td>Dudhichua</td><td>10.00</td><td>2020-21</td><td>1.50</td><td>1.95</td><td>13.45</td></tr>
<tr><td>Jayant</td><td>15.00</td><td>2020-21</td><td>-</td><td>-</td><td>15.00</td></tr>
<tr><td>Jhingurdah</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Kakri</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Khadia</td><td>-</td><td>-</td><td>-</td><td>1.95</td><td>1.95</td></tr>
<tr><td>Krishnashila</td><td>4.00</td><td>Dec’19</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Nigahi</td><td colspan="2">Equipped with CHP</td><td>-</td><td>-</td><td>-</td><td>1.95</td><td>1.95</td></tr>
<tr><td>Total</td><td>4.00</td><td></td><td>35.00</td><td></td><td>1.50</td><td></td><td>44.30</td></tr>
</table>

Table 4(c): Existing Loading Wagons/Trucks Arrangements

<table>
<tr><th rowspan="2">Project</th><th colspan="2">Loading facility</th></tr>
<tr><th>Silo/Hopper</th><th>Wharf-wall</th></tr>
<tr><td>Amlohri</td><td>Silo 1 – 3500 T
Silo 2 – 3000 T</td><td>1</td></tr>
<tr><td>Bina</td><td>WL Hopper – 500 T</td><td rowspan="2">1</td></tr>
<tr><td>Krishnashila</td><td>-</td></tr>
<tr><td>Block-B</td><td>Silo – 3000 T
TL Hopper 3x100 T</td><td>1
(Spur Siding)</td></tr>
<tr><td>Dudhichua</td><td>Silo 1 – 4000 T
Silo 2 – 3000 T</td><td>1</td></tr>
<tr><td>Jayant</td><td>Silo 1 – 2400 T
Silo 2 – 3000 T</td><td>1
(Spur Siding)</td></tr>
<tr><td>Jhingurdah</td><td>WL Hopper – 300 T &TL</td><td>1</td></tr>
<tr><td>Kakri</td><td>WL Hopper – 300 T</td><td>1</td></tr>
<tr><td>Khadia</td><td>Silo 1 – 3000 T
Silo 2 – 3000 T</td><td>-</td></tr>
<tr><td>Nigahi</td><td>Silo 1 – 3000 T
Silo 2 – 3000 T</td><td>1</td></tr>
</table>

- WL – Wagon loading, TL – Truck Loading

In compliance of environmental standards and regulatory requirement for efficient coal loading into Rail Wagons, Rapid Loading System (RLS) has been planned and all wharf wall installations will be equipped with RLS by fiscal 2023. The system has computer aided movement, weighment, and discharge into wagons.

Environment Management Plan

Apart from having well laid down guidelines, NCL has laid emphasis on occupational health and safety, Corporate Social Responsibility (CSR) through its community development programs. These efforts have significantly contributed towards improvement and development local population comprising of tribal, non-tribal and project-affected persons. NCL could ensure overall improvement of quality of their life through self-employments schemes, skilling programs, imparting education and providing health care.

In addition to various technological features in its draglines, shovels, other excavating units, it has a systematic reclamation plan in place. The planned development of mines with proper layout, greening, housing colonies, roads, planned backfilling and bio-reclamation has been the highlights of Environment management. The number of trees planted till now has been the highest among all the coal companies in India, and more than 23.3 million trees have been planted. At NCL, all activities and operations are guided by sound environmental practices.
Environment Management Plan includes the following:

- Technical Reclamation – Backfilling and technical reclamation of voids and dumps form an integral part of method of working at NCL.
- Biological Reclamation
- Plantations
- Air Pollution control & Dust Suppression
- Effluent Treatment
- Noise control
- Hazardous waste management

Technical and Biological Reclamation (Fig. 6)

NCL has biologically reclaimed an area (Mined out area + External dump area) of 2708.13 hectares since inception to 31.03.2019. Beside this, social afforestation (Colonies, Roadsides, Blank plain areas etc.) since inception to 31.03.2019 was 2932.56 ha. Thus, total biological reclaimed area by NCL is 5640.69 hectares (Table 5).

Table 5 : Status of biological reclamation by NCL

Plantation Area	Mined out Area (Ha.)	External Dump Area (Ha.)	Plain Areas (Ha.)	Total Area (Ha)
Since Inception	**1313.49**	**1394.64**	**2932.56**	**5640.69**

23.7 millionplant species have been planted by NCL since its inception and NCL has planned for plantation of 0.4 million Plants in fiscal 2019-20. Similarly, Mine Water is used in different mining activities and therefore there is Zero Discharge of Mine Water in NCL.

Figure 6: Technical and biological reclamation at Jayant Mine of NCL.

Ecological restoration of mines (Fig. 7)

The work for eco-restoration has been completed through Forest Research Institute, Dehradun for 2 sites for 5 ha each at Nigahi and Krishnashila Projects. This is one of the endeavors for improving the quality of afforestation through the latest scientific methodology which will create a rich biodiversity with 3 tier plantation, grassing, etc. For this work, NCL was awarded with SKOCH BSE-Order of Merit Award in 2016. At Nigahi about 90% area was flat and remaining 10% was slope. However, at Krishnashila Project, the ratio of flat and slope area was about 1:1. Both of these areas contained about 90% boulders and 10% loose material. The complete restoration work was done in following steps:

- Spreading of topsoil depending on amount and availability at the sites
- Mulching on slopes for conserving and retaining soil moisture
- Identification of suitable grasses, herbs, shrubs, and tree species depending on site condition and objective of the study
- Establishment of plants through application of various means i.e., direct seed sowing, seed mix soil ball, seedling planting, stem cutting, root stock, culm planting etc.
- Digging of pits of size 2x2ft, and plant to plant distance 3m.
- About 5500 pits at Nigahi and 3000 pits at Krishnashila were dug out

Figure 7: Ecological restoration work at Nigahi and Krishnashila mines of NCL.

Air pollution control and dust suppression (Fig.8 to 13)

NCL has well established infrastructural system for air pollution control and dust suppression. Major steps taken in this regard are as follows:

i) Automatic mobile dust sweeping machine has been procured by Block- B project for cleaning dust from coal transport roads regularly.
ii) 4 nos. of Surface Miners have been introduced in 3 projects of NCL. This is an eco-friendly machine which eliminates the blasting and crushing of coal and hence reducing the air and noise pollution.
iii) 45 nos. of fixed Water Sprinklers have been installed on Coal Transportation roads of Krishnashila project.
iv) RO Plants have been installed in about 40 villages around the mines of NCL for supply of potable drinking water.
v) Continuous ambient air quality monitoring stations (CAAQMS) are going to be installed in 9 Projects of NCL.
vi) Replacement of all incandescent lamps and sodium vapor lamps to LED in phase wise.
vii) Study of carbon footprints of all NCL with suggestions/ measure from improvement is going on.
viii) Introduction of Mist spray/Fogging Gun system in all Mines of NCL to control fugitive dust is in process.

Figure 8: Air pollution control measures taken by NCL: (a) Water sprinkler for dust suppression at haul roads, (b) Drill machine with dust extraction system, (c) HEMMs with dust proof cabin

Figure 9: Fully enclosed Coal Handling Plants at NCL: Mist Spray Dust Suppression System at (a) gyratory crusher point, (b) Rapid Loading System of Silo and (c) bird eye view of CHP at NCL

Figure 10: Thick green belt for air pollution control across (a) haul road in mines, (b) railways and MGR sidings and (c) light vehicle roads.

Figure 11: Belt Pipe Conveyor (BPC) installed for coal transportation from Krishnashila Project of NCL to Renusagar (Hindalco) plant (Belt length is 4.31 KM and capacity is 3MTpa)

Water Pollution Control Measures for ensuring long term protection of Water regime

Effluent Treatment Plant (ETP) capacity	271.74 MLD
Silt Arrestor	+5 L CuM
Water harvesting & recharge ponds	+ 15 L CuM
Sewerage treatment plants capacity	17.5MLD
Oil and grease recovery	80% and 20% in Oil/Grease Trap at ETPs
water circulation figures in m^3/day	Generation: 43753 Treatment: 36384 Use/Reuse: 38024 Discharge:1100 (2.5%)

Figure 12: Effluent Treatment plants at NCL for ensuring Zero Mine Effluent Discharge.

Figure 13: Domestic Sewage Treatment plants at NCL.

Carbon footprint of NCL

Siri Energy, Hyderabad, conducted carbon footprint study on behalf of NCL for the year 2017-18 with base year as 2016-17. According to this the main contributors to GHG emissions are electrical power consumption, transmission and distribution losses, use of diesel operated HEMMs and other vehicles, use of LPG in canteens, travel by air, rail and road.

Carbon offsetting is being achieved by energy conservation, improving efficiency in transmission and distribution of electrical power and diesel engines, using green power, extensive use of LED bulbs and lighting, video conferencing, carpooling and extensive use of mass transport vehicles, plantations and changing mind set.

It has been studied that specific emission reduced by 14.6% over the baseline year due to implementation of various energy / environment improvement initiatives taken up by NCL and the total emission reduction for NCL was 126712 Tonnes of CO_2 for 2017-18 compared to 2016-17.

New initiatives for reduction in carbon footprint of NCL

i) Deployment of Surface Miners eliminates the activities like *drilling, blasting and crushing* of the mining cycle. Presently there are four surface miners deployed in NCL, two in Jayant and one each in Dudhichua and Krishnashila. Amlohri, Nigahi, Khadia and Bina are the projects where future deployment has been planned. Mining by Surface Miner is a blast free extraction technique thus eliminating air blast, ground vibration and dust problem caused by drilling and blasting.

Figure14 : Surface Miner under operation at Jayant mine of NCL

ii) Introduction of Surface Miner for Overburden Removal

iii) Mist Spray Systems and Fog Gun and Industrial and Road sweeping machines

iv) Introduction of In-pit Crushing and Conveying technology in NCL

v) Installation of Rooftop solar panels in NCL colonies, solar plant setup at OB dumps and allotted areas for PV power generation

vi) Introduction of new blasting techniques for blasting.

Conclusion

In a World of shifting energy mix from thermal to non-conventional sources of energy, Coal continues to be the major dominating source of power in India. To meet the challenges in coal mining, NCL has developed a full proof system of equipment selection and management along with eco-friendly mining technologies. Management thrust has been for monitoring and controlling the corrective measures to maximize productivity of machineries and minimize the effect of mining operations on air, water, soil etc. Further, we mine with new technologies to ensure reduction in carbon footprint.

This Paper has already been presented in Curtin University, Perth, Australia.

Deep-sea minerals as source of critical metals - Indian and global scenario

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Abstract

As terrestrial mineral resources are getting exhausted, deep-sea minerals such as polymetallic nodules, ferromanganese crusts and hydrothermal sulfides, are emerging as potential sources of metals such as Cu, Ni, Co, Mn, Fe, and other rare earth elements that could be mined in future and contribute towards green energy alternatives. As many of these mineral deposits lie in the international waters in all the oceans of the world, the International Seabed Authority that regulates all activities related to seabed resources has signed exploration contracts with several entities under UN Convention on Law of the Sea (UNCLOS). Mapping of these resources has been underway for several decades using sophisticated sounding, sampling and imaging techniques leading to resource evaluation of these minerals that are found in millions of tones and estimates show that these contain strategic metals worth billions of dollars. Research and development on technology for mining and extraction, as well as environmental studies to develop suitable guidelines for impact assessment and environmental monitoring as well as exploitation of these deposits are underway.

Significantly, India was the first country in the world to have been given the Pioneer Investor status under UNCLOS as early as 1987, and has made significant progress in all components of deep-sea mining, viz. resource evaluation, environmental impact assessment, mining technology development and metallurgical processing of deep-sea minerals. Under the aegis of Ministry of Earth Sciences (Govt. of India), India has signed contracts for two areas in the Indian Ocean, one each for polymetallic nodules and hydrothermal sulfides. Several research organizations including National Institute of Oceanography (NIO, Goa), National Institute of Ocean Technology (NIOT, Chennai), National Centre for Polar and Ocean Research (NCPOR, Goa), Institute of Minerals and Materials Technology (IMMT, Bhubaneswar), National Metallurgy Laboratory (NML, Jamshedpur), Hindustan Zinc Limited (HZL, Udaipur) and others have contributed towards India's efforts towards becoming self-sufficient in this field.

This paper looks at the economic potential, technology development, its environmental issues as well as the future steps for sustainable deep-sea mining, and the status on India as well as world in the field of deep-sea mining. Whereas, different deep-sea minerals are introduced briefly, most of the sections are described on the basis of one particular mineral type that covers the largest areas on the seafloor, viz. polymetallic nodules, and have been studied most extensively.

Paper submitted for International Conference on Sustainable Mining Options ... Way Ahead from 3-5 June 2022, at Nagpur, India. Nagpur.

1. Introduction

Increasing metal and raw-material requirement combined with depleting land-based reserves for critical minerals / metals is the key reason for development of deep-sea minerals in future. For example, the global demand for nickel has risen by 3.2% annually for the last sixty years. On the other hand, the oceans cover much larger area on the surface of the earth and are a store house of untapped mineral resources. It is estimated that present land reserves will last for two decades for metals such as Mn, Cu, Ni, Co and for one decade for Pb, Zn, whereas there is an increase in annual production rate of some of these (from 1.1% for Au to 8.3% for Co) implying higher consumption rates. The metals available from deep-sea minerals can be used for a variety of applications (eg. machines, electric transmission, alloys etc) and also some of these are key metals for high capacity batteries, solar and wind farms to transition to green and renewable energy alternatives from fossil fuel (Sharma, 2022). These will require millions of tons of metals (including Mn, Ni, Cu and Co) that can be derived from deep-seabed. The EU and USGS have identified 27 and 50 CRMs (critical raw materials) for economic and sustainable development, whereas some of these CRMs are controlled by few countries (60% of raw Co comes from Congo - critical for lithium-ion batteries and 80% of refined Co comes from China) (Al Barazi et al, 2018, Hein et al., 2020). So, several countries have embarked upon exploration for deep-sea minerals to become self reliant.

Different minerals can be found in offshore areas right from sand and gravel to placers very near to the coast, phosphorites along the continental shelf, oil and gas on the continental slope and rise that are within the Exclusive Economic Zone of any country; whereas polymetallic nodules occur along the abyssal plains, cobalt rich ferromanganese crusts on the seamounts and hydrothermal (polymetallic) sulfides along the mid-ocean ridges and back-arc regions (Figure 1), the latter three being generally categorized as deep-sea minerals.

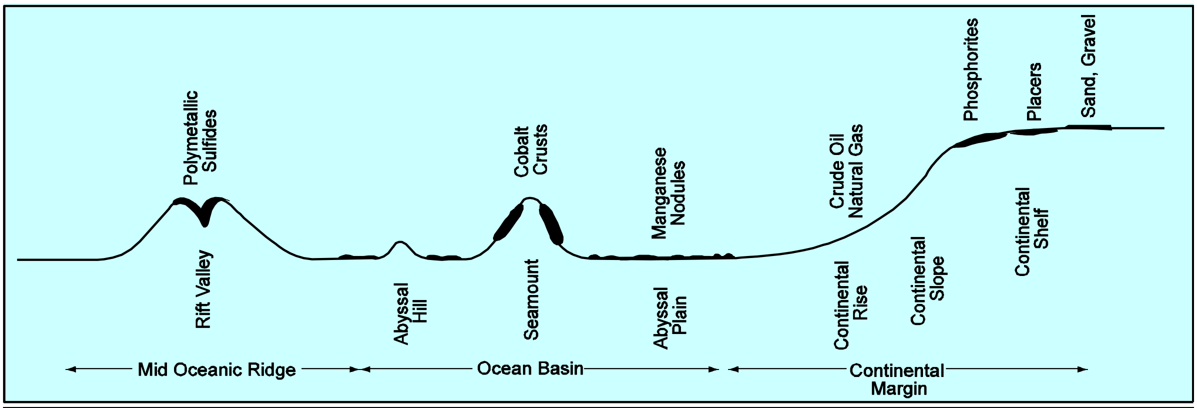

Figure 1. Distribution of offshore minerals along different topographic settings

As most of the deep-sea minerals that occur in the International waters and are considered as 'common heritage of mankind', all activities related to these seabed resources are regulated by the International Seabed Authority (ISA) as per the UN Law of the Sea (www.un.org). Currently, ISA has signed 31contracts for exploration of deep-sea minerals that include 19 for polymetallic nodules, 7 for hydrothermal sulfides and 5 for ferromanganese crusts (Table 1) in the Pacific, Atlantic and Indian Oceans. India has signed two contracts with ISA, one for polymetallic nodules and one for hydrothermal sulfides (Figure 2). The other three contract areas in the Indian Ocean are also for hydrothermal sulfides for Korea, Germany and China. Whereas, NIO has been mainly responsible for exploration and environmental collection of polymetallic nodules, NCPOR is currently responsible for hydrothermal sulfides exploration.

Table 1: Estimated area under exploration contracts (as of May 2021)

Mineral type	**Area (km^2) / contract**	**Total contracts***	**Total area (km^2)**
Nodules	75,000	19	1425000
Sulfides	2500	7	17500
Crusts	1000	5	5000
		31	1447500

- (www.isa.org.jm)

It is important to note that (Sharma, 2022):

- there has been a four fold increase in no. of Contractors from 8 (2001-2010) to 31 (2011-2021)
- a typical nodule area of 75,000 km^2 contains at least 375 MT (wet) or 281.25 MT (dry) nodules (@ 5 kg/m^2 cutoff abundance)
- this can be mined for 187 years (at 1.5 MT/y) or 93.5 years (at 3 MT/y)

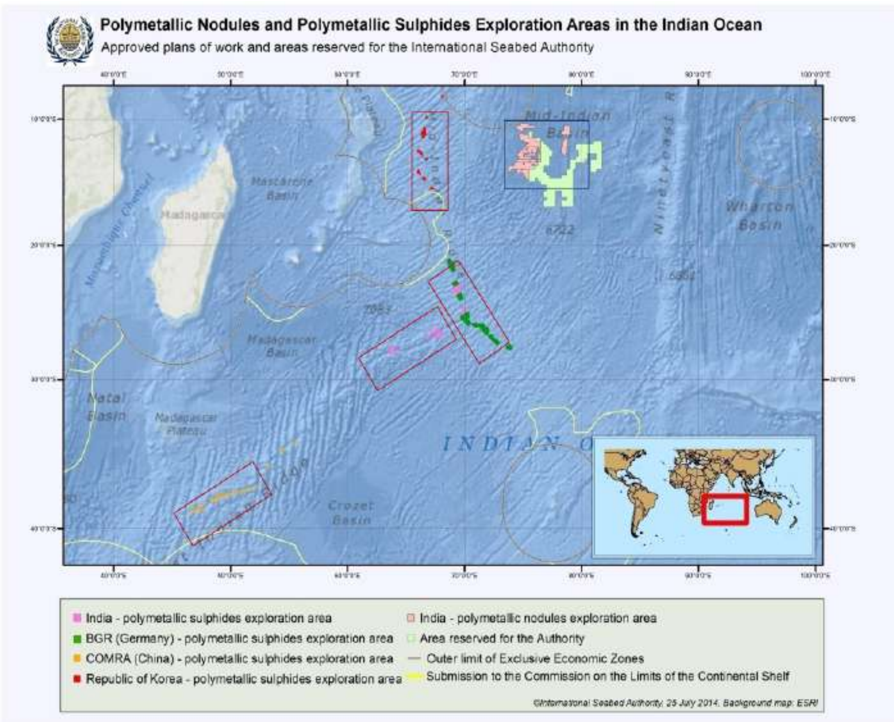

Figure 2. Contract areas for deep-sea minerals in Indian Ocean (www.isa.org.jm)

2. Indian polymetallic nodules campaign

India has been actively involved in various components of deep-sea mineral exploration. The campaign for polymetallic nodules started in 1981 when the first nodule was picked up by the scientists of CSIR-National Institute of Oceanography (NIO, Goa) onboard an Indian Research Vessel Gaveshani from equatorial Indian Ocean, which was followed by extensive surveys (~100 expeditions) for seafloor mapping as well as sample collection (>12000) and underwater photography (~50000 seafloor photographs). The major landmarks have been as follows:

- 1981 : First nodule picked from Equatorial Indian Ocean
- 1982~ : India recognised as Pioneer Investor under UNLOS, exploration programme launched
- 1987~: Pioneer Area allotted (150,000 sq. km.) and exploration continued
- 1994 - 2002 : Phase wise relinquishment and 75,000 sq.km. area retained for finescale surveys
- 2006: Pilot plant for metal extraction established
- 2010 : First generation mine-site identified
- 2013: Test mine-site (TMS) identified
- 2017~: Detailed surveys in TMS
- 2021~: Testing of pre-prototype mining system

The total resource of polymetallic nodules in retained area (75,000 km^2) is estimated to be 382.80 MT (dry) that contains 95.17 MT of manganese, 4.51 MT of nickel, 4.45 MT of copper and 0.42 MT of cobalt, amounting to 104.55 MT of these metals in addition to minor metals and REEs (Source: NIO/PMN data bank).

3. Environmental impact assessment of deep-sea mining

It is envisaged that there could be several impacts of deep-sea mining at different levels, such as the seafloor from where the ore will be collected, the water column through which the ore will be lifted to the mining platform, and at the surface from where the residues will be discharged back (see Figure 3 as an example). Moreover, the areas impacted by different activities of deep-sea mining will include offshore as well as onshore as given in the following sections (Sharma, 2022).

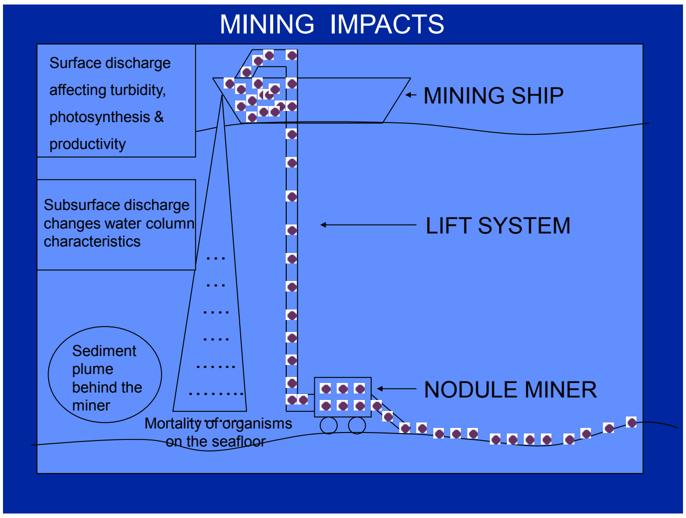

Figure 3. Likely impacts of deep-sea mining on marine environment

3.1 Likely environmental impacts of offshore activities of deep-sea mining

i. Pick up or separation of minerals and the quantity of substrate disturbed on the seafloor due to operation of the miner, crusher, and discharge mechanisms
ii. Suspension of fine particles of minerals and associated sediment into the water column
iii. Resettlement of suspended particles and smothering of seafloor
iv. Impacts due to light and sound during mining operation
v. Oil spills and leakages from mining platform and transport vessels
vi. Ballast water discharge from transport vessels
vii. At-sea processing, dewatering, waste disposal including chemicals, debris
viii. Sub-system losses such as pipes, chains, tools or any other hardware
ix. Human waste such as garbage including plastics, metals, glass and other non-biodegradable items

3.2 Likely environmental impacts of onshore activities of deep-sea mining

i. Pollution during loading / unloading, onland transportation of ore from the port to the processing plant
ii. Pollution during processing (fumes, discharges) around the processing plant
iii. Pollution after processing (dumping of slag or unwanted material) away from the processing plant

3.3 Indian Deep-sea Environment Experiment

In order to understand the extent of potential impacts on deep-sea environment, several countries conducted simulated mining experiments in deep-sea areas using devices such as plow harrow as well as hydraulic suction in different oceans. The Indian Deep-sea Environment Experiment (INDEX) was conducted in 1997 in an area of 200 x 3000 m at water depth of 5400 m in the nodule area of Central Indian Ocean, during which a hydraulic suction device called the 'benthic disturber' was operated 26 times, over a period of 47 hours and a total distance of 88000 m, resuspending 580 tonnes of sediment into the water column (Sharma et al., 2000).

The experiment comprised of collection of environmental data for baseline (1996), pre-mining (1997), post-mining (1997), monitoring of restoration (2001-2005) as well as spatial and temporal variability (2005-2009). The parameters included physical and chemical water column characteristics, sediment thickness, size, mineralogy, shear strength, water content, geochemistry, biochemistry, microbiology, as well as faunal diversity and abundance. Based on the observations, it was concluded that whereas there is an environmental impact immediately after the experiment, the conditions were restored over a period of time and masked by the natural variability in the area.

Several mitigation measures also proposed for restricting the environmental impacts that include minimizing sediment penetration, restricting sediment dispersal to the seafloor, reducing nodule-associated sediment transport to surface, discharge tailings below oxygen minimum zone, treat tailings before discharging and inducing high rate of sedimentation (Sharma, 2017).

4. Technology development for deep-sea mining and mineral processing

Several state sponsored as well as private enterprises are in different stages of developing and testing their mining systems around the world. In 2017, Japan Oil, Gas and Metals Corporation (JOGMEC) successfully excavated seabed ores containing Zn, Au, Cu, Pb from a depth of 1600 m off the coast of Okinawa (Kawano and Furaya, 2022). In 2017, Nautilus Minerals (recently taken over by Deep Sea Mining Finance Limited - https://dsmf.im) announced successful completion of seafloor production tools with an aim to mine the seafloor massive (sulfide) deposits to produce Cu, Au, Ag from 1600 m depth off Papua New Guinea (http://dsmobserver.com). During April-May 2021, Global Sea-mineral Resources NV (GSR, Belgium) deployed a 25 ton deepwater robot on a 5 km long power and 2-way communication cable for collecting nodules (De Bruyne et al, 2022). Korea has developed a pilot mining robot designed to operate at 5000 m depth, and a lifting pump and buffer station were tested with a truncated lifting pipe of 500 m (Hong et al., 2019). China has also carried out a successful nodule collecting test at 500 m depth in South China Sea (https://chinadialogueocean.net).

Similarly in India, the National Institute of Ocean Technology (Chennai) is developing a self propelled tracked mining vehicle that will collect, crush and pump polymetallic nodules through a flexible riser using a single positive displacement pump mounted on the vehicle. An integrated mining system is also being developed by India, of which a pre-prototype nodule collector has been tested at around 500 m water depth with an aim to upgrade it for operation at 6000m (Atmanand and Ramadass, 2017). Similarly, for development of metallurgical extraction process whereas the lab scale work on different routes was initiated in 1993, three routes were chosen in 1987, that included reduction-roasting-ammonia-ammonium carbonate leaching (developed by National Metallurgical Laboratory, Jamshedpur), NH3-SO2 (developed by erstwhile Regional Research Laboratory, now Institute of Minerals and Materials Technology, Bhubaneswar) and Acid pressure leaching (Hindustan Zinc Limited, Udaipur). In 2006, a pilot plant was established also established with 500 kg/day capacity at Hindustan Zinc Limited (Source:NML, RRL, HZL).

5. Techno-economic evaluation

It is estimated that in a typical nodule contract area of 75000 sq km with a cutoff abundance of 5 kg/m2, the total available resource would be 375 MT (wet) or/ 281.25 MT (dry), containing total metal resource of 67.53 MT (@Mn=22%, Ni=1%, Cu=0.78%, Co=0.23%). At the metal prices of 2021, the gross in place value of these four metals would be $ 21.15 billion at the mining rate of 1.5 Mt/y. The CAPEX and OPEX for mining of 1.5 Mt/y for 20 years, including the cost of mining system, ore transfer and processing plant currently works out to $ 14.64 billion, implying that metals worth $ 21.15 billion can be extracted for an investment of $ 14.64 billion from a single nodule operation (Sharma, 2022).

6. Regulations for deep-sea mining

Whereas, the International Seabed Authority is responsible for all activities related to deep-sea resources, including developing environmental guidelines, issuing exploration contracts, as well as developing the mining code, the regulations from other agencies will also be applicable to deep-sea mining depending upon the area of operation (Table 2).

Table 2: Agencies for regulating activities related to deep-sea mining

Agency	Role
International Seabed Authority (For deep-sea mining activities)	Developing guidelines and regulations for all deep-sea mining activities as well as issuing exploration and mining license
International Maritime Organization (For shipping in international area)	Prevention of marine pollution by dumping of wastes and other matter and preservation of marine pollution from ships.
National / Local Government (For territorial waters and on land activities)	Regulate all activities related to ore handling at local ports, transportation, processing and waste disposal

7. Steps towards sustainable mining

In view of the likely requirement of deep-sea minerals as a source of critical metals in future as well as their abundant availability in all oceans of the world as revealed by the exploration data, as well as the interest of several entities in developing the technology for mining them, in addition to the regulations being put in place, it is likely that deep-sea mining would become a reality in the coming decades. In order to make it sustainable it is important to carry out risk assessment studies and incorporating mitigation measures for minimising environmental impacts on deep-sea ecosystems. Evaluation of techno-economic models of different mining systems would help in optimising the required mining rates with respect to metal markets. Further, incorporating measures such as use of renewable resources and a zero-waste approach while recovering the metals would help making deep-sea mining more sustainable.

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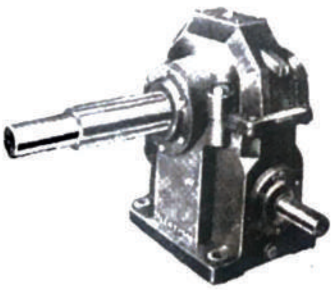

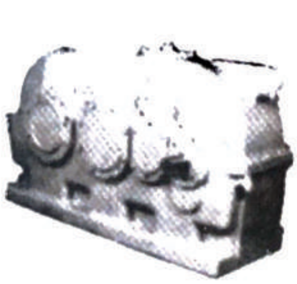

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Coalbed Methane in India – Key Technical Challenges and Possible Solutions

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Abstract

India has an abundance of coal resources. Given the current energy outlook of India indicative of the country's continued reliance on coal as a future energy source, the development, and application of technologies to improve the sustainability of coal mining is imperative. The coal seams of India are largely sub-bituminous and are in the appropriate coal rank window for generation and retention of methane in coal seams. In many situations, only a few coal seams have been mined or proposed to be mined leaving several virgin coal seams below with methane drainage potentials. The process is also aligned with the concepts and principles of sustainable mining to prevent fugitive GHG emissions into the atmosphere due to mining.

As per an estimate of USEPA in 2015, India's coal mine methane (CMM) emissions increased from 1,007 million m3 in 2000 to 1,397 million m3 at the end of 2015. Methane emission from coal mining in India is a matter of concern which is around 1.2 billion m3 annually as per USEPA estimate. Without proper methane mitigation techniques implemented in the future, India's trend of increased methane emissions is expected to continue. It is worth mentioning that India had promised in the 21st Conference of Parties meeting in Paris, in December 2015 to lower emission intensity of GDP (or how much emissions would happen to achieve one unit of GDP) by 33-35 percent from 2005 levels. Therefore, India's requirements for production enhancement are conflicting with its commitment made at the Paris Summit. This triggers the need for a strategy of a balanced approach that can serve both purposes.

In view of this, the application of coal bed methane (CBM) drainage technology in India would contribute to the national goal of increasing domestic natural gas and coal production, while helping the country satisfy its commitments made at the Paris Climate Summit. This paper aims to review the status of CBM in India, the key challenges CBM industry is facing, and proposes the way forward with possible solutions.

Introduction

The depleting conventional natural gas resources across the world as well as the growing energy demand globally has led to increased focus towards the use of unconventional gas sources such as CBM, shale gas and tight gas. The amount of methane available in the major coal basins across the globe has been estimated at 85 - 222 TCM (Kuuskraa, Boyer, & Kelafant, 1992). Table 1 lists the major CBM resources globally.

Table 1: (Global CBM Resources)

Country	CBM Resources (TCM)	
	In-place	Recoverable
Russia	16 - 44	N/A
China	10 - 33	2.0
United States	14 - 49	4.2
Australia	9 - 12	1.7
Canada	16 - 65	4.0
Indonesia	5.9	0.8
Western Europe	3.4	N/A
Southern Africa	2.8	0.6
India	2.5+	0.6
Poland/Czech Republic	2.0	N/A
Turkey	1.4	0.3
Ukrain	1.4	N/A
Kazakhstan	1.1	0.3
Total	**85 - 222**	**14.4**

A recently released report, "Global coal bed methane (CBM) market analysis size and segment forecasts to 2020" suggests that the global coalbed methane (CBM) market is set for substantial gains over the coming years to 2020. The report says that recoverable unconventional sources of gas, including CBM are much larger than the conventional natural gas resources, and this will help drive the industry to become a multi billion-dollar market in the next few years. Key finding from the study suggests:

- Global CBM production was 2,920.3 Bcf in 2013 and is expected to reach 4,667.4 Bcf by 2020, growing at a Compound Annual Growth Rate (CAGR) of 7% from 2014 to 2020.
- Power generation and industrial applications dominated CBM usage, accounting for over 64% of global volumes in 2013, with the former expected to be the fastest growing CBM market, at an estimated CAGR of 8.5% from 2014 to 2020.
- U.S., Canada and Australia are the largest CBM producers, accounting for over 70% of global volume in 2013. U.S. CBM market revenues were estimated at USD 7.22 billion in 2013 and are expected to grow at a CAGR of 5.4% from 2014 to 2020.
- Asia Pacific is expected to be the most dynamic regional market, with significant unexplored reserves. China, India and Indonesia are expected to lead the Asian CBM industry.

In light of the expected growth in CBM industry in near future, it becomes important to gather key learnings from the existing commercial CBM projects, understand the reservoir parameters that impact the development of CBM reservoirs and utilize the key learnings for the future development of CBM projects.

CBM Resources – Indian Scenario

In Indian context, CBM resources in coal seams at a depth more than 600 meters where no mining activity is proposed for next 20 – 25 years is listed in Table 2.

Table 2: (CBM Resource of India)

S. No.	State	Prognosticated CBM Resource (BCM)
1	Jharkhand	722.2
2	Rajasthan	359.7
3	Gujarat	351.2
4	Odisha	243.6
5	Chhattisgarh	240.7
6	Madhya Pradesh	218.1
7	West Bengal	218.1
8	Tamil Nadu	104.8
9	Telangana & Andhra Pradesh	99.1
10	Maharashtra	34.0
11	North East	8.5
Total CBM Resource (BCM)		**2599.8**

(Source: Directorate General of Hydrocarbons (DGH), MoP&NG, GOI)

Govt. of India has allocated a number of CBM blocks in various coalfields to various govt. and private sector entities such as ONGC, IOC, Reliance Industries, Essar etc. for extraction of CBM resources. Most of them are still exploring the resource with limited success. The exploration and appraisal activities in these allocated blocks have led to establish 280.4 BCM of the total prognosticated resources as Gas-in-Place (GIP). Table 3 lists the details of established GIP in the existing CBM blocks.

Table 3: Existing CBM Blocks and Gas-in-Place

S. No.	Block Name	State	Operator	Area (Sq.km.)	Gas-in-Place (BCM)
1	RG(E)-CBM-2001/1	West Bengal	EOGEPL	500	60.9
2	BK-CBM-2001/1	Jharkhand	ONGC	95	30.2
3	NK-CBM-2001/1	Jharkhand	ONGC	340	9.5
4	SP(E)-CBM-2001/1	Madhya Pradesh	RIL	495	47.9
5	SP(W)-CBM-2001/1	Madhya Pradesh	RIL	500	55.5
6	Raniganj North	West Bengal	ONGC	350	7.4
7	Jharia	Jharkhand	ONGC	85	14.6
8	Raniganj South	West Bengal	GEECL	210	54.4
Total				**2575**	**280.4**

(Source: Directorate General of Hydrocarbons (DGH), MoP&NG, GOI)

CBM Reservoir – An Introduction

Coal deposits are naturally fractured reservoirs with two set of cleats – Face Cleat and Butt Cleat. The face cleat is the dominant fracture set composed of parallel extensive fractures. Butt cleats are also parallel set of fractures oriented perpendicular to the face cleats. Both sets of cleats are normally perpendicular to the bedding plane.

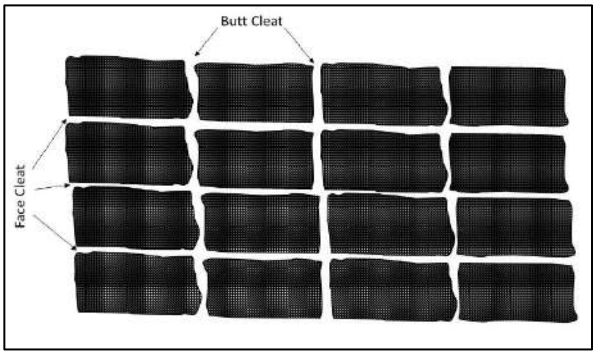

Figure 1 – Coal Structure and Cleat System

Coalbed methane (CBM) is mainly stored as adsorbed gas within coal matrix. The cleats are initially water saturated. Desorption of gas takes place as and when reservoir pressure depletes below desorption pressure. The desorbed gas diffuses through the coal matrix to the coal's natural fracture system, known as cleats. The adsorption capacity of coal is described by Langmuir parameters (Langmuir, 1916). The Langmuir volume VL represents the monolayer adsorption capacity of the coal. It is a characteristic of the coal and often correlates with Vitrinite reflectance and coal rank, which in turn correlates against depth. The Langmuir Pressure (PL) is mathematically the pressure at half the Langmuir volume, and may give some information about the heterogeneity of the pores. Figure 2 illustrates the relationship between the Langmuir isotherm, saturation and gas content.

At any pressure, maximum gas content coal can hold is given by

$$[GC]_{max} = \frac{V_L P}{P_L + P}$$

If coal contains the amount of adsorbed gas which it can at that pressure, it is saturated. If coal contains less than the amount of adsorbed gas which it can hold at that pressure, it is under-saturated. The more under-saturated coal is, the more dewatering is required before any considerable gas production is observed in a CBM well.

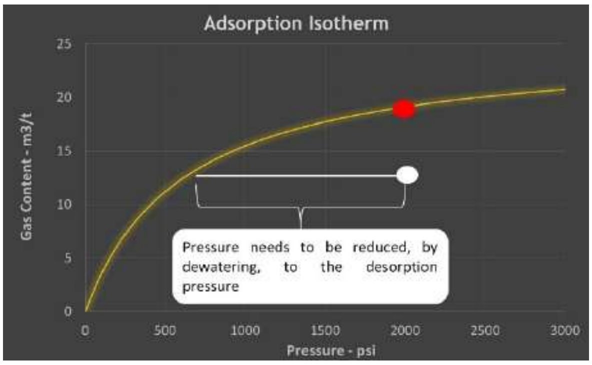

Figure 2 – Gas Adsorption Capacity of Coal

The above figure shows that, for a CBM well, the production of gas starts when the reservoir pressure depletes below desorption pressure. The depletion of reservoir pressure is achieved through a process of dewatering the coal seam. Typically, there are three stages of production in a CBM well – Dewatering phase, Stabilized gas production phase, and decline phase. Figure 3 illustrates a typical CBM production profile.

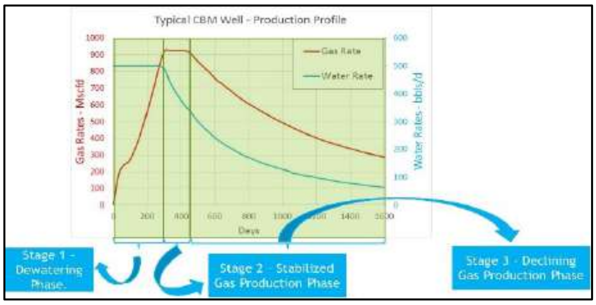

Figure 3: Typical CBM Well Production Profile – Values in the plot are only illustrative

The reason for the production profile lies with the gas storage and fluid flow mechanism within coal reservoir. Stage 1 represents dewatering phase when reservoir pressure is depleted by producing water present in the cleats. When reservoir pressure reaches desorption pressure, gas saturation starts building up in the areas far from well bore and it establishes Stage 2 of the production life. Finally stage 3 is seen when reservoir pressure depletes considerably, and gas saturation develops in entire reservoir with no further scope for increase in gas saturation within reservoir. Figure 4 illustrates the stages of production as explained:

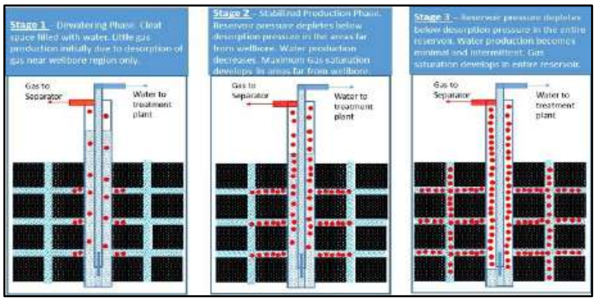

Figure 4: Stages of production in a CBM well

Coalbed reservoirs are unusual; their properties and behavior vary significantly on both regional and local scales. Unlike conventional reservoirs, CBM projects have to deal with additional risk and uncertainties both on subsurface and surface front. The mitigation of the risks with strategic planning and reduction of the key uncertainties with continuous data acquisition as the project matures is the key to success in a CBM project.

Critical Success Factors

The producibility of coalbed Methane is highly dependent upon tectonic/structural setting, depositional systems and coal distribution, coal rank, gas content, permeability, and hydrodynamics (Figure 5)

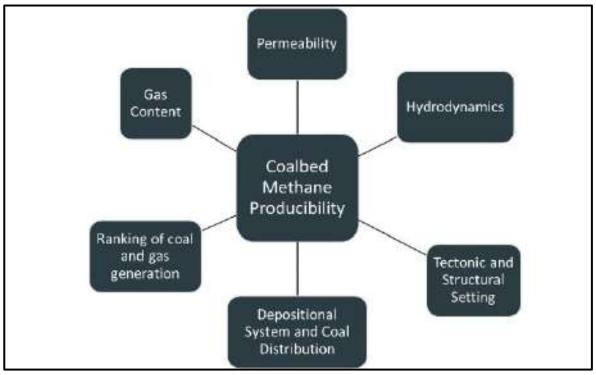

Figure 5: Coal Producibility Model and critical controlling parameters

Key Challenges and possible solutions

The development of CBM in India is reliant upon overcoming the subsurface and operational challenges associated with the project. Maximizing CBM recovery requires proper understanding of storage and flow mechanism within coal reservoir to deal with the unique challenges and characteristics of coal. Although different CBM field may have their unique challenges and limitations, the key challenges can be classified under five broad categories – 1) Exploration & Planning challenges, 2) Reservoir Evaluation challenges, 3) Drilling & Completion Challenges, 4) Production challenges and 5) Environmental challenges.

To deal with the challenges as above, right approach and technical solutions are required. All of this comes at a cost, impacting CBM economics.

Table 2 outlines the summary in the wake of the existing challenges and knowledge gap CBM industry is facing. Figure 6 to Figure 10 describe major CBM challenges and possible solutions in detail.

Summary and Conclusions

Coalbed reservoirs are unusual; their properties and behavior vary significantly on both regional and local scales. Unlike conventional reservoirs, CBM projects have to deal with additional risk and uncertainties both on subsurface and surface front. The mitigation of the risks with strategic planning and reduction of the key uncertainties with continuous data acquisition as the project matures is the key to success in a CBM project.

Table 4: Major CBM activities, key challenges and problems

Major CBM Activities at different stages of CBM reservoir life	Key Challenges	Key Performance Indicators	Major Issues and Existing Gaps in CBM Industry
Exploration	• Resource Estimation:- Quantification of original-gas-in-place (OGIP) and defining the resource category is critical for decisions on next steps. • Identification of fairway:- To identify where right combination of coal reservoir properties- gas content, permeability and coal thickness – is existing. This is critical to spot the best locations for drilling development wells. • Data analysis and integration:- Proper analysis of the available geological, geophysical, petrophysical, reservoir and production data & subsequent integration of these data to correctly characterize the coal reservoir is critical.	• Coal Quality and Maturity • Measured Gas Content of coal • Adsorption Capacity of coal and shape of Adsorption Isotherm • Coal permeability and porosity • Regional trend of the reservoir parameters	• Majority of CBM projects of India are in early stages of exploration and production. Therefore, lack of exposure and learning curve with fully developed projects for CBM operators of India • Lack of experts equipped with knowledge and experience required for strategic development of CBM projects.
Reservoir Evaluation	• Reservoir characterization, simulation and modelling • Stress dependent reservoir parameters - Reservoir permeability, being stress dependent parameter in CBM reservoirs, changes with pressure depletion.	• Performance of Pilot wells • Peak gas rate and time to peak gas • Length of dewatering time period	• Lack of experts equipped with knowledge and experience with implementing full CBM workflow of integrating geological, geophysical, petrophysical, reservoir and production data from CBM perspective • Knowledge gaps in understanding the impact of reservoir geomechanics in the performance of CBM

	• Fracture network modelling - Mapping of fracture network to increase reservoir productivity and reduce completion costs by optimizing well placements and fracturing programs. • Reduction of uncertainties and mitigation of risk	• Regional variation of reservoir properties and compartmentalization.	wells • Knowledge gaps related to CBM specific reservoir simulation and modelling at full filed scale.
Drilling and Completion	• Integrated drilling with reservoir understanding • Implementation of successful hydraulic fracturing for well stimulation: - problems due to extension of fracs into overlying/underlying water bearing formation, early proppant screen out, Micro-seismicity induced by pressurized fluid injections etc. • Implementation of Horizontal drilling to maximize reservoir exposure in CBM wells with marginal permeability. • Selection of drilling fluids:- air, air-mist, foam, air-foam or produced formation water. • Well integrity and formation damage:- selection of completion technology critical. Intelligent completion architectures are necessary for efficient drainage of complex reservoirs. • Low fracture gradients of coal. designing cementation operation is challenging	• Core analysis • Geomechanical Parameters • In-situ stress conditions	• Lack of specialized technical skills and mindset relevant to unconventional reservoirs to deal with CBM drilling and completion challenges • Knowledge gaps in understanding the impact of reservoir geomechanics in the drilling and completion of CBM wells (Deviated wells, Horizontal wells, Multi-lateral wells etc.)

Production	• Field optimization:- A proper or smart reservoir management has to deal with downhole monitoring and data acquisition system, management of large and continuous stream of data, and identification of value adding opportunities in CBM perspective. • Avoiding and reversing formation damage:- Timely identification of the reason for any production decline and reversal of production decline by removing wellbore damage is challenging. • Selection of right production enhancement technique:- Cavitation, Underreaming and Hydraulic Fracture stimulation • CBM well shut-downs for extended period:- If a CBM well is shut down for an extended period after it has started producing gas, the water in the coal will collect at the wellbore, requiring a repeat of the long de-watering process.	• Productivity Index (PI) of CBM wells • Trend of pressure depletion in CBM reservoir • Early stage Permeability reduction due to increase in effective stress with pressure depletion • Late stage permeability enhancement due to the phenomenon of coal matrix shrinkage driven by gas desorption	• Knowledge gaps in understanding the impact of reservoir geomechanics on the performance of CBM wells • Lack of understanding on how to quantify geomechanical parameters using pilot well production data • Lack of knowledge on how to conceptualize a coal permeability model and develop a stress-strain based model suitable for a particular CBM field to predict the change in permeability with pressure depletion
Environmental Aspects	• Disposal of produced water and water management. Once removed, water must be disposed of properly, used for a beneficial purpose, or reinjected into a compatible subsurface formation to ensure that there is no negative impact on the environment. • Management of fracturing fluids. Fracturing	• Water salinity of formation water and produced water • Quality of produced water • Quality of fracturing fluid	• A controlled fracturing operation is imperative to ensure that the fracture growth doesn't extend into the overlying or underlying water bearing formations leading to the water formations being polluted due to the chemical substances of fracturing fluid. The containment of fracture into the zone of interest is reliant upon the thorough understanding and

	fluids used in the production process must also be carefully managed to ensure their environmental impact is reduced.		knowledge of geomechanics accompanied with a mature operational experience with CBM fracturing. CBM operators face difficulties on this front. • In other parts of the world, there are an increasing number of public objections due to the possible seismicity induced by hydraulic fracturing

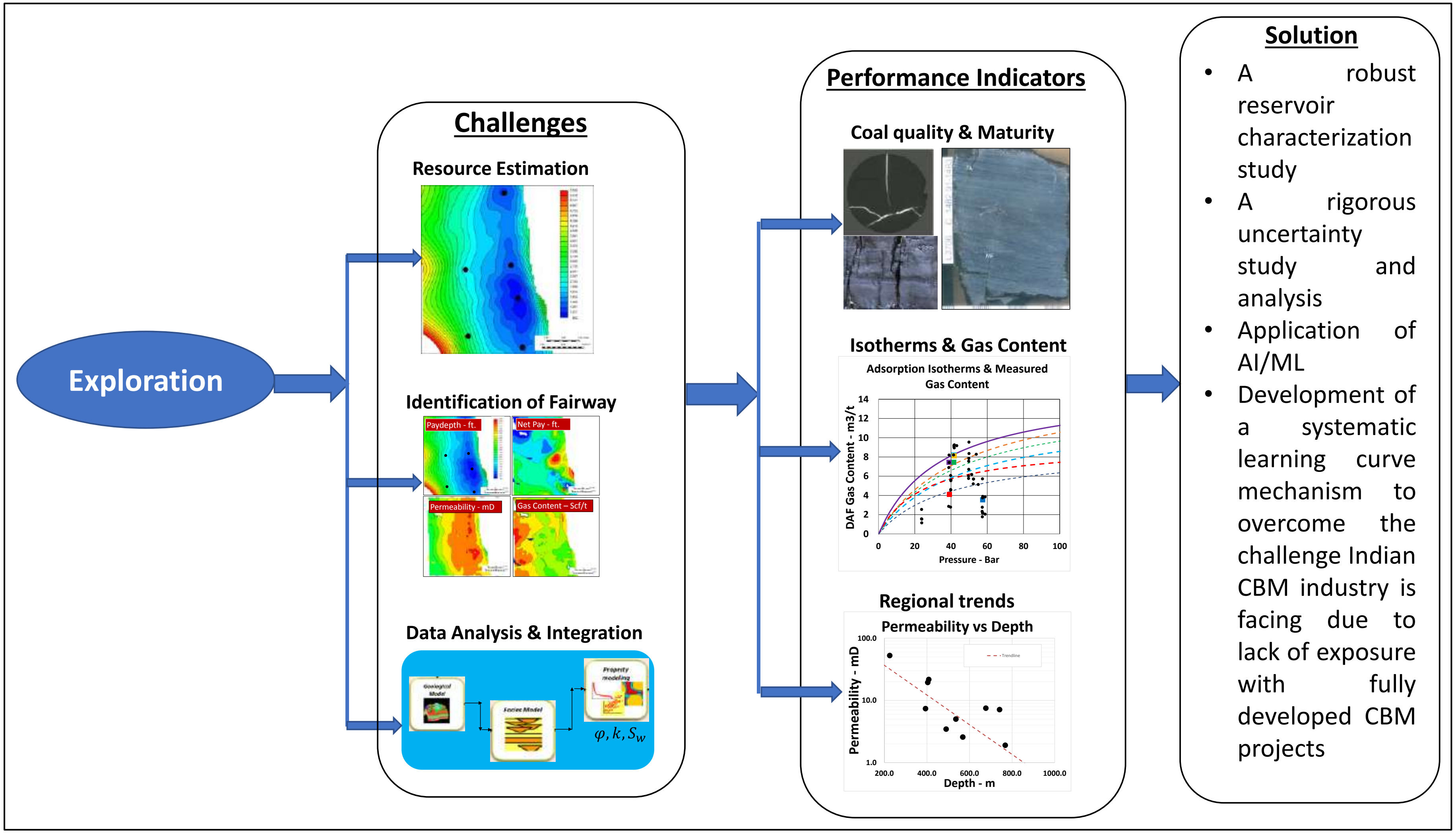

Figure 5: Major Exploration Challenges and possible solutions

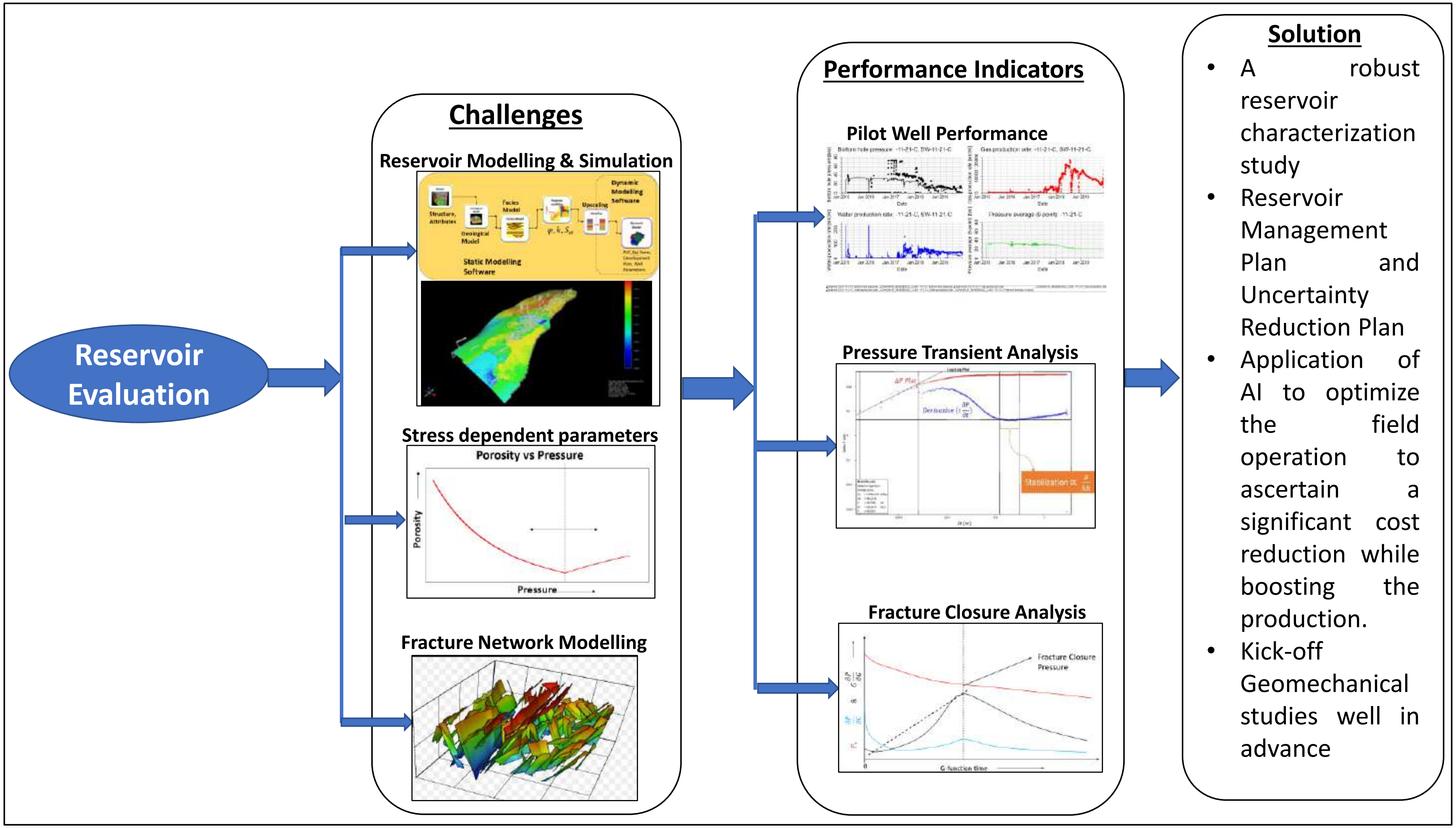

Figure 6: Major Reservoir Evaluation Challenges and possible solutions

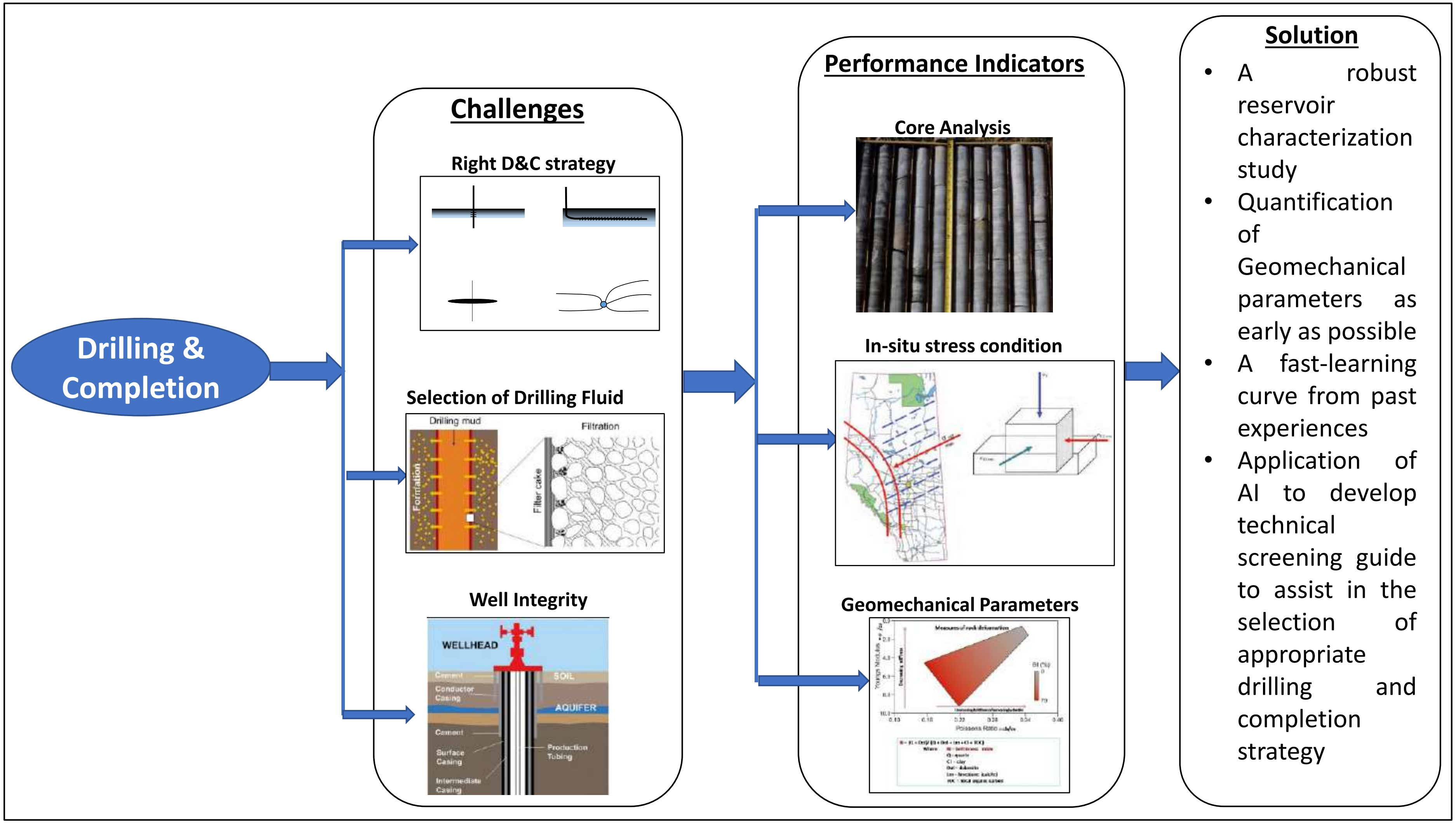

Figure 7: Major D&C Challenges and possible solutions

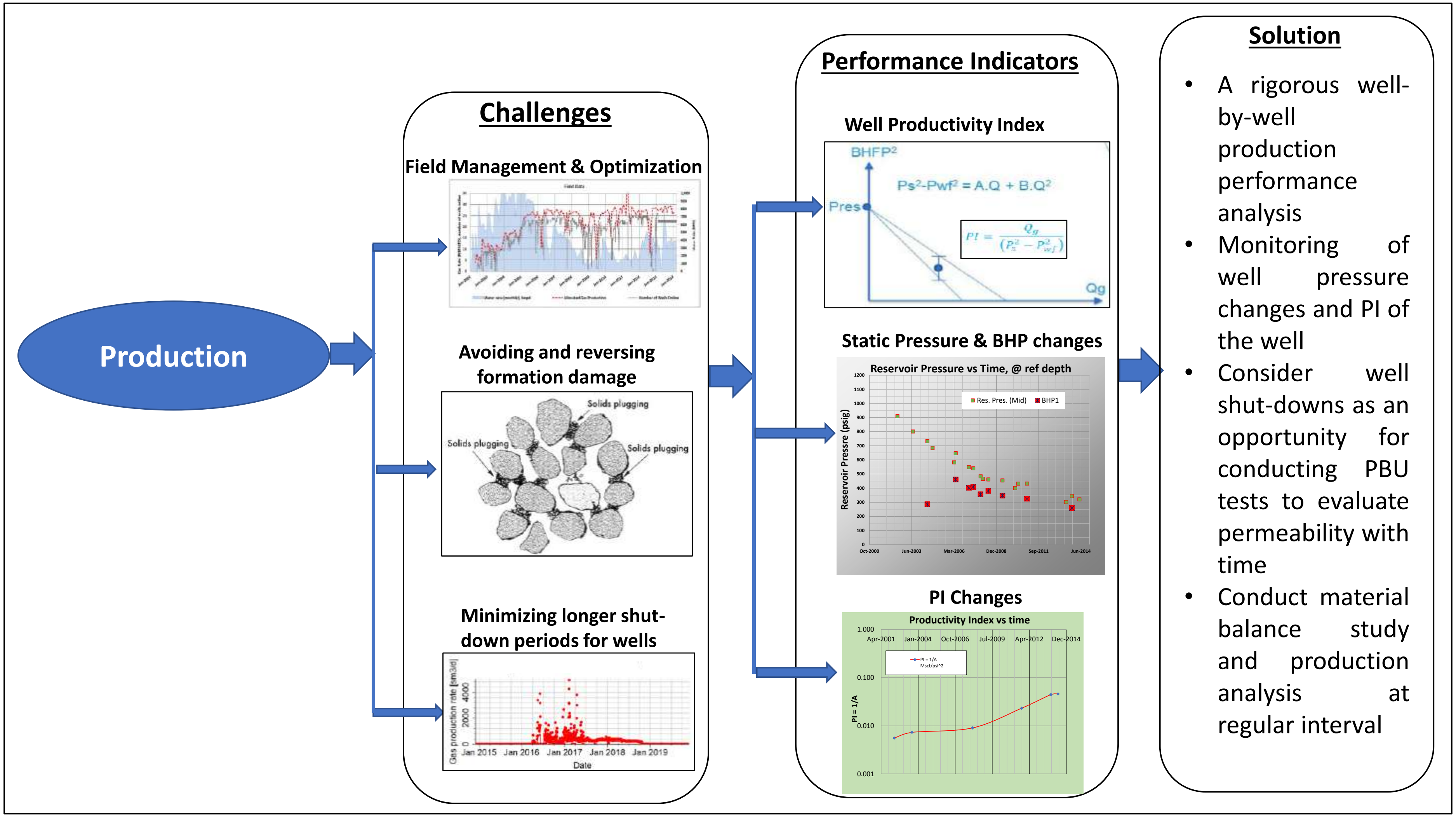

Figure 8: Major Production Challenges and possible solutions

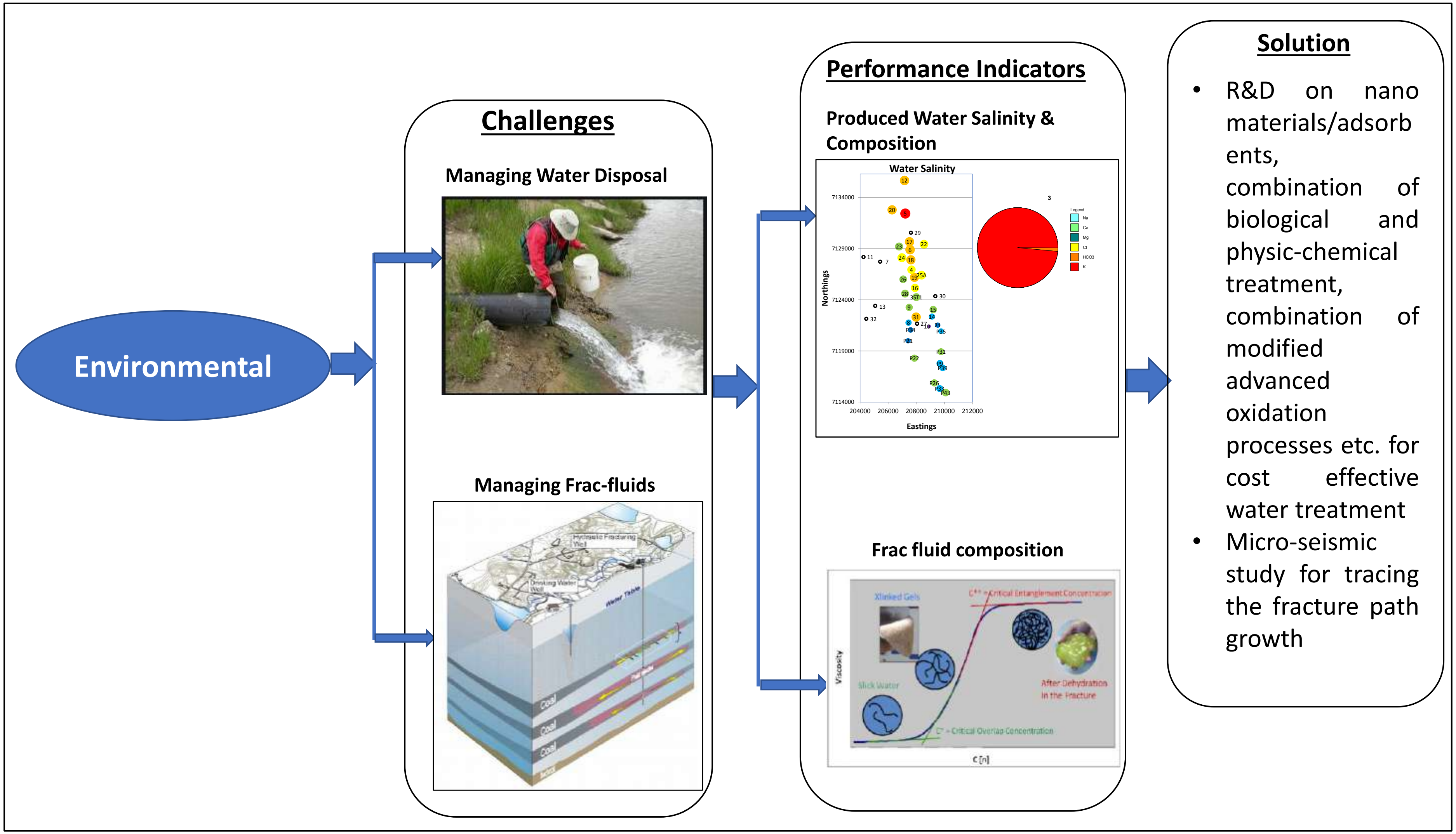

Figure 9: Major Environmental Challenges and Possible Solution

Conflict of Interest

The authors declare that there is no conflict of interest in the publishing of this paper.

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Implementing Mining 4.0 through Cyber Physical Systems (CPS)

India is heavily dependent on coal based power for its electricity needs with Coal's contribution to electricity generation is 70%. Coal continues to be the largest domestic source of energy supply and electricity generation. Demand is increasing and there is a need to bridge the demand-supply gap by adoption of frontier technologies.

The Future of Mining has to be smarter, faster, safer, and more data-driven than ever. There is an urgent need to develop CPS based innovative technologies in mining industry to bring a step change in productivity, safety, and sustainability in mining.

There is an urgent need for transformation in the mining sector. There are a number of drivers of modernization in the mining sector. In order to remain competitive and meet the increasing demand, the mining companies are required to increase the efficiency of deposit discovery; strengthen their mineral recovery rates; improve the productivity of their assets; reduce their operational risks; recover metals and minerals of higher quality; and drive their own growth.

The mining industry has typically lagged behind other industrial sectors when it comes to the adoption of digital technologies such as AI/ML, sensors, IoT, Block Chain etc. Large amount of data generated across the mining processes need to be captured and leveraged on close to real-time basis to predict accurately about the variability in the mining processes to bring consistency in operation. Complex mining tasks such as geological modelling and mine planning, production planning and scheduling, equipment maintenance and spare parts management, and continuous monitoring and capturing of operation data can now be brought under the domain of statistical and optimization algorithms of CPS technologies.

There is growing consensus in the Indian mining industry that the application of technology and innovations is going to bring a step change in productivity, safety, and sustainability in mining. Results and initial estimates have shown that the use advanced digital technology solutions in mining processes have resulted into productivity gain up to 15 - 20% with enhanced safety and sustainability.

The scope of Digital Mining Technologies are :

AI and ML: Use of AI and ML in Discovery of Mineral Resources and decision-making process in mines.

Augmented Reality: Integrating information from digital system to physical workplace. A real-time problem-solving system such that problems and solutions can be shared and visualized in real-time.

Virtual Reality: Hardware and Software based simulation and training on real-life mining situations such as simulating mine fire, roof failure, dump slope etc., Operation and maintenance practices for Heavy Earth Moving Machines etc.

Smart Sensors and Miner's Tracking Systems: Development of wearable sensors and underground positioning systems (UPS) akin to GPS systems.

Smart and Intelligent Sensing System: Heavy Earth Moving Machineries (HEMM) Real-time condition monitoring & health prediction to improve Overall Equipment Efficiency (OEE), Intelligent personal assistance system for miners for interfacing with machines, computers/PDAs and other information system. At present RFID based systems are in place for communicating with smartphones and other personal devices for reporting purposes.

Robotic Miners System: Robotic based systems and their integration for performing hazardous and repetitive operations in mines such as drilling robots, rescue robots, robotic Loading and Hauling machines, Robotic roof bolters and dressers etc.

Enterprise based Decision Support Systems: Introduction of robust underground hybrid communication system (WIFI/TTE/5G) for interaction between the miners in operations and decision makers with IoT in place.

Mine Data Analytics: Use of Big Data and other related tools for useful information discovery and prediction of various unforeseen events in mines such as prediction of roof fall, dump failure, unsafe mine environment etc.

The mining industry's contribution (excluding petroleum and natural gas) to India's GDP is 1.63% (2018-2019), a sharp contrast to India's true potential, being a geologically rich country. This against the backdrop of the fact that eight core sectors of the Indian economy – coal, fertiliser, electricity, steel and cement – were dependent on mining. A significantly higher contribution to GDP will go a long way in achieving India's dream of becoming a USD 5 trillion economy, as evinced across economies like South Africa where mining contributed 7.5% to GDP, and Australia where it is 6.99% to GDP.

Barriers of the Technology Adoption

(i) Disrupting existing value chains: New technologies may disrupt established value chains.
(ii) New safety challenges: Rapid integration of new technologies may create hazards for workers not accustomed to working with them (e.g., failure rates of new technology, reliability, interoperability and connectivity issues in mine environments).
(iii) Managing labour transitions: Challenges of striking the balance between managing the transition toward a smaller workforce and filling labour gaps without losing the sector's licence to operate in communities that depend on mining jobs.

(iv) High upfront costs: Upfront costs of some technologies may hinder adoption until the sector can develop a better understanding of new financing models for high-tech applications.
(v) Standard, costs and regulations: Interoperability is a key issue in mining applications
(vi) Disrupting existing value chain: Local communities can react by strongly objecting to project development

The top four technologies are not surprising: they are (i) robotics and automation (over 50 per cent expected); (ii) the use of unmanned vehicles and drones; (iii) the use of wearable and other connected items; and (iv) remote operating centres, necessary to control all of the three other technologies. Taken together, those are sufficient to reshape the organizational and operational structures within the mining industry and the relationship it will have with its employees, suppliers, local communities and host governments.

By deploying best practices in mine planning, scheduling and process improvements, mines will reap direct and indirect cost savings, and become more productive, predictable and profitable. Each mine is different, but key to deploying best practices is the use of a modern integrated mine planning and Scheduling solution that can keep pace with the incoming mine data, ensure accuracy, accelerate mine modelling and plan output, facilitate information sharing, enable the mining of complex geographic areas, and free up valuable human resources to focus on continual improvement and operational excellence.

As the mining industry moves toward complete integration of production systems, planning and production process will be integrated seamlessly. Technologies for integrated mine planning, scheduling and production process will be developed to cater to the variabilities of mining operations. Optimization algorithms will account for uncertainty in all parts of the production process, from variability in geo-metallurgical properties to reliability and availability of fixed and mobile plant to fluctuations and trends in costs. TIH will make use of industry standard technologies of mine planning and operation and develop over them an integrated solution using CPS technologies.

Artificial intelligence and knowledge based expert systems can be utilized for planning of mining operations. Approach to planning of mines involves property selection, site characteristics, equipment analysis, and mine parameters. Traditionally, the time and resources required to continually collect this data, model and remodel scenarios, build and adjust mine plans, and plan out the effects on scheduling, has meant that no one could keep pace with the reality of what's happening in the ground. Even the best mine plans were still full of inaccuracies and best guesses based on past experience, not quantifiable data. This resulting gap between a mine plan and reality is where costly surprises creep in to negatively affect production schedules, output, and ultimately, mine profitability.

The following aspects of Mineral industries require a special attention:

a. Sustainable Mining Practices: Environmentally friendly mining activities

Reducing water and energy consumption, minimizing land disturbance and waste production, preventing soil, water, and air pollution at mine sites, and conducting successful mine closure and reclamation activities

1. Mining from tailings: Development of Advanced Technologies for Mineral Processing of uneconomic grade of ore– Electrowinning process for obtaining copper, use of cyanide in gold extraction etc.
2. Dust suppression techniques:
3. Zero Discharge Water: Innovative water conservation practices with an aim to bring the ratio of wastewater disposed of to water recovered to zero. Rain water harvesting structures for use of rain water and augmentation of ground water table
4. Energy: Reducing energy consumption at mine site.
5. Land disruption: reducing the overall footprint of the mining area, minimizing the amount of waste produced and stored, maintaining biodiversity by transplanting.
6. Mine Waste: Waste Management Plans.
7. Mine site reclamation and closure activities: aim to restore land disturbed by mining activities to an acceptable state for re-use by people or ecosystems.

b. Scientific Mining: adoption and continuous development of technology to ensure the efficient use of the resources. There are many examples of non-sustainable mining practices such as extracting only the highest-grade material in a deposit, ignoring the lower grades, for short-term gains.

c. Adoption of Advanced Technologies:

A summary of possible innovations in mining are listed below:

Exploration

- Identifying minerals, chemical compositions, and physical properties directly in the field
- Detecting deep concealed mineral deposits
- Exploration and extraction strategy for REE and PGE
- Modelling mineral deposits, their potential economic assets, and challenges right from the earliest stages of exploration

Smart and Efficient Mining

- Selective Mining using Automation & Robotics
- AR and VR based Mine Planning and Operational Processes
- Real-time monitoring of the flow of rock and ore through the mine and processing plant
- Asset Management System
- Operational Efficiency

Safe Mining

- Improved underground communication
- Risk Assessment and Safety Management System
- Ground Control Management System for Deep Mine/Slope Stability

- Increasingly sophisticated means of ore transportation
- Emergency response measures developed for the harshest conditions

Eco-friendly Mining

- Air-borne based Mine Surveillances and Earthworks Estimation
- Spatial Visualization using AR, VR and LIDAR Technologies
- Mining Area LRM: BIS and LIS integration through GIS
- Solutions to deal with acid mine drainage
- Solutions to transform mine tailings into beneficial products

SUSTAINABLE DEVELOPMENT FOR GROUND SUPPORT SOLUTION WITH ALTERNATIVE FILL MATERIAL FOR HYDRAULIC STOWING IN UNDERGROUND NON COAL & COAL MINES IN INDIA

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Abstract:
Sustainable mining practices have developed solutions for conversion of mining method from opencast to underground in non-coal mines and underground to opencast in coal mines. In non-coal mines, MOIL Limited is operating 7 underground and 4 opencast mines in central India and producing annually more than 1.3 million tonnes of various grades of manganese ore. The underground mines are operating at shallow - 120 m at Munsar mine to moderate - 453 m at Balaghat mine below the surface with horizontal cut and fill (HCF) or its variant method of stoping with post filling by hydraulic sand/other fill materials stowing. The case study is conducted at Munsar mine of MOIL, which is being worked underground since 1903. The open cast mining is presently stopped. The ore body below the opencast quarry is geological continuity of the area excavated in past by opencast method of mining. The underground mining is done through the adit in three levels i.e. 270'L, 220'L, 170'L and by incline in western part of the property at 70'L. The horizontal drift development has been developed in the manganese ore body with sill drive of 5 m above the sill pillar in lower level at 70'L and barrier pillar of 5 m thickness is left for protection of upper level at 170'L. Valuable mineral has been locked in sill pillar and therefore rock mechanics investigations have been carried out. On the basis of study now the drift development has been carried out in footwall rock at 70'L, (-) 30'L and below levels and it has improved the minable manganese ore by about 20%. In this modified HCF stope design, an alternative fill material in place of sand, which has been developed in house by use of overburden (OB) material after heat treatment, has been used for hydraulic stowing and the company received its 1st patent after inception on 10/05/2021 on "A composition useful as an alternative filling material for hydraulic stowing in an underground mine and the methods thereof" from 31st March 2018 for a period of 20 years from the patent office, Government of India. The trials find out that the alternative fill material of OB is more compact and forms a non-expansion floor for the men and machines in the stope. This will certainly help for introduction of underground mobile mining equipment for drilling in the stopes and mechanical mucking, transportation and loading of the ROM. Moreover, Sunflag Iron & Steel Co. Ltd (SISCO) has also proposed to conduct the paste filling with fly ash & bottom ash with binders on experimental basis for excavation of coal at Belgaon underground coal mine. The paper presents rock mechanics investigations for development of app and future use of alternative fill material of overburden / fly ash and bottom ash for paste filling in underground mines of the country.

Keywords: Cable Bolting, Fly Ash, Heat Treatment, Overburden, RMR

1. INTRODUCTION

The case study has been conducted at Munsar Mine of MOIL Limited. The mine is located in Munsar town in Ramtek tehsil of Nagpur district in the Maharashtra state.The geological formations of the area belong to munsar formation of sausar group. The sausar fold belt is an important Mesoproterozoic (~1300 Ma age of Sausar Group) mobile belt in the Central India Peninsular Shield. Sausar belt extends for a length of over 215 km from Ramakona to Paraswada (Baihar) with an average width of 35 km and covers an area of about 7000 km² in the state of Maharashtra and Madhya Pradesh. It is an arcuate fold belt trending ENE-WSW with convexity to the south (Ramakrishna M and Vaidyanandhan, 2010). The lease area is undulating with highest level of 90 m towards north-west, and a general ground level of 315 m MSL towards south and east. The hillock is having almost NW-SE trend. At present, the manganese ore is being produced from the underground sections of 70’L, (-) 30’L and below levels (-) 130’L, (-) 230’L and (-) 330’L are under development stage. The level interval is 30 m. These levels are now attached with vertical shaft sunk at Ch. 2600. Horizontal cut and fill method of stoping with post filling by hydraulic sand stowing is being practiced. The lease plan of the mine is appended in Figure 1.

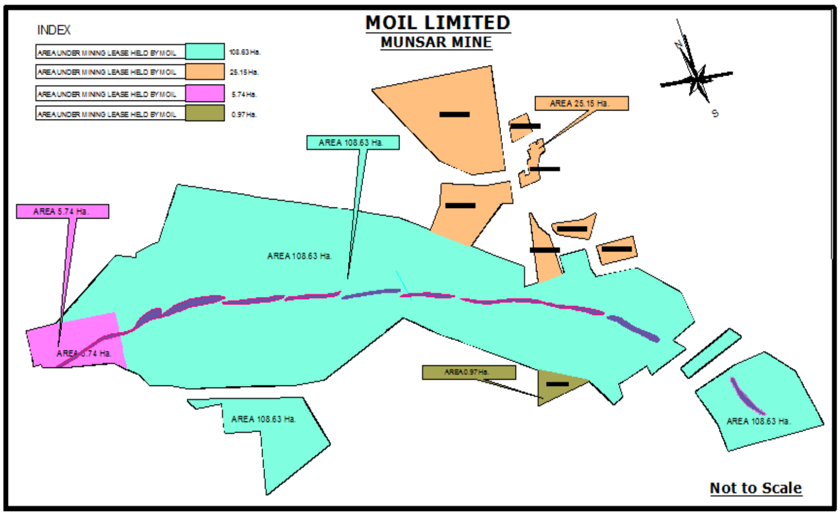

Fig.1: Lease Plan of Munsar Mine

The opencast working was carried out in the eastern part of the property from surface 366 mRL to 309 mRL. The opencast working has been stopped since the year 1980. For the underground excavations, upper levels 270’L, 220’L and 170’L have been accessed by adit in the western part and central part of the property. Thereafter to access the 70’L incline has been developed in the western part. During the development of incline continuous fall of back and side walls of rock has been noticed and therefore incline was terminated at 70’L. Longitudinal section of present mine working is mentioned in Figure 2.

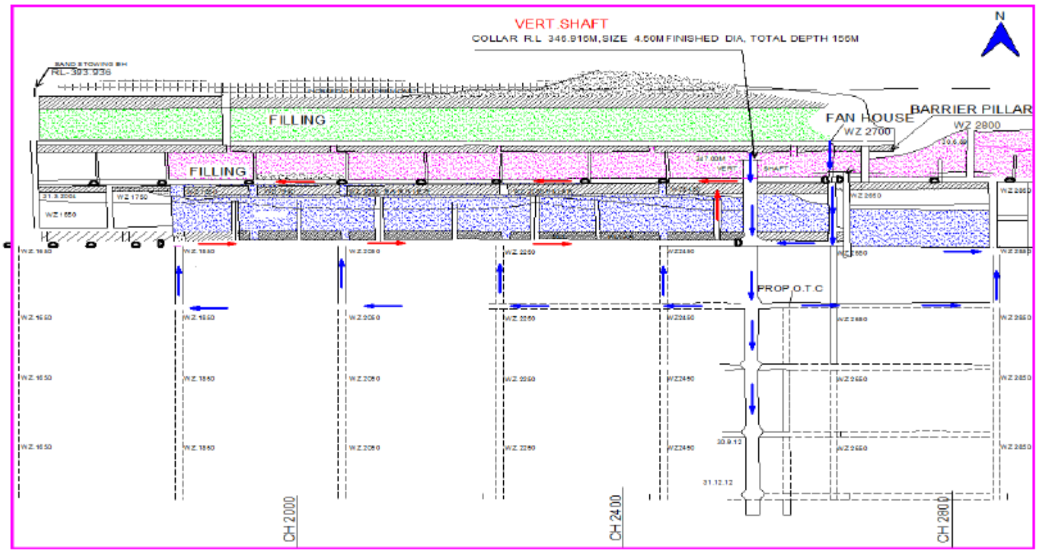

Fig.2: Longitudinal section of present mine working at Munsar Mine

Moreover, in the eastern side, there was collapse of adit brow of 170’L. It was also anticipated during the development stage of incline that the rain water may enter in underground and hence to avoid the inrush of water in the underground stoping operations, haulage road is placed in the sill pillar and sill drive has been developed 5 m above the sill pillar to protect the 70’L (Lower level) and for the safety of 170’L (Upper level) barrier /crown pillar of 5 m thickness has been kept. In this method around 33% valuable manganese ore has been locked in the underground (Manekar G G, Shome D, and Chaudhari M P, 2018).

2.GEOLOGY OF AREA

The land based deposits are mainly of three types; (i) Hydrothermal Mn deposits; (ii) Sedimentary Mn deposits; and (iii) Lateritoid Mn deposits, of which second group is most important economically (GSI – 2018). The manganese deposits in the area are associated with rock of Sausar. These rocks are mainly meta-sediments composed of quartzites, various types of schist and gneiss. These are found at the base of the lower most Sausar Series of rock and have been involved in the movements along with the other rocks and thus have developed certain features which make it difficult to identify them from the other rock of the Sausar Series. The ore bed in this area occurs in the Munsar formation of the Sausar rock belongs to the Dharwar metasediments and comprises of “various types of schists and gneisses, dolomitic marble” calgranulites and Biotite gneiss is found at the base of the lower most Sausar formation and it is involved in the movement with rocks of the same group. During this movement it might have developed some features which make it difficult to identify. Moreover, these rocks have undergone a high degree of metamorphism and the rocks are characteristically metamorphosed.

3.ROCK MASS CLASSIFICATION

The rock mass classification parameters namely, rock quality designation (RQD), joint set number (Jn), joint roughness number (Jr), joint alteration number (Ja), joint water reduction factor (Jw), stress reduction factor (SRF), uniaxial compressive strength (UCS), spacing of discontinuities, joints conditions, orientation of discontinuities and hydro-geological conditions, were estimated for ore as well as wall rocks using 3-D geological mapping and core logging. Based on these parameters, the rock mass has been characterized using Q-system (Barton, 1976) and RMR system (Bieniawski, 1973). Empirical estimation of support requirement for the modified stope design was made using the above two rockmass classification systems. It is observed that the foot wall and hang wall rocks have Q value of 4.75-9.37 and 6.06 - 9.38 respectively (Raju G D, NIRM, 2016), categorizing them both as “Fair”. On the other hand, the estimated “Q” value for the Ore is 22.5 - 66.67, which falls under ‘Good’ to ‘Very Good’ category as per the Q chart. Another widely used rockmass classification system, RMR is also examined. It is observed that the average RMR values of footwall, hang wall and ore body is estimated to be 44.5, 59 and 56 respectively (CMRI, 2001). Obtained Q and RMR value is presented in Table 1.

Table 1: Obtained Q Value and RMR of Munsar Mine

Geo-technical Parameters of wall rocks and ore body for Q-system		
Location	Rock description	Q-Value
Hangwall	Mica schist/Quartz mica schist/Rhodonite with mica schist	6.06 – 9.38, (Fair)
Ore zone	Mn-ore body	22.5 – 66.67 - (Good – Very Good)
Footwall	Quartz mica schist/Mica schist	4.75 – 9.37, (Fair)
Geo-technical Parameters of wall rocks and ore body for RMR		
Location	Rock description	RMR
Hangwall	Mica schist/Quartz mica schist/Rhodonite with mica schist	59, (Fair)
Ore zone	Mn-ore body	51 – 61, (Fair – Good)
Footwall	Quartz mica schist/Mica schist	33 – 56, (Poor – Fair)

4.EMPIRICAL DESIGN

The maximum stope width of 7 m is considered for the modified stope design for the mine. The excavation support ratio (ESR) is taken as 1.6. It can be observed from the ‘Q’ chart, which is shown in Figure 3 that the region falls in unsupported area for 6 m stope width. However, considering the damage due to blasting and other unforeseen geological effects, systematic bolting is found correct for new stope application in which the haulage road and cross cut is placed in the foot wall rock.

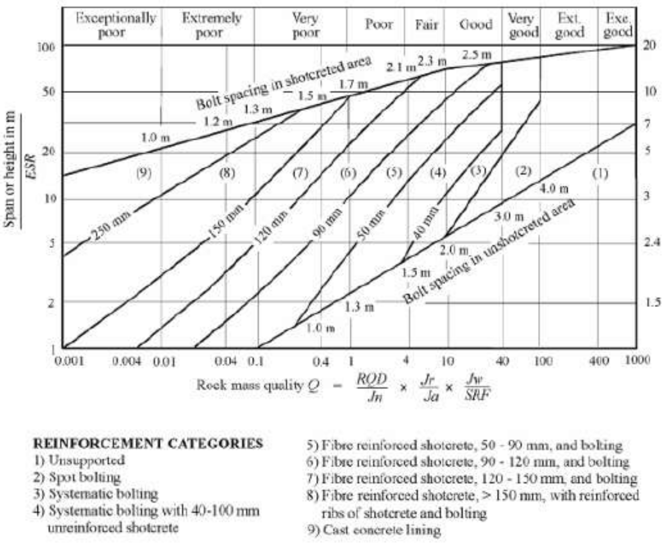

Fig.3: The excavation support ratio (ESR) as per the ‘Q’ chart

Based on the RMR chart proposed by Bieniaski (1973) for the span, a stand-up time, it has been examined for the RMR 56 of ore body. It is found that the stand up time for an average stope width of 7 m is between one week and one month. However, the stope is supported with 1.5 m long rock bolts and hence the actual stand up time for the stope width will be much higher than that shown in RMR chart.

5.ROCK MASS CLASSIFICATION

The rock mass classification parameters namely, rock quality designation (RQD), joint set number (Jn), joint roughness number (Jr), joint alteration number (Ja), joint water reduction factor (Jw), stress reduction factor (SRF), uniaxial compressive strength (UCS), spacing of discontinuities, joints conditions, orientation of discontinuities and hydro-geological conditions, were estimated for ore as well as wall rocks using 3-D geological mapping and core logging. Based on these parameters, the rock mass has been characterized using Q-system (Barton, 1976) and RMR system (Bieniawski, 1973). Empirical estimation of support requirement for the modified stope design was made using the above two rockmass classification systems. It is observed that the foot wall and hang wall rocks have Q value of 4.75-9.37 and 6.06 - 9.38 respectively (Raju G D, NIRM, 2016), categorizing them both as “Fair”. On the other hand, the estimated “Q” value for the Ore is 22.5 - 66.67, which falls under ‘Good’ to ‘Very Good’ category as per the Q chart. Another widely used rockmass classification system, RMR is also examined. It is observed that the average RMR values of footwall, hang wall and ore body is estimated to be 44.5, 59 and 56 respectively (CMRI, 2001).

MOIL has developed in house “A system and a method for rock mass characterization and rock support system in mining” and filed a patent on 31.01.2020 and published on 14.08.2020 for examination by patent office. The app MOIL RMR & Q in which all the parameters can be put directly and software indicates the actual width of opening and stand up time in RMR and required support system in Barton’s Q. There is no human-machine interference in this software. This software/app has been developed in JAVA programming language with JAVA development kit (JDK) version 1.8.0_u131 or higher and Front End in JavaFX using Netbeans IDE. It saves times and accurately furnishing the opening width of excavation, stands up time and support system. Software generated RMR value and Q is presented below in Fig. 4 and 5.

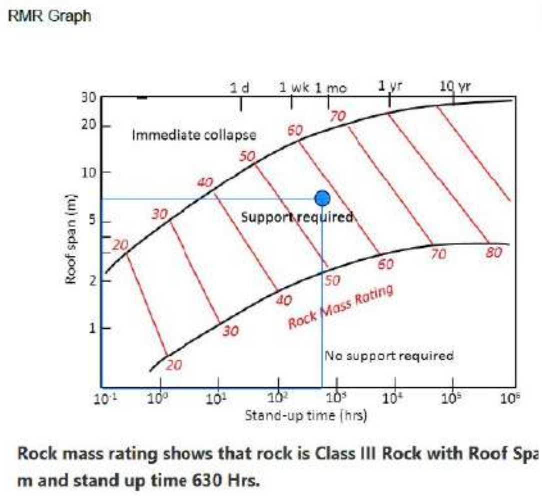

Fig. 4: RMR Graph

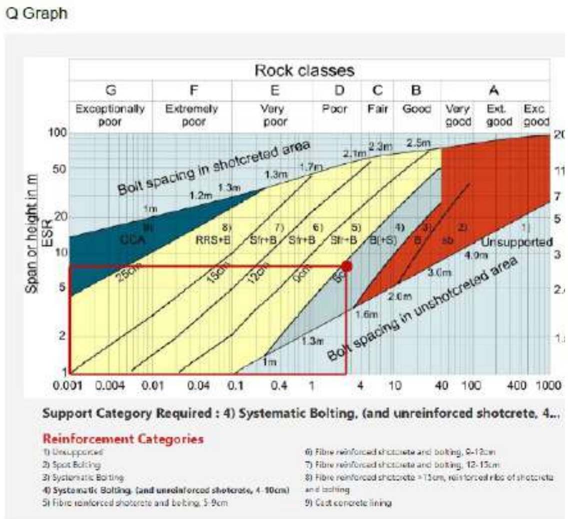

Fig.5: Graph of Barton’s Q

5.1 EMPIRICAL DESIGN

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5.2 MODIFIED STOPE DESIGN

Manner of extraction in sill pillar stopes, in earlier procedure of extraction in sill pillar through sill drive is described as below;

A stope drive not more than 2.4 m wide and 1.8 m high shall be made in the ore body between the two winzes leaving a block of ore 5m thick (called sill pillar) against 70’L drivage in ore, called haulage road. In the stope an ore pass and a man way at an interval of 30m shall be constructed between 70’L and stope drive. The ore pass chute shall be made of steel in segment and man way shall be made of steel /R.C.C. The man way shall be equipped for travelling with suitable platform and ladder way. The sill pillar and sill drive stopes was exhausted at 70’L from Ch. 800 to Ch. 2650 and the same stopes are under operation from Ch. 2650 to Ch. 3050 only in 70’ L at Munsar Mine. Ch. 3050 onward at 70’L and below levels drift has been designed to be developed in footwall rock.

5.3 Modified Stope Design

Now at 70’L from Ch. 3050 onward up to Ch. 4300, and lower levels (-) 30’L, the haulage drive of size 3.4 m x 2.1 m has been developed in footwall rock and is placed 20 m away from ore body and cross cuts of size 2.4 m x 2.1 m are driven from haulage road to intersect the ore body from foot wall to hang wall. The cross cuts are placed at an interval of every 30 m. Moreover, the raise/ winzes is placed at 60 m interval. The modified strike length of stope is 60 m. In this modified stope along with the rock bolt support system has been applied.

5.4 Applied Support System

- Rock bolt support system of 1.5 m long at 2m spacing in haulage road, cross cut, ore drive and stope back in square pattern is being introduced.
- 5 m thick crown pillar is being designed with a safe conservative estimate with FOS of 1.5. Rock mechanics instrumentation work for installation of Multi Point Bore Hole Extensometer (MPBX) from upper level 170’L and Strain Bar installation at lower level 70’L are in progress.
- The maximum stable unfilled volume at any point of the stoping operation is estimated to be 840 m^3. This has generated new avenue for introduction of LHD for mechanical handling of ROM in the stope for better productivity.

6. MODIFIED STOPE DESIGN

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- The maximum stable unfilled volume at any point of the stoping operation is estimated to be 840 m³. This has generated new avenue for introduction of LHD for mechanical handling of ROM in the stope for better productivity.

7. ALTERNATIVE FILL MATERIAL OF OVERBURDEN

To replace the sand as fill material, MOIL used old OB material for experimental purpose, which is available at the mine in huge quantity for filling the underground voids by hydraulic transportation. Initially some pills/pellets of overburden material at Dongri Buzurg mine of MOIL Limited were developed in the month of November 2017 with various compositions. In these pallets, polymer and binder have been used and trials were conducted at Munsar Mine in the month of December 2017. During the trials it is found that only the following product mix shows partial success for hydraulic transportation in underground, which is given in Table 2 and shown in Figure 6.

Table 2: Product mix found suitable for hydraulic stowing operation

Mix No	Fine OB (< 2 mm)	Course OB (2 to 10 mm)	Sand	Clayey soil	Gypsum based Putty	Water Content
4	45 %	45 %	NIL	NIL	10 %	9 %

Fig.6: Product mix found suitable for hydraulic stowing operation

Observed primary results during the initial trails at Munsar Mine found that:-

- The developed product mixes after heat treatment is suitable for underground hydraulic stowing purpose in underground mines.
- Some product mixes are rejected due to its non-compatibility and properties are not matching with sand.
- It is also concluded as the increase in temperature will cause the change in bond of the mix it will change the hardness also.

- It may kindly be noted that the developed product mix is prepared only for use of fill material in underground mines for hydraulic transportation.

7.1 Field trials after treatment of material

It was then recommended and suggested that final field trial on experimental basis should be conducted at Munsar Mine in underground for minimum quantity of around 30 m³ of the material to confirm the physical properties of the OB material as fill material by hydraulic transportation in underground for future industrial application in MOIL mines. The suggested developed product mix along with the photograph is given in Table 3 and Figure 7.

Table 3: Product Mix Used for Field Trials at Munsar Mine after heat treatment

Mix No	Fine OB (< 2 mm)	Course OB (2 to 10 mm)	Sand	Clayey soil	Gypsum based Putty	Water Content
4	45 %	45 %	NIL	NIL	10 %	9 %

Fig.7: Product mix used for hydraulic transportation after treatment at Munsar Mine

The trails show that the developed product mix material of overburden dumps can be useful only when it will be treated with heat for change in the engineering properties of the material for hydraulic stowing purpose in underground mines of MOIL. From the literature (Christine Saiang, 2010), when the samples of the Schist, Granite and Mica tested at 400^0 C, 750^0 and 1100^0 C, it is found that after heat treatment the rock affects the mechanical behaviour. It is also assumed that the heat treatment will reduce the breaking of material and retention of water properties. On the basis of the above data, the product has been developed at Munsar Mine after treatment from the OB material and trial was conducted.

Over burden material of Munsar Mine is mica schist of meta-sedimentary rock formation contain sand particle and dolomite band intrusion. Most of the Overburden material having the characteristics of plastic type paste formation and sudden fragmentation rock particle connection with water. Overburden material is erodible with respect to water, air and temperature. This research program is carried out to use overburden material inside the underground and generation of land for infrastructure and plantation purpose same as sustainable solution to environment

The developed product mix has been tried earlier at Munsar mine for hydraulic stowing but it was suggested to go for heat treatment for better results. Accordingly, in house developed kiln has been used for heat treatment of the material of product mix. The final field trial on experimental basis has been conducted at Munsar Mine in the month of February 2018 at underground for quantity of around 30 m³ of below developed product mix material to confirm the physical properties of hydraulic fill in underground for future industrial application in MOIL mines. The product mix along with the photograph is given below in Fig. 8 and Fig.9;

Fig.8: Initial trial run for 30 minutes at Munsar Mine	Fig. 9: Compact filling of OB material after 2 hrs at Munsar Mine

The treated materials used as fill material in place of sand have following advantages:

- The material does not retain the water. The retaining capacity is very less than the sand.
- Minimum expansion of OB material floor with higher load in compares with sand fill
- OB fill floor is easy for movement of men and machines
- Old refuse material can be utilized for hydraulic transportation in underground.

7.2 Experimental Paste Filling with Fly-ash, bottom ash in coal mine:

Many underground coal mines in the country have adopted filling of underground void by using fly-ash and bottom ash for multi seam mining. Sunflag Iron & Steel Co. Ltd.(SISCO), has also proposed to conduct paste filling by fly-ash and bottom ash for excavation of coal from board and pillar mining method by de-pillaring. Geo-technical studies have been conducted by CSIR-CIMFR, Nagpur, IIEST, Shibpur and found that depillaring with paste filling by fly ash and bottom is feasible to extract coal by paste filling at Boregaon underground coal mine of SISCO. Preparatory infrastructural activities are going on at the site like large diameter bore hole from surface to underground, site preparation of mixing of fly ash with binders and high positive displacement pumps for putting the paste in underground panel with additives.

8. CONCUSIONS AND RESULT

In the modified stope design of Munsar Mine underground lateral development has been increased for stope preparation and production from the underground has been increased considerably. After implementations of the roof bolt support system, roof bolt 1.5 m long at 2 m spacing in square pattern in haulage road, cross cut and in stope back, the progress of the underground development quantity has increased. However, in turn it has improved the minable reserves in underground as sill pillar of 5 m thickness at lower level has been totally eliminated. The production from underground has been shown improvement at Munsar Mine of MOIL Limited. After the introduction of alternative fill material of OB in place of sand for hydraulic transportation to fill the voids in the stope, the floor of OB stowed material is more compact and non-expansion in nature. It will improve the face productivity by basket loading manually in comparison with sand floor and modern mobile underground equipment could be used for drilling in stope and loading, transportation of ROM in the stope by side discharge loaders or load, haul and dump machines. With the rock mechanics instrumentation program of Multi Point Bore Hole Extensometer (MPBX) and strain bars and continuous monitoring may reduce the thickness of barrier pillar from 5m to 4m in coming years. This will help to conserve the manganese ore locked in underground.

Moreover, introduction of paste filling by fly ash/bottom ash in underground coal mine of SISCO may generate new avenue for sustainable mining practices with eco-friendly solution. It will certainly boost the production of coal from underground.

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Current trends in efficient mining

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Abstract

The current scenarios with the introduction of technology IV concepts are transforming mining also into mining IV. The developments are more focussed on automation with high standards of safety and security on all aspects through intelligent techniques ranging from high end sensors, IoT enabled devices for generation of point specific and project specific data. A comprehensive analytical paradigm is all set to lead the mines towards efficiency with tangible benefits and overall safety of the business. This paper discusses the latest technological developments in the field of mining and benefits of digitalization.

Introduction

In the early days of modern civilizational establishments 1st Industrial Revolution (IR) was mechanization of work with the help of steam and water power. The 2nd IR consisted the use of electric power to enhance production speed. The 3rd IR jumped to the use of electronic technologies such as computers and digitalization of work to improve automation. And now 4th IR is considering use of data to auto communicate devices with the help of Internet of Things (IoT) to reduce the need of human interaction which will help in saving time and energy, providing cost efficiency and work safety.

The IoT is changing the way we live. With its pervasive consumer economy, IoT is now emerging as a force in every industry. This is not a coincidence. The Internet of Things creates an estimated number of private and public organizations alike. It is estimated that approximate 29 billion devices will be connected by 2022, with approximately 18 billion connected to IoT[1].

The total base of the IoT network of connected devices worldwide is expected to be 30.9 billion units by 2025, indicating a sharp jump from 13.8 billion units expected at 2021. Examples of IoT connections include connected cars, smart home devices, and connected industrial equipment. By comparison, non-IoT communications include smartphones, laptops, and computers, with connectivity to these types of devices set at just over $ 10 billion by 2025 i.e., three times less than IoT device communications. As a result, revenues from the global IoT market will grow significantly in the coming years[2].

The first "thing" on the Internet was created in 1982. A soda machine at Carnegie Mellon University in Pittsburgh, Pennsylvania, reported the number of the beverages contained in the

[1] https://www.ericsson.com/en/about-us/company-facts/ericsson-worldwide/india/authored-articles/ushering-in-a-better-connected-future
[2] https://www.statista.com/statistics/1101442/iot-number-of-connected-devices-worldwide/

machine along with their temperature. Due to poor internet connectivity and least computational, analytical, data handling capabilities and processing, things were different at that time. However, in 2008 - 2009, the number of Internet-connected things came to exceed the number of people in the world for the first time in history. Since then, IoT has experienced phenomenal growth[3].

The IoT is just not about things now. It incorporates a wide circuitry of hardware devices, precision sensors, data collection devices, data storage devices, and analytical domains of autonomous or managed nature. The basics of such intricate mechanism is explained with the help of Figure 1.

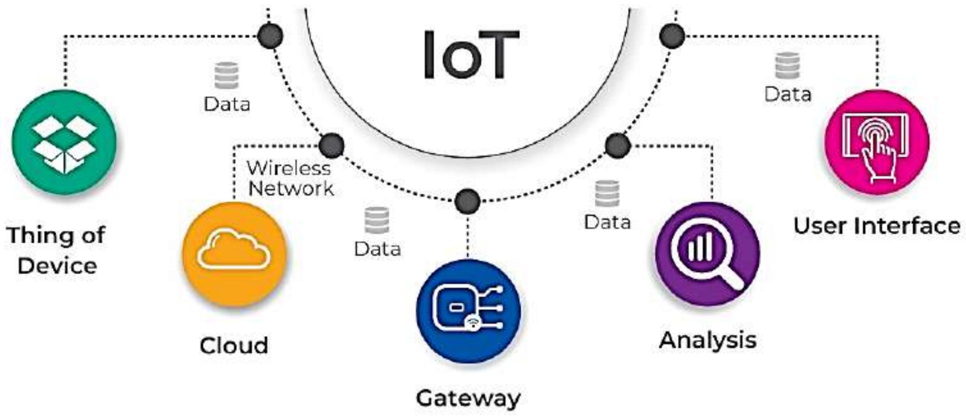

Figure 1 Internet of Things (IoT): Basics

Mining arena has also seen such implementation. Currently in the mining industry, production, distribution (haulage), internet of things, intelligent production, cyber-physical system, and artificial intelligence are being implemented to effectively control the production activities in the mines once the operating system is in place. The main purpose of IoT here is to empower a data-driven decision-making system to improve mining efficiency.

Recent Trends

In recent times the mining industry has been collecting and storing process data for a long time, but now it is focused on using this data to drive business understanding. Digitalization and the Industrial Internet of Things (IIoT) enable mining companies to extract more comprehensive information throughout the business and operations, preventing breaking downs through system integration and collaboration between business units and their teams. This approach, sometimes called digital conversion, empowers companies to make full use of powerful data analysis tools and techniques. Descriptive, predictable and prescriptive analytics are now common in the industry and the use of these methods gives significant value to the mining industry.

The introduction of Industrial 4.0 provides flexible approaches that can lead to improved productivity and a positive impact on the people of the industry through increased safety and ease of operation. The future of mining and other key industries, according to technology giant Siemens, can be summed up in two terms: autonomous and digitalization[4]. The

[3] https://www.ibm.com/blogs/industries/little-known-story-first-iot-device/
[4] https://www.australianmining.com.au/resources/welcome-future-data-mining/

technology that will bring more efficiency is real and is already being used in businesses around the world.

Digitalization and automation in mining, or Mining 4.0, can be defined by deploying smart equipment, shoving data-driven processes via IoT for better decision making, boosting connected communications and providing easier and cost-effective maintenance as explained in Figure 2. According to Tripathi et al. (2022) industries are emphasizing the implementation of a smart shop floor management method because of different types of problems faced in controlling the production activities in Industry 4.0.

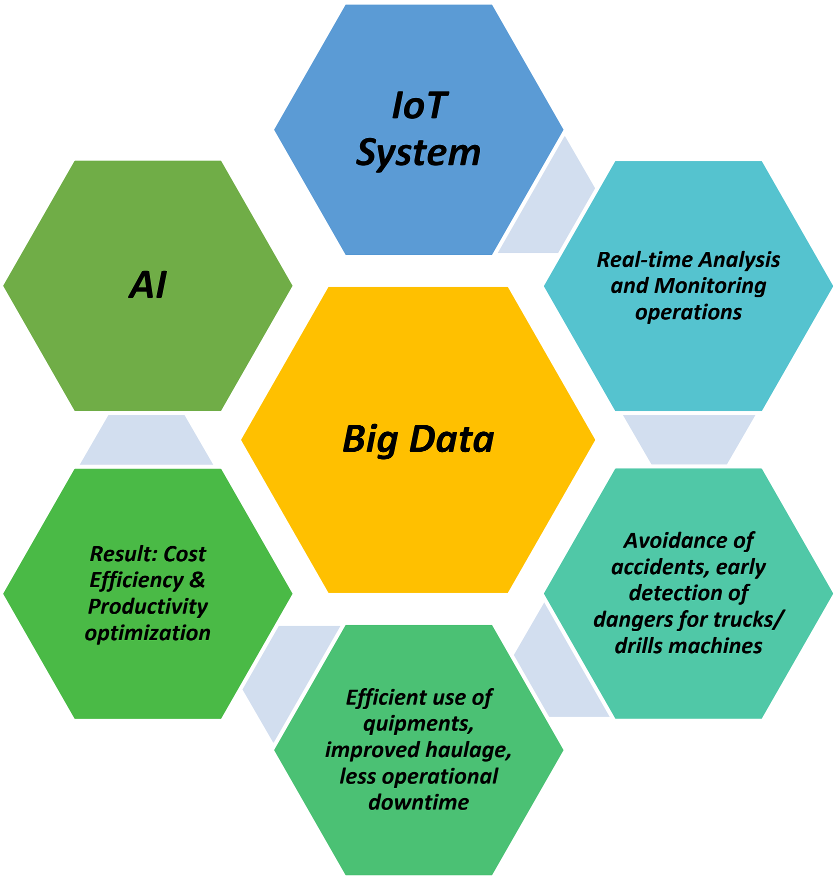

Figure 2: Processing of IoT application in Mining

There's a good reason why so many devices are connected to the Internet because data is important. Raw data is processed to obtain new information. The value is created as soon as the information has been used to initiate an action such as placing an order to repair, brake, or close a valve. A few examples show how value is made throughout Mining and other industries by IoT:

Functionalities	**Use cases**
Product Development	In the food industry, the monitoring of food processing temperatures, and the age and chemical composition of raw materials, enhances the quality, safety, and shelf life of products.
Service Performance	Random time in factories or transportation systems is not just an effective killer; it is expensive and dangerous. By detecting the

	performance of substandard goods (factory items, for example), repairs can be made before the equipment fails.
Using Resources	Real-time information about the use of resources, whether smart grid electricity, piped gas or factory equipment, makes it possible to use resources as needed and detect leaks, thereby reducing or eliminating waste.
Reflection (Sustainability)	Wise cities powered by IoT use sensors to collect data about weather and air quality. If air quality is considered low, the city can take immediate action (such as providing free public transportation) and can easily measure the impact of remedial action.
(Energy) Utilization	A solar-powered mall generates more energy. The IoT-enabled solution collects and analyses data on climate, energy consumption, and market prices. The system then automatically determines the less expensive way to use the energy generated by the mall. Options included using energy, storing it, or selling it at a higher market price.
Manufacturer	IoT also plays an important role in the future of production. Industry 4.0 creates a new paradigm for production halls. By integrating all the components of supply chain and production, production can be efficiently and quickly adapted to new requirements including the production of customized products (first batch size) at competitive prices.
Interruption Business Models	Changing the way business is run in industry e.g., “Pay per User” or “As a Service” business models instead of selling equipment.

Use of Artificial Intelligence is also rapidly increasing in the world in every aspect of life from computer laptops to operating cars and big machineries. But there is difference in IoT and AI, the large amounts of data provided by IoT often hide important information that cannot be obtained using simple analysis techniques such as mathematics. Artificial Intelligence (AI), on the other hand, is generally more efficient at accomplishing this type of task. For example, it can independently identify patterns in measured values from production and use the information to continuously improve the production process - making artificial intelligence one of the key factors.

Making the most of collected available data is very crucial. The digital transformation of the industry brings an uncontrollable increase in the amount of data produced. Manufacturing equipment, machinery, processes, and plants all produce data that contains important company information. Used wisely, this data can help you to streamline the processes and products, make better use of resources, and improve planning. New business models such as new service concepts are also being created based on Internet of Things (IoT). With Industrial Edge, all of the data can be used, locally and in the cloud, depending on industry needs. Industrial Edge is an integral part of the Digital Enterprise portfolio that works to transform endless data volumes into unlimited possibilities Figure 3.

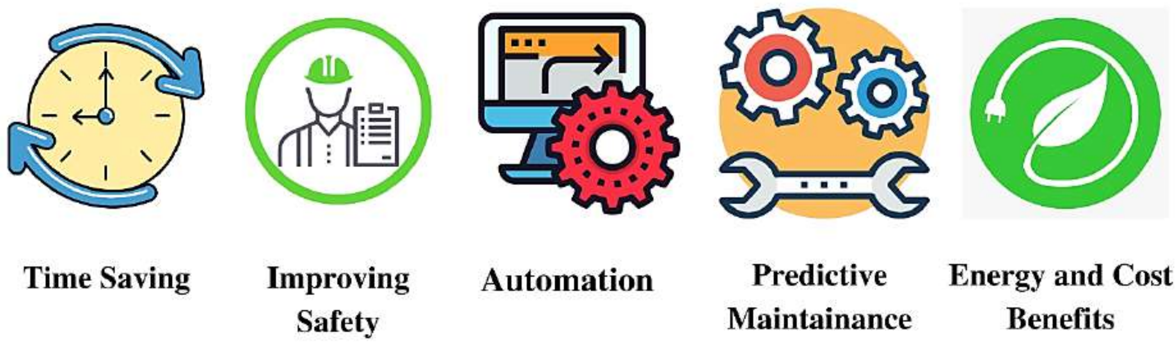

Figure 3 Benefits of IoT in Mining

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