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Surface Mining Technology: Progress and Prospects

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Abstract

Surface mining methods dominate the world production of minerals. Currently, almost all non-metallic minerals [more than 95%], most metallic minerals [more than 90%] and a large fraction of coal [more than 60 percent] are mined by surface methods. Of the over 30 billion tonnes of ore and waste materials that are mined each year, surface mining accounts for nearly 25 billion tonnes. The subsurface of the earth is the only source for fossil energy and mineral products, and mining is the only way to get at them.

There is a wide variety of surface mining methods. The operations of drilling, blasting, loading and hauling are common to most methods. Technological developments over the years have enabled the application of surface methods to deeper and leaner deposits. Also common to all methods is the removal of the surface cover over the deposit, the changes to the original topography, the effects on soil and hydrologic conditions, the issues of mining and processing wastes, and the effect on the future economic potential of the mined areas and communities. However, the scope of the issues and the potential solutions to the issues vary widely and are often site-specific. While research and development are needed to address technical aspects associated with these issues, innovative policies for addressing the overall problem of environmental and ecological planning for post- mining development on lands with mineral resources are needed.

In the last two decades, the mining industry has seen consolidation of operating companies, growth in the size of individual operations, increase in size of equipment, and greater demands for sustainable development. These trends would continue into the future impacting both the opening of new mines and the closure of existing operations. In this paper, an overview of surface mining technology is presented. The discussion follows the mineral development cycle and concludes with an identification of future research needs.

Keywords: : *unit operations; mining technological systems; reclamation; sustainable development; mining research needs*

1. Introduction

This paper is concerned with the technology of surface mines, an assessment of the current status and the prospects for the future. The term "technology" is fairly complex with various shades of meaning, not anyone of them completely meaningful. Mining technology is a broad topic with two possible views:

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- A simple view is that it is the actual process of extracting the mineral reserves. In this view, a mine is an industrial operation set up to extract the mineral deposits wherever and whenever they are economic [mining technology].

This myopic view leads to the conclusion that a mine is a rock factory. Most people who hold this view are generally unfamiliar with the mining industry.

- A more global view is that it is a human endeavor encompassing several complex processes to utilize one of the natural resources of planet earth - mineral resources - for the benefit of mankind [mining technological system].

This larger view of mining - the total systems view - is important from several considerations. The foremost is the idea of interaction and interdependent nature of the various aspects of the mining system and other related systems, whether natural or engineered. The relationship between mining and natural systems is most intimate, almost symbiotic. Another is the role of mining as a primary wealth generator and in many cases, as the foundation for both manufacturing industry and the materials cycle.

Shown in Figure 1 is a satellite view of the Berkeley Pit and the region around Butte, Montana [USA] as captured by a NASA satellite in August 2006. This region had been named the "richest hill on earth ," has been mined for over a century now for silver, gold and copper. At the present time, it is probably the "costliest superfund site." This image shows many features of the mine workings, such as the terraced levels and access roadways of the open mine pits. The proximity to the town of Butte, the major transportation corridors, the economic impacts, and the natural features are worthy of note. While the positive economic impacts during the active phase of the mines can be easily gauzed, at the present time, the effects on surface and ground water - in terms of quality and quantity - are important. This is a clear illustration of the spatial and temporal considerations of mining. While not all operations is this complex nor all have these problems, the Butte case points to the importance of drawing up a comprehensive list of things to address during the planning and designing phases so that the analyses and designs are rigorous.

Fig. 1.An aerial photograph of Butte, Montana, USA, from NASA showing the Berkeley Pit

Further, in the search for optimum, the goal is to seek the optimum for the total system. In addition to the idea of interaction of the mining system with other systems [such as natural systems], there are several sub-systems of the mining system [such as exploration and extraction], components of each of the sub-systems [such as drilling and blasting] and parts of the each of the components [such as drills and draglines]. Also, such a systems view brings into focus the large number of technology issues that one has to address in mining and the cross and multi-disciplinary nature of the issues. The complexity of mining systems arises from not only the interactions of its sub-systems and their components and parts, but also due to interactions with other man-made systems such as communities and land uses and natural systems such as topography and groundwater [1]. Reclamation planning, environmental planning, ecological planning, and sustainable development are approaches which take an increasingly broader view of the impacts of an industrial operation both in spatial and temporal dimensions. In this view, mineral development is a means to develop the economic base through which both the present and future generations can benefit [2]. New approaches are required to planning and operations in general, and mine planning, in particular.

2. Importance of Surface Mining

The rapid growth in the use of earth's natural resources is raising questions on several fronts, most importantly on the quality of life and the needed actions to prevent irreversible damage. According to a report from Sustainable Europe Research Institute in 2009, the amount of natural resources [renewable and non-renewable] extracted from earth for the production of goods and services around the turn of the 20th Century was around 60 billion tonnes per year, an average of about 25 kg per citizen per day [3]. There are however great differences in the extraction and consumption of the natural resources by regions of the world [Table 1]. There is concern that citizens of developed countries use more natural resources [as high as four times] than those in some developing countries.

Table 1. Per capita per day extraction and consumption of natural resources [kg]

Regions of the World	Extraction	Consumption
North America	68	88
Latin America	41	34
Europe	36	41
Africa	15	10
Asia	14	14
Oceania	158	100

The relevance of the mining to modern way of life is evident from the fact that the source for about 20% of the natural resources is the world mining industry. The major products include fossil fuels, metallic and non-metallic ores, and construction and fertilizer materials. It is safe to assume that as the world economy grows, the demand for natural resources would only grow. The demand for mined products is assured to grow for two reasons: the growing world population and the growing expectations for increased standards of living all over the world [4]. At the present time, the subsurface of the earth is the only source for mineral and fossil energy resources and mining is the only way to get at them.

Mining industry production is often expressed in terms of surface and underground mining segments and metallic and non-metallic and coal sectors. Data from Atlas Copco's Mining Methods booklet [5], abstracted here in Table 2, show that mining is associated with large volumes of waste production. The extraction of about 12 billion tonnes of ore is associated with an extraction of about 19 billion tons of waste [over 12 kg per day per citizen]. In recent years, the coal sector has accounted for about 6 billion tonnes of coal production with an associated waste production of about 8 billion tonnes. The metallic/non-metallic sector has an annual production of about 5.6 billion tonnes of ore and about 14.4 billion tonnes of waste. Over 80% of the metallic/non-metallic sector ore production and 50% of the coal production are by surface mining methods. Over 80% of all materials handled in the mining industry is by surface methods. At least for the foreseeable future, surface mining would be the major source for most mining commodities.

Table 2.Global mine production, 2005 [billion tonnes]

	Surface Mining			Underground Mining			Total		Grand Total
	Ore	Waste	Total	Ore	Waste	Total	Ore	Waste	
Metallic and Non-metallic Mines	4.5	10.2	14.7	1.1	1.2	2.3	5.6	14.4	17.0
Coal Mines	3.0	7.2	10.2	3.0	0.8	3.8	6.0	8.0	14.0
Total	7.5	17.4	24.9	4.1	2.0	6.1	11.6	19.4	31.0

With regard to phosphate, the theme of this symposium, phosphate mining plays an important role in addressing the needs of one of the grand challenges facing the world population - that of maintaining the productivity of the food system. In fact, the agricultural industry and phosphate industry are inextricably tied to each other. Phosphate mining and processing affect the environment but is the source for the nutrients to increase the productivity of the soil. Further, a large fraction of the phosphate mined in the world is mined by the surface mining method. Surface mining however affects the topography and subsurface and has implications for productive use of mined lands particularly at this time when there is great demand for habitable land surface for other uses.

There are a number of goals that geologists, mining engineers and mineral processors should be pursuing to address the major issues of production, product quality, environmental conservation and land uses that confront the mining industry [6]. The following goals, stated in very broad terms are some of the most important.

- Search for high grade deposits
- Adopt the best applicable technology for each operation
- Search for selective mining methods
- Search for bulk mining methods for lower grade deposits
- Reduce waste
- Utilize waste
- Reduce processing needs by utilizing more of the mined products
- Locate processing facilities close to mines
- Address effectively both near and long term environmental issues
- Contribute to the sustainable development of the region
- Define research and development needs for specific operations.

For the achievement of these goals, in addition to the deployment of latest developments in technology, efforts are to be directed to enhance development of new knowledge and technology.

3. Major Trends Affecting Mining

There are major trends in the worldwide mining industry that can raise serious impediments to the mining companies abilities to meet the projected demands for mined products. It is necessary to understand the implications of these trends to face head-on the potential challenges.

- Mining is increasingly becoming global with several new entrants acquiring properties around the world. This is likely to increase the competition for reserves and markets.
- Mining industry is growing to meet the rapid expansion of economies in several countries, Such expansion is likely to create intense competition for capital and equipment.

- Consolidation of mining and original mining equipment manufacturing companies is likely to continue. This would have both positive and negative impacts.
- Size of future mining operations is likely to be even larger than now. The number of small and medium-sized operations is already decreasing affecting their role as "niche" operators.
- Size of mining equipment is likely to grow even bigger providing even greater economies to scale. This would require, in addition to greater demands in mine planning and design, larger reserves and more capital for their deployment.
- Availability of lands for industrial development is already becoming a serious issue in many communities. This has serious implications for all phases of a mining project from exploration to opening new mines and even, expanding existing operations.
- Engagement with communities will become more critical. Demands to define and demonstrate the application of sustainable development principles and practices in mine planning and design will become intense.
- The demand to reduce the footprint of mining will become even louder. In addition to governments and the NGOs, investors and other stakeholders will join the call for action.
- New laws and regulations can be expected in several areas such as tax rates, tax bases, permits to mine, health, safety and environment, and social programs. The impact on lead times, production, productivity, costs, revenues and profits needs to be addressed with innovative technical and business plans.
- Volatility in prices of mined commodities will continue. If recent experience is any indication, this volatility will extend to metallic and non-metallic products and fossil fuels.
- Mining conditions are likely to be more difficult in the future. While finding a world class mineral deposit cannot be ruled out, if history is a guide, future discoveries will be deeper, thinner, lower grade and have severe conditions, all increasing the difficulty of mining and processing.
- Attracting and retaining quality personnel will be a challenge. World over there is recognition of the shortage of skilled personnel in all ranks - hourly workers, technicians, engineers, specialists, managers and executives.

Clearly, the situation with regard to future is a case of "known knowns, known unknowns, and unknown unknowns." Some trends are predictable, others we may know the direction and in others, we may not know much about the direction or the amount of swing. Under the circumstances, one must have a robust strategy to overcome the swings in factors which cannot even be predicted accurately, let alone controlled, through identification and management of those factors which can be influenced and controlled. Critical factors for success are quality personnel, outstanding organization, good data and information, appropriate tools, techniques and methods for analysis, and effective technologies and strategies that are sensitive or less so, as appropriate, to the changing conditions. The strive to continue to be a low cost producer through continuous improvement in performance and cost cannot be overemphasized.

4. Mineral Resource Development Cycle

The understanding of the mineral resource development cycle is essential to fully appreciate the problems and issues of the needed technologies to start the flow of materials from a deposit to the consumer. The major steps in the cycle are:

- Exploration
- Development
- Extraction/Production/Operation
- Mine Closure and
- Reclamation and Rehabilitation

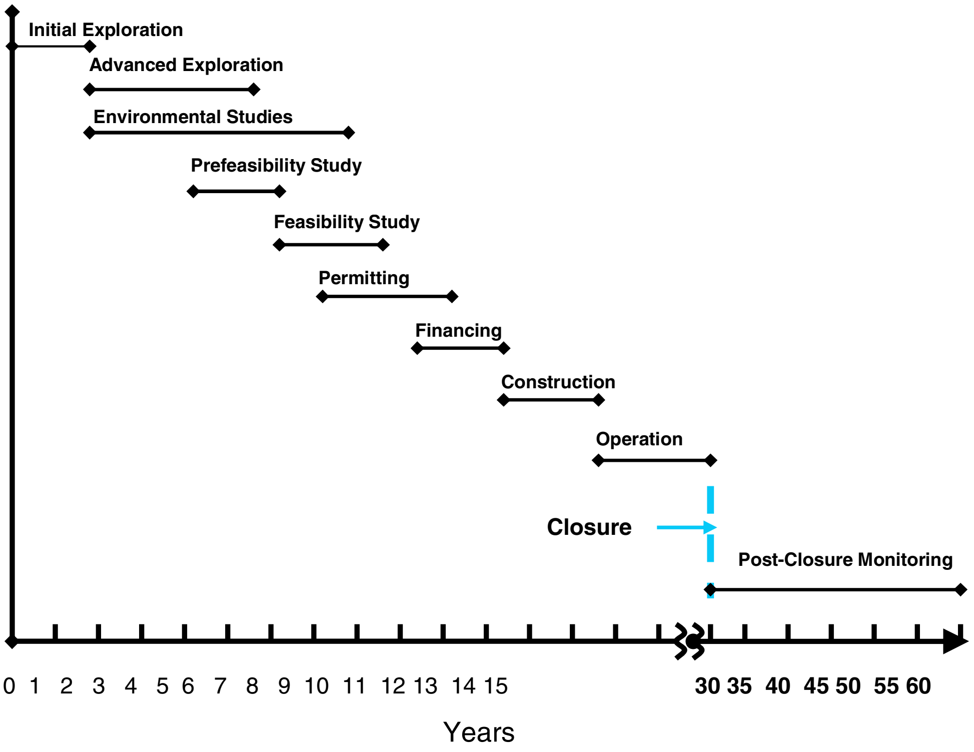


Fig. 2.Typical time frame for a completed mine project [Alaska Forum on the Environment, Anchorage, Alaska, February 12, 2008]

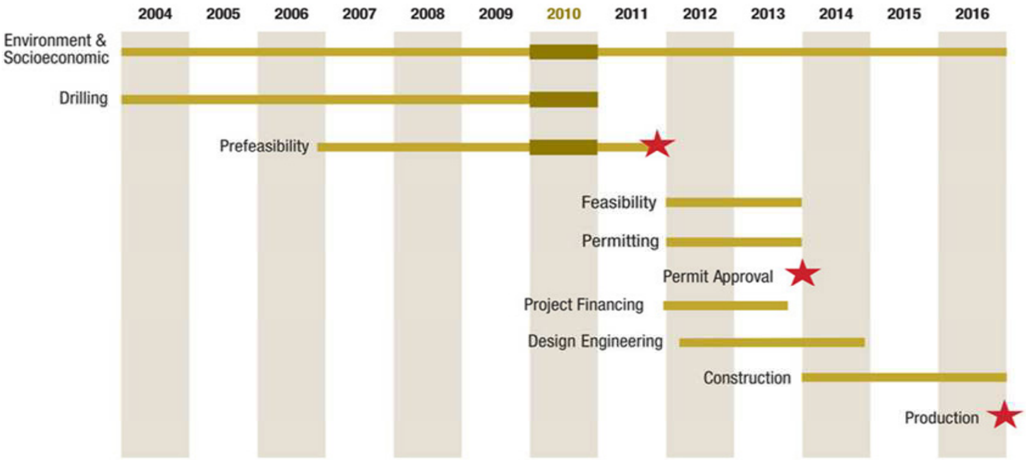
The finding of an economical mineral deposit is in itself a major accomplishment as the number of aborted or stillborn exploration projects is unusually large. In fact, less than 2% of exploration projects eventually reach the extraction phase. Shown in Figure 2 is a timeline for a large precious metal mine project from initial exploration to post-closure monitoring.

The lead time from initial prospecting to start of mining operations can be anywhere from 15 to 20 years or more. If time value of money were to be conservatively assumed to be around 6%, the initial investments in exploration, if made in any other investment would have more than doubled by the time the first profits commence from mining, if at all, and that too, without the risk that is associated with mining. It is absolutely essential to quickly identify mineral deposits with development potential so as to avoid expenditures in deposits that would not result in an operating mine.

The identification of favorable areas for prospecting and detection of anomalies, targets and economic deposits demand qualified personnel, new tools and techniques and capital. Greater reliability in exploration needs better technologies for geophysical sensing, imaging techniques, uncertainty evaluation and ore body modeling. Preemptive environmental factors that can lead to permit denial require detailed consideration.

The prefeasibility and feasibility studies require a major commitment of funds. In the Pebble project in Alaska, exploratory drilling and prefeasibility studies have been underway for over a decade now. By the end of 2009, about U.S. $430 million have been spent with total project capital investment estimated at $4 to $5 billion [Figure 3].

The Pebble Project Status – 2009
Expenditures to 2009 – U.S. $ 430 Million
Life – 50 to 60 years; Cap Inv - $4 to $5 billion



Reserves: [1] 5.94 billion tonnes of measured and indicated ore containing 55 billion lb copper, 66.9 million oz gold and 3.3 billion lb molybdenum and [2] 4.64 billion tons of inferred ore containing 25.6 billion lb copper, 40.4 million oz gold and 2.3 billion lb molybdenum. Quantities of silver, palladium and rhenium are also contained in the deposit.
A range of options for project planning are currently being examined including a conventional open pit, high-volume underground mining (block caving) or a combination of both.

Fig. 3.The Pebble Project Status [after northerndynastyminerals.com]

The decision to go ahead with mine development is one of the most critical as it is will ensure large capital outflows. As the feasibility study is the basis for all future decisions, it must meet the following minimum requirements:

- Reliability of the project to meet the mining companies goals and objectives is high.
- Details and quality of the supporting documents are sufficient for it to serve as a bankable document.
- A firm conceptual framework for the mining project is evident.
- Data and analyses are based on sound testing and engineering principles and serve as a basis for detailed drawings and construction.

Critical aspects of mine planning and designing such as fixed facilities, mobile equipment and organizational development require great attention. Selection of appropriate mining methods, operating plans and equipment is of utmost importance. Fortunately, several excellent computer-oriented mine planning packages are available for use during this phase of the project. These packages allow, in a reasonable time, evaluation of several alternatives to mine a deposit.

Time and performance during mine development must be kept under strict control with adequate project planning and field management. Here again, computer-oriented management tools are available to track performance and provide timely information for control. Delays in this phase are deadly to profit and performance goals of the total project. Most projects fail to achieve their projected financial performances due to delays in this phase of the project.

The extraction/production/operation component of the development cycle in surface mining encompasses the removal of both the strata over the mineral deposit and the mineral deposit itself. There are numerous variations to the basic methods of surface mining a deposit, each one most effective for a particular combination of surface topography, the type of strata above deposit, and the thickness, depth , inclination, extent and type of mineral deposit. The difficulty of extraction increases tremendously with increases in depth and inclination. Great difficulties are presented by very thin or very thick deposits and by high relief.

The repetitive unit operations include drilling, blasting, loading, hauling and reclamation, for each of which there are wide choices of equipment. Among the important issues in drilling and blasting are accuracy of drilling, assessment of strata conditions, blast pattern, explosive choice and loading, ground vibration, and health and safety. Several of these factors affect fragmentation and consequently, the performance of equipment in all downstream operations. Several of these issues can be addressed with the current technology available for remote data acquisition during drilling, rapid on-board data processing and technological advances in drilling systems. At the current time, much of the expertise in drilling and blasting lies with the consultants who provide the equipment and services.

Loading and hauling of the mined materials is a major operating cost item in surface mines. There are three kinds of materials that one has to handle: the top soil [something that was not common in the long past], the overburden [waste rock] and the ore. A large number of factors such as topography, distance, mining method, and reclamation needs dictate what equipment may be appropriate or necessary for each system. The correct choice of method and equipment is critical. Though not very common, trains and pipelines have been used to convey materials directly from the mine to the plant over very long distances. The most common systems employ shovels, trucks and conveyors.

The choice of equipment for loading and hauling is dependent on the hardness of the strata and how much preparation, such as fragmentation, is necessary for loading purposes. In bedded deposits in flat terrains, overburden removal by draglines in the side casting mode [opencast mining] is the most common method for exposing the deposit [Figure 4]. Trucks and shovels are also commonly employed for loading and hauling the materials, more often for ore removal in bedded deposits.

Fig. 4.A dragline in a strip coal mine. Draglines have bucket capacities of 140 m^3 and reach of up to 90 m. Notice the two loading shovels and the trucks in the pit for ore handling.

Where the in-situ material does not require preparation through drilling and blasting, i.e. fragmentation can be achieved by ripping by a machine or the material is soft enough to be easily picked up by a bucket, continuous mining technology can be adopted [Figure 5]. As shown in the figure, the overburden bucket wheels cut and load the materials on to belt conveyors that convey the material around the open pit to areas where the ore has been mined. The bucket wheels in the ore load the material to conveyors for transporting out of the pit.

Continuous surface mining has been a dream of mining engineers. Several equipment manufacturers have developed continuous surface miners which employ a milling cutter head to cut and load the rock on to trucks or conveyors. The use of these machines in earthworks and construction sites has been well accepted due to their performance characteristics in these earth moving tasks. The performance of these machines however is very much dependent on the hardness of the rock. Experimental data indicate a rapid decrease in production [m3/hour] as the unconfined compressive strength [UCS] of the rock increases. Where the UCS of rock is over 100 MPa, the production performance and resulting economics may not justify their deployment. The application of these machines for soft overburden and soft ore removal is becoming popular, particularly where production requirements are not very high, selective mining is required and capital availability is small.

Fig. 5.A large continuous surface mine with bucket wheel excavators in the overburden [60 m thick] and the ore body [20 m thick]

Ore or overburden removal with dredges is common in several applications such as sands, clays and phosphates. Under suitable conditions, production can be continuous and productivity, quite high. Several phosphate projects around the world are in various stages of development with dredge being the principal equipment for both overburden and phosphate removal.

As the size of mining operations has grown, the size of equipment deployed in these mines have also grown. Shown in Figure 6 is one of the largest truck in operation being loaded by one of the largest loading shovel. Trucks of this size can cost up to U.S. $6 million and can operate at speeds of over 65 km/hr. The excavator can cost up to U.S. $12 million.

Fig. 6.Truck sizes can be up to 400 tonnes and shovel sizes, up to 80 tonnes

Clearly, to take advantage of these massive loading and hauling equipment, one must have a fairly large operation with large reserves. The high capital requirements and large production capacities must be supported by a stable market. Design of haul roads, slopes and other supporting facilities must be proportionately upgraded.

The last of the unit operations is the initial reclamation of the mined area in preparation for the long term reclamation. Depending on the type of surface mining method, several critical actions can be performed at this stage.

- Burial of toxic materials
- Encapsulation of toxic materials
- Surface soil and sub-surface spoil amendments
- Backfilling, contouring and rough grading the land surface for future land uses
- Top soiling and plantings for immediate growth to control erosion

These actions are essential for successful mine closure, and reclamation and rehabilitation of mined lands.

Mine closure is an important planning consideration starting from the preliminary feasibility study stage and ending with the successful closure of the mine. Provision of adequate funds for closure is often overlooked during the initial stages and therefore, a major problem at the later stages. Several critical closure activities are associated with the pit, the various dumps and water quantity and quality. In addition to these physical issues, there are issues that deal with the socio-economic aspects such as the loss of economic activity, community health and safety, and dedication of the mined area to other land uses. A good rule to follow is that if an adequate closure plan cannot be developed, then the mine should not be opened. Several mines of the past are now a major liability for mining companies and governments due to the threats they pose to health, safety and welfare of communities.

Reclamation and Rehabilitation of mined lands support the future economic development of the area. Sometimes it is not possible to imagine how current mining can lead to future economic development of the mined area or improve the conditions for the community after mining. Intense controversies around such mining districts are quite common. Conflicts of economic, environmental, ecological and private and public interests are not easily handled. Where the conditions are favorable, the land reclamation and land use potential after mining is limited only by need and imagination. Stone, sand and gravel, and coal mines have been reclaimed to several successful post-mining land uses including agricultural, commercial, residential, institutional, recreational, and industrial land uses [Figure7].

Fig. 7.The development of mined lands for post-mining land uses. The uses highlighted [clockwise from top left] are cattle grazing, recreational, residential and agricultural uses.

Inevitably, mining has to cease due to either the physical depletion of the reserves or the poor economic viability of the operation. While environmental issues are considered and generally accounted for during the operation and after closure, the mineral extraction based economy of the region is not easily replaced. Clearly, mineral development is only a bridge between the present and future generations through which the foundations for a new economic base needs to be fostered. The spatial and temporal characteristics of a mining operation, particularly the environmental and economic impacts, point to the need for identifying and involving all the stakeholders in a meaningful way in defining and achieving specific sustainable development goals for mined lands. An economic safety net for affected communities and long term commitment to funding the post-mining reclamation and rehabilitation operations are essential components of a prudent plan. The new mine development paradigm consistent with the initial objective of utilization of all the resources of the area is sustainable development planning [Figure 8].

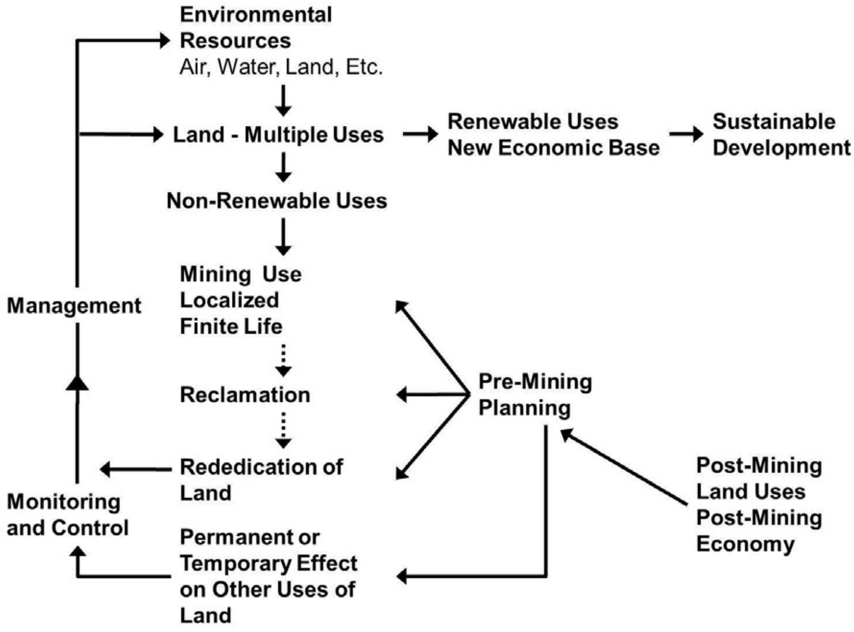


Fig. 8.Diagram illustrating essential steps to the development of new economic base

5. Developments in Mining Technology

The search for safe, productive and environmentally more desirable methods for extracting the mineral riches of the earth should be apparent from the earlier sections of this paper. There is great potential however for further developments, particularly through the application of advances in several fields of science, engineering and technology [7, 8, 9]. While much is known about the advances in information technology, examples abound in several other fields such as medicine, materials and agriculture where these advances have greatly aided the development of equipment, processes and systems to diagnose, track and solve complex problems. All technological developments depend on mineral products. In fact, all human endeavors --- farming to communications to space travel to nano technology --- would continue to be dependent on the products of mining. In the event of a supply threat to an essential mining commodity, be it oil or gas or coal or minerals, there will be reverberations in the far corners of the globe. One of the grand challenges for the mineral industry is to supply the population with its material needs. Given that earth is the only viable source of all materials that we use today, their economic extraction, processing and utilization will continue to be an essential, productive human activity for the foreseeable future, as it has been in the past. In the following discussion, two developments that can be of significant aid to the mining industry of the future is addressed.

Global Positioning Systems [GPS] has great potential to make major impact on surface mining operations. GPS has become an integral component of large surface mines for tracking mobile equipment, precision positioning of shovels, trucks and other equipment, guiding equipment and monitoring of advance of mining and impact of mining. All future mines must be prepared to utilize this technology, pushing both mine equipment manufacturers and government to adopt more of this technology for mining, beginning with exploration and proceeding all the way to mine monitoring and control during mine closure and reclamation.

Another area where progress can be expected in future mines is automation and autonomous operation. The progress towards autonomous operation of mining systems has been slow. Even then, remarkable progress has been made in remote and automatic control of equipment and systems as well as in many successful autonomous operations of conveyors, trains and pipelines. In surface mining, significant progress has been made on the remote and autonomous operations of mobile equipment such as trucks and shovels. When a modern automobile has features to "fly by wire," recognize obstacles, self-diagnose problems and offer suggestions to fix problems, it is not a question of technology that is lacking but the unique issues with mining applications that are impediments to developments. Specifically these are:

- the inability to know exactly what is ahead of the mining face. There is a need to develop look-ahead technologies for making real-time decisions. In fact, efforts to make the earth transparent is a major objective of earth scientists.
- the ability to predict the mining conditions accurately for reliable control of equipment and systems such as drills and excavators. Performance of excavators is extremely sensitive to the cutting conditions which in a heterogeneous material are not easy to predict.
- the mining work environment is quite different from most other work environments. The ambient environmental conditions in mines are quite different from those in other work environments. Frequent changes in the environmental conditions cannot be ruled out and require that adjustments be made to the task requirements of a mining task during execution. All these factors have contributed to the slow pace of automation and autonomous operations.
- the cognitive component of the autonomous operations is the least developed for mining applications. The mining machine operator's abilities to successfully maneuver the machine through the changing geological and environmental conditions are developed over a long time and are not easily captured.

Integration of remote control, automation, and autonomous operations has been facilitated by advances in global positioning systems, communications, computer speed and robotics, again more so in surface mining than in underground mining. Automated and autonomous systems would require changes in the design of equipment and systems. Provisions for human intervention have to be incorporated for non-routine and non-cyclic components of the operations. Equipment manufacturers and mining companies are in fact actively engaged in these efforts. Research is underway in a number of areas such as mine wide machine to machine communications, and human-machine interface that should make mines more productive and safer. One of the most advanced project in this area is Rio Tinto's Mine of the Future Program [10]. In the robotic Mine of the Future which is developed at the West Angelas iron ore mine in Australia, it is hoped that the employees will supervise the automated production drills, loaders and haul trucks from a remote operations center in Perth.

6. Summary

Despite the great accomplishments in mining technology over the last quarter century, mining methods and equipment applications have not radically changed. The progress has been mostly evolutionary, not revolutionary [11]. As in the past, in the future, one will witness the introduction of new technologies in several unit operations and sub-systems. For continuous improvements in performance and costs, major advances are needed in all the sub-systems and unit operations. Research and development is critical to

- enhance the success of exploration programs
- improve the characterization of the mining deposit and the reserves
- decrease the lead time to development and full production
- increase the recovery of the mining reserve
- conserve better all the resources of the mining region
- advance continuous surface mining technologies to wider variety of deposits
- achieve greater progress on the development and applications of automated technologies
- enhance product recovery and mined-product utilization
- improve health, safety and welfare of the miners and mining community
- enhance the contribution of the mining operation to the community and general population
- assess better the long term impacts of mining on communities so as to meet the aspirations of the community

As far as the total system is concerned, new technologies will be introduced in an evolutionary manner as to avoid compounding the uncertainties of mining conditions with the risks of new technologies. The operators, equipment manufacturers and government have to come together to take the risk in advancing and adapting the emerging new technologies to mining as it is too much to expect one or the other to bear the entire burden.

Search for innovative policies to ensure that lands where mineral deposits are likely to occur are available for exploration and mining. Timely action in this area is essential by concerned authorities to ensure that mineral riches of the land are not sterilized.

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