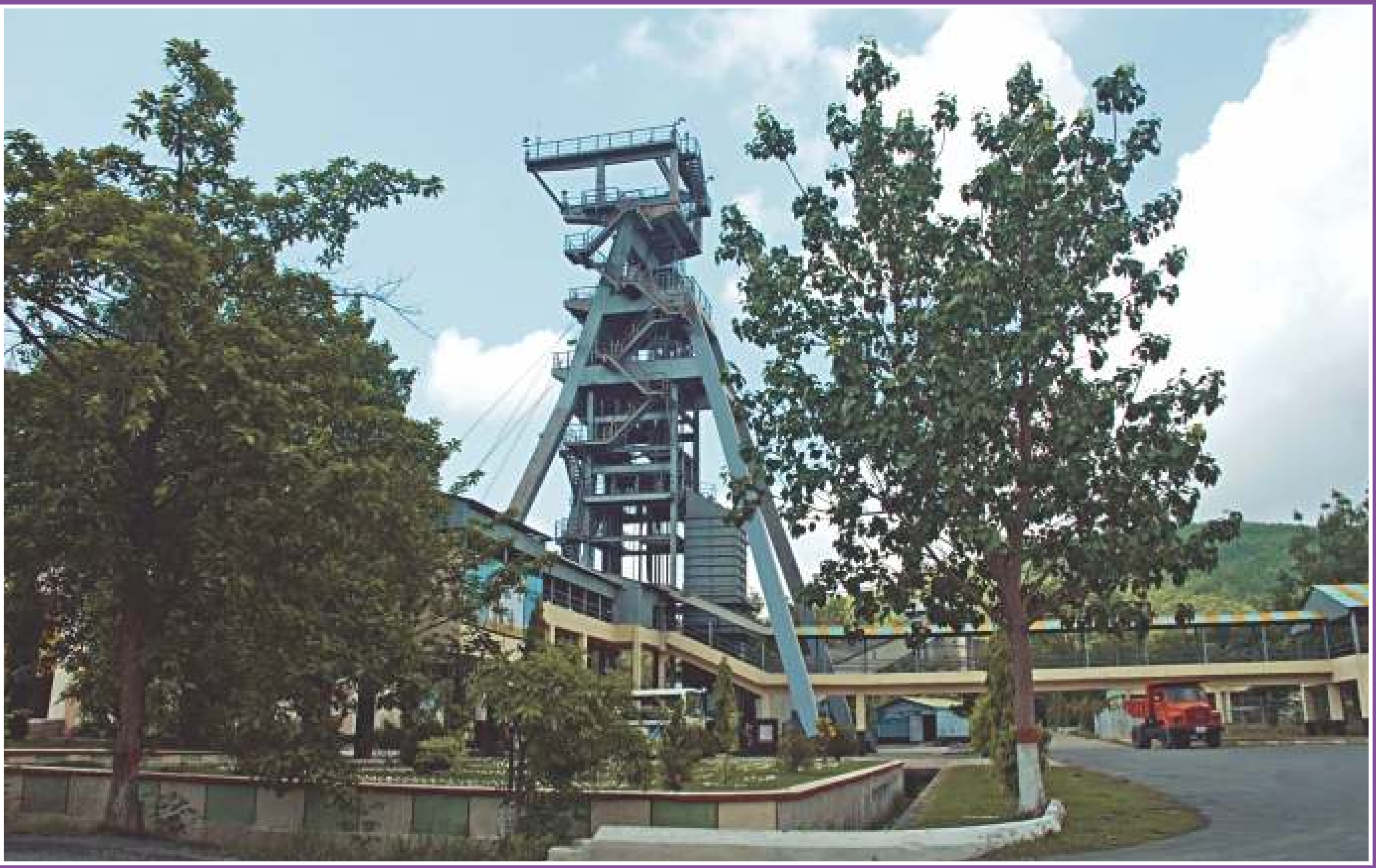
Impacts of R&D on Indian Mineral Industry Performance – Identifying New Priorities and Strategic Initiatives

Ajoy K Ghose   R N Gupta   Jayanta Bhattacharya



Indian National Academy of Engineering

The frontispiece shows an Indian underground metal mine (Courtesy: UCIL)

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FOREWORD

It is a pleasure for me to write this foreword to the INAE Study on "Impacts of R&D on Indian Mineral Industry Performance – Identifying New Priorities and Strategic Initiatives". The mineral industry in India has had a hoary tradition dating back to the days of Kautilya (circa 330 BC) and continues to underpin the Indian economy with a share of some 2.5% of the GDP. The minerals sector however is plagued by its low-tech labour-intensive visage and R&D has not made any significant inroad in upgrading its performance. The research topic was therefore of importance in assessing the contributions of R&D on the industry's performance metrics, especially on productivity, environment and safety, and in configuring a R&D roadmap for the long-term health of the industry. Predictably, the study has revealed the glaring lacuna in mining industry's R&D investment which has veritably been a miniscule with a research portfolio somewhat out of step with the requirements of the industry. Likewise, the study has identified the skill deficit that prevails in the minerals sector vis-à-vis research manpower, the lack of private sector investment in research and development, the low level of interaction between industry, academic and government research and failure to harness scientific results.

On behalf of the Academy, I must gratefully acknowledge the support of the Office of the Principal Scientific Adviser to the Government of India for funding the study. I must also appreciate the initiative taken by Dr. P.S. Goel , the then President of the INAE, who actively supported and approved of a raft of R&D studies, including the present one. I compliment the INAE Study team for their critical assessment of the impacts of R&D on Indian mineral sector and for envisioning a purposeful R&D Roadmap.

Dr. Baldev Raj
President, INAE

March, 2012

PREFACE

Mining is the process of extracting raw materials from the earth's crust and is the oldest vocation of mankind pre-dating agriculture. Since minerals are basic to our way of living, and the Indian minerals sector contributes to over 2.5% of the national GDP, this seminal study was initiated by the Indian National Academy of Engineering and received the support of the Office of the Principal Scientific Adviser to the Government of India.

This report has sought to assess the impacts of R&D on the performance of Indian mineral industry to prepare a roadmap for future research and development directions which could provide a purposive thrust to the minerals sector. The study has called for an in-depth enquiry and synthesis of the R&D studies carried out in the industry and sought to define the appropriate metrics of evaluation of performance which has tenuous link with R&D. A 2-round Delphi exercise was undertaken to elicit views of "experts from the minerals sector" to be able to crystallize the directions of future R&D thrusts.

The study was overseen by a Project Review and Monitoring Committee (PRMC) chaired by Shri R.K. Saha, Chairman and Managing Director of Central Coalfields Ltd. The Committee desired that the contributions of the impacts of ICT on mineral industry performance be highlighted and the status of "green" mining was also recommended by the Office of the Principal Scientific Adviser to the Government of India. A brain-steering exercise was undertaken on 3rd July 2010 at Kolkata to further refine the results of the Delphi exercise. Since R&D outputs are closely linked with the quality of research manpower, a survey on skill deficit in Indian mineral industry vis-à-vis R&D was also undertaken.

The study was hamstrung by inevitable barriers vis-à-vis access to R&D data initiatives from the industry and the government sources. Despite such shortcomings, hopefully, the study has been able to make a comprehensive and realistic assessment of the impacts of R&D on Indian mineral sector performance. This may be of value in guiding the formulation of future projects in keeping with the mandates of National Mineral Policy, 2008.

AJOY K. GHOSE
Principal Investigator

R. N. GUPTA
J. BHATTACHARYYA

March, 2012

ACKNOWLEDGMENTS

This study on the impacts of R&D on the performance of Indian minerals sector and identifying the trajectory of future research directions could not have been accomplished without the contributions of many individuals. The study was supported by INAE and the Office of the Principal Scientific Advisor to the Government of India and we acknowledge this support with grateful thanks. The Chairman of Project Monitoring and Review Committee Shri R.K. Saha and the members of the Committee Prof. U. K. Singh, Shri D. Dutta, and Prof. S. Dasgupta maintained an active interest in the Committee throughout the study. The Controller General of Indian Bureau of Mines and the Director General of Mines Safety provided invaluable information for the study. Dr. Amalendu Sinha, Director, Central Institute of Mining and Fuel Research and Mr. A. K. Singh, CMD, Central Mine Planning & Design Institute, Shri Akhilesh Joshi, COO, Hindustan Zinc Limited, Shri R. Gupta, CMD, Uranium Corporation of India, and Shri R. P. Ritolia, Advisor to the Managing Director of Tata Steel supplied background and pertinent information requested by the committee besides useful exchange of ideas. We are indebted to the respondents of the Delphi study and the participants at the Brainstorming exercise held on July 3, 2010 at Central Glass and Ceramic Research Institute, Kolkata. Prof. Indranil Manna, Director, Central Glass and Ceramic Research Institute extended valuable cooperation in hosting the event in his Institute. Dr. P. S. Goel, President, INAE enriched the Workshop by his valuable advice which was instrumental in establishing the framework of the study. The committee also wishes to acknowledge discussions with the several executives from the mining industry who gave their views on the research needs of minerals sector. We extend our thanks to Dr. Ketaki Bapat of the office of the Principal Scientific Advisor for help and guidance and to Shri Pradip K. Chanda, Executive Editor, Journal of Mines, Metals & Fuels for secretarial assistance and collating the report of the study.

ACRONYMS

BGML	Bharat Gold Mines Limited
BCCL	Bharat Coking Coal Limited
CCL	Central Coalfields Limited
CIL	Coal India Limited
CIMFR	Central Institute of Mining & Fuel Research (earlier CMRS)
CMPDI	Central Mine Planning & Design Institute
CMRS	Central Mining Research Station
CRC	Cooperative Research Center
ECL	Eastern Coalfields Limited
HCL	Hindustan Copper Limited
HGML	Hutti Gold Mines Limted
HZL	Hindustan Zinc Limited
IBM	Indian Bureau of Mines
ICT	Information and Communications Technology
IIT	Indian Institute of Technology, Kharagpur
INAE	Indian National Academy of Engineering
ISM	Indian School of Mines, Dhanbad
LHD	Load-Haul-Dump
LTCC	Longwall Top Coal Caving
MGMI	Mining, Geological and Metallurgical Institute of India
MOIL	Manganese Ore India Limited
MCL	Mahanadi Coalfields Limited
NEC	North Eastern Coalfields Limited
NLC	Neyveli Lignite Corporation
NCL	Northern Coalfields Limited
NMDC	National Mineral Development Corporation
OITDS	Operated Independent Truck Dispatch System
PSLW	Powered Support Longwall
SCCL	Singareni Collieries Company Limited
SDL	Side Discharge Loader
SECL	South Eastern Coalfields Limited
TDS	Truck Dispatch System
UCIL	Uranium Corporation of India Ltd.
VIMS	Vital Information Management System
WCL	Western Coalfields Limited

EXECUTIVE SUMMARY

Mining is the bedrock of our everyday life. Kautilya's Arthasashtra bears testimony to Indian heritage in minerals and mining and to its contributions to society. Mining is, was and shall continue to play a seminal role in Indian economy. This study on the impact of R&D on mineral industry performance, initiated by the Indian National Academy of Engineering (INAE), and funded by the office of the Principal Scientific Advisor to the Government of India has basically two goals: to evaluate the track record of R&D initiatives in Indian minerals sector in terms of their impact and relevance and to articulate a Roadmap for R&D for giving a propulsive thrust to the minerals sector and in turn to the national economy. As of today, mining and minerals contribute to over 2.5% of the GDP with a production of some 87 minerals, of which 4 are fuel minerals, 10 metallic, 47 non-metallic, 3 atomic and 23 minor minerals which aggregate to a total tonnage of over 1300 million tonnes valued at Rs.200,609 crores. This is produced from some 600 mines spread over the nation. Technologically, the minerals sector is a laggard and the introduction of new technology has been slow and halting. Surface mining is the predominant system in use which can be rated as a success story with increasing application of large sized draglines and shovels and widespread application of surface miners.

R&D *per se* had been launched in Kolar Gold Fields in 1904 when problems of rock burst first surfaced and called for scientific investigations; the Mining, Geological and Metallurgical Institute of India delved into problems of mine safety and subsidence way back in 1913. Organized research under the Council of Scientific & Industrial Research was mounted with the establishment of the Central Mining Research Station at Dhanbad in 1955 and over the past 55 years the Institute has rendered yeoman's service to Indian minerals sector. A premier centre for research in applied rock mechanics, the National Institute of Rock Mechanics, was set up in 1988 under the Ministry of Mines and has addressed a whole host of research and development issues in coal and non-coal mining arenas. A National Institute of Miners' Health was also established in 1990 which operates today from Nagpur with a limited infrastructure and research manpower to address specifically the occupational health of miners. To improve production, productivity and safety in underground metal mines, in-house Research Cells have been established in major state mining enterprises such as HCL, MOIL, UCIL, HGML, NMDC and at HZL, who collaborate with national research institutes and academic institutions like Indian School of Mines, I.I.T., Kharagpur and I.T-BHU, for seeking solutions to a wide array of problems. In the coal sector, the Central Mine Planning and Design Institute at Ranchi serves as the research arm of Coal India and also the nodal agency for coordinating coal S&T programmes. The Singareni Collieries Company Ltd., Neyveli Lignite Limited and National Mineral Development Corporation have also created limited research infrastructure for addressing their specific mining research needs. In government organizations in the minerals sector, the Indian Bureau of Mines and the Directorate General of Mine Safety have research wings for dealing with a wide variety of problems. Chapter 2 surveys the problem areas which have been addressed through R&D in these organizations since their inception.

Appropriate metrics for defining the "performance" of the minerals sector vis-à-vis deliverables of R&D are next examined which converge upon productivity and the track record in safety and environmental stewardship. Difficulty of access to international benchmarks, however, makes a meaningful comparison difficult. Causal relationships between research outcomes and productivity are equally tenuous to discern. R&D leading to technological innovations can be identified as the best measure for evaluating the research outcomes. Much of the innovations in Indian minerals sector have been of the "nuts and bolts" type of innovation and trials/demonstrations with new technology have been relatively few. Despite significant focus of attention on longwall performance, there are hardly any success stories and the only underground coal mining technology which has yielded good results is the "blasting gallery" method. Trials are currently underway in the application of highwall mining and surface mining sector has witnessed significant innovative developments in blasting techniques. Likewise, largescale application of surface miners in coal and limestone sectors is a noteworthy technology absorption case while the underground metal mining sector has been successful with "mass blasting" technique. Of significant impact has been the use of Georadar for slope monitoring. Technology changes on a broad front have resulted in improved safety records; there have been however a spurt in mine disasters which continue to mar the safety statistics. Environmental management has been an area of concern and much remains to be done in water management, solid waste management and development and application of best practice rehabilitation methods.

Green mining, even if some view it as a fad, is being espoused increasingly by the minerals sector aiming at footprint reduction of environmental damages, innovation in waste management, ecosystem risk management and sustainable use of mined out land. In China, green mining has a wider connotation with focus on preservation of mine water in mining areas, protection of surface structures with grout columns to retard bed separation and surface subsidence and underground waste disposal for effecting a harmonious balance between mining and the surrounding environment. Particularly, mine water can be thought of as a drinking water solution as most of the mining areas are also water deficit areas. The research agenda for green mining encompass a very wide front including structure protective mining techniques, progressive land filling and reclamation, recovery and reuse of wastes from tailings impoundments and more mundane research on noise, vibrations and fugitive dust.

Information and Communications Technology (ICT) has not made any major dent so far on the performance of the minerals sector. ICT remains however a potent bag of tools offering a source of solutions for a multitude of problems in the minerals sector. The sector-specific R&D in ICT in the minerals sector has received limited funding so far and included support for the development of Operator-Independent Truck Dispatch System (OITDS) at Jayant Opencast mine in Northern Coalfields Limited. Currently, there are 5 truck dispatch systems operating in the minerals sector; installation of 11 more imported systems in the coal sector is contemplated. With funding from DIT, CIMFR has worked on the development of wireless communication systems for underground mines (including trapped miner communication) and information and safety system for underground mines and proximity warning device for heavy earth moving machinery. With venture capital from the industry, Indian Institute of Management, Kolkata has developed software and hardware for managing enterprise resources through real-time tracking. Applications in the industry thus far have not been significant. There is an imperative need for demonstration of Vital Information Management Systems (VIMS) for machine health monitoring and development of 21st century Digital Mines.

A 2-round policy Delphi exercise was undertaken in the study to identify the areas of thrust for R&D in the future based on the views, judgments and opinions of a group of informed respondents. The response however was not satisfactory in terms of number of respondents. To crystallize the perceptions, a brainstorming exercise was undertaken through a workshop at Kolkata with some of the respondents, which helped to reconfirm the views on the future directions of R&D thrust. A second round of questionnaire was circulated based on the responses. In view of very low response, the results from the 2nd round are not included in the report.

R&D in the minerals sector has been plagued by skill deficit, both in terms of availability and quality of manpower for research. Despite the proliferation in the number of institutions offering degree courses in mining engineering, currently numbering 17 and with an intake capacity of 650, the two premier research institutions in the nation are unable to attract suitable and sufficient number of researchers for their expanding manpower needs. There is also a large disconnect between the industry and academia on the areas of research which would be relevant. The level of funding is a miniscule and the research output only of academic value devoid of any innovative content. The academics are also averse to supplicate for research grants despite availability of large funding from the Government.

Much remains to be done in formulating a grand R&D strategy for the Indian minerals sector to address key areas of concern of the industry in the next decade. There is a need to evolve such a vision for future R&D with strong institutionalization which could help strengthen the scientific and technologic bases of the industry and encourage competitiveness. Regrettably, the funding for R&D has been far too small in size, and the projects have been fragmented without much of a well-defined objective. For maximizing the R&D outcomes of impact and value, there is need for assembling a critical mass of resources and integrate research efforts by pulling them together in mega projects on a network of R&D institutions, academia and industry. There is an equally pressing need for funding major academic institutions for basic research in mining, preferably in the model of Cooperative Research Centres in Australia. The annexes to the chapters provide snapshots of several key research areas which call for funding on a private-public- partnership model. To help identify the priority research themes and in general to configure an appropriate research structure for the Indian minerals sector, the annexes also provide an overview to the evolving spectrum of R&D in the minerals sector in Australia, the United States and Canada. Indian School of Mines had set up in 1993 an experimental mine in collaboration with BCCL for performing live experiments in the underground mining environment. For a wide variety of research and field testing, the Indian minerals sector needs urgently to develop an experimental mine, as a national facility in the pattern of Canmet-MMSL experimental mine in Canada, Lake Lynn Experimental Mine in the United States, Queensland Experimental Mine or the Edgar Mine of Colorado School of Mines. The creation of an umbrella organization of a National Institute of Mineral Development, as recommended in National Mineral Policy,2008 also needs to be realized early.

Finally, a Road Map for future R&D initiatives over the next two decades is unveiled with focus on co-funding of research projects on Public-Private –Partnership mode which would lead to the identification of need-based projects and effective peer review of the projects with industry assistance. The substantial funding for support of R&D needs to be garnered through a new mechanism. Much of the funds for the enhancement of research and institutional capability should come from the mineral endowments to the local and central governments; however, the idea of levy of a cess on value of mineral production is mooted for the greater good of the minerals sector.

The report also highlights the formation of Public-Private Partnership (PPP) models and private sector participation in institutional development and industrial research. While the report carries the details, given below is a brief list of new research projects, institutions and centers that are required to fundamentally strengthen the mineral development of the country in the immediate future as well as to cover the yawning deficit of manpower and technology application, existing currently:

Actionable Items as Outcomes of the Study

This INAE Study has underscored the risk the country faces due to a very weak and fragile mining industry. It pinpoints the need for augmented R&D initiatives and rapid capacity building, the efforts and resources towards that have been miniscule in R&D and the visible skill deficit in minerals sector for R&D. In the light of the above findings, and the imperative to bridge these gaps, the study team would like to recommend substantial investments to overcome the near-moribund and lackadaisical state that prevails in the arena of R&D in the minerals sector. For overcoming skill deficit, a major effort is called for capacity building in R&D manpower by creating high-value Fellowships/Scholarships in selected post-graduate institutions in mining which can help attract and create a R&D talent pool. Substantial R&D investments are also needed in the areas of ICT, rock excavation engineering, and sustainable development issues affecting the mineral industry. Through this project, the INAE study team seeks to strengthen the institutional capabilities to make informed policy decisions through a suggestive roadmap as follows:

1. Creation of focused efforts through national centers of excellence in specific areas;
2. Launching mission-mode projects of relevance for the minerals sector's future and sustenance of mineral supply and
3. Enhancing the capability and capacity of the Existing National Laboratories.

The components of the roadmap may be elaborated in the following:

CREATION OF NATIONAL CENTERS OF EXCELLENCE IN THE GAP AREAS

Center of ICT for Mineral Industry

Objective: To help develop and refine appropriate application areas of ICT in the minerals industry for which aggressive and radical research only can provide solutions beyond the current scientific and technological framework. The Center will also provide guidance to different institutions on the current developments in Management Information Science and Technology.

Location: The Center should come up within or in the proximity of a reputed Institute

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is IIT, Kharagpur.

Budget : The Center will be initially funded with Rs.30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 crores for the 5 subsequent years. From the 7th year, grant should be on the basis of internal resource generation and a central matching grant.

Center of Rock Excavation Engineering

Objective: Center of Rock Excavation Engineering shall exist to cater to the many problems of blasting and development of mechanical rock excavation systems for which there is a crying national need as of present. The Center will provide research inputs to mineral and construction industry as well as the machine and cutting tool manufacturing units of the country

Location: The Center will come up within or in the proximity of a reputed Institute

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is ISM, Dhanbad.

Budget : The Center will be initially funded with Rs.30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 Crores for the 5 subsequent years. From the 7th year, grant should be on the basis of internal resource generation and the central matching grant.

Center of Sustainable Mineral Development

Objectives: Center of Sustainable Mineral Development will help to mount defensive research on regulatory and policy requirements on environmental issues and innovations that could safeguard national and mineral industry's long-term interests on sustainability through research on best practices.The Center will also advise the industry on the global best practices.

Location: The Center will come up within or in the proximity of a reputed Institute. The ideal candidate is Indian School of Mines, Dhanbad.

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering and the ideal candidate is ISM, Dhanbad.

Budget: The Center will be initially funded with 30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 crores for the 5 subsequent years. From the 7th year, grant should be on the basis of internal resource generation and the central matching grant.

Center of Mine Environment and Reclamation

Objectives: The Independent Center of Mine Environment and Reclamation that would conduct researches integrating environmental issues of mine development and mine closure, landform reconstruction and ecosystem development primarily focusing on technology development, testing,implementation and field engineering besides research on management of mineral industry waste.

Location: The Center will come up within or in the proximity of a reputed Institute having proven skills.

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is IIT, Kharagpur or ISM, Dhanbad.

Budget : The Center will be initially funded with 30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 Crores for the 5 subsequent years. From the 7th year, grant should be on the basis of internal resource generation and the central matching grant.

The Centers will be developed on the campus of a mining university or institution where post-graduate programmes in mining are being offered and could cooperate on areas of short-term research and training of manpower for future of mineral industry R&D. The CRCs will provide a multidisciplinary overview in research areas for the greater good of the minerals sector.The likely candidates will be Indian Institute of Technology, Kharagpur and Indian School of Mines.

LAUNCHING MISSION-MODE PROJECTS OF RELEVANCE FOR THE MINERALS SECTOR'S FUTURE AND SUSTENANCE OF MINERAL SUPPLY

In terms of immediate research relevance, the minerals sector needs to launch a number of mission-mode projects in specific areas. These include:

- Ventilation on demand for large underground mines in coal and non-coal sectors where payoffs could be substantial. Research funding of about 5 crores at a modest level would be adequate. Project duration will be 3 years.
- Demonstration project on thick seam mining using Longwall Top Coal Caving (LTCC) system. In view of the large national endowment in thick seam reserves the project is of great relevance. The project investment will be of the order of Rs.200 crores and the time frame would be 5 years. The project will be based on a networked synergy of coal industry and research establishments like CIMFR, and the DGMS amongst others.
    - Demonstration project on partial pillar extraction using the Duncan Method is also of seminal importance and the rationale for the project is the existence of over 2000 million tonnes of coal in developed pillars. Besides the coal industry, the project will be conducted on the synergy of CIMFR, the CMPDI and DGMS with a project investment of Rs.60 crores and will be completed in 4 years
    - Demonstration of a green mining project reclaiming a worked out surface mine back to reformed contours and economic use. The project investment will be Rs.75 crores and participating players will be CMPDI, a CRC and a coal/metal open pit mine. The project duration will be 5 years.
    - Demonstration of a green mining concept in an underground mine with progressive control of subsidence for preventing surface damage and underground aquifer. This will call for a networked project with the coal industry, CMPDI, CIMFR and an academic institution as partners. The project cost will be Rs.75 crores and will be completed in 5 years.
    - Demonstration of new and innovative technology in surface mines in the following areas:
    - Application surface miners for overburden removal
    - Use of International Rock Excavation Data Exchange Standard, IREDES, in surface mining industry
    - Demonstration and evaluation of techniques of highwall displacement monitoring using Ground Probe Slope Stability Radar(SSR) and Reutech
    - Remote Health Monitoring of excavating equipment (PreVail). Overall, the project investment for R&D will be Rs. 50 crores and the project duration will be 5 years.

Additionally, the mining industry needs to develop an Experimental Mine for live demonstration and testing in safety techniques and new equipment and for capacity building in R&D manpower support at mining institutions with attractive Fellowships. The total project cost will be Rs. 20 crores for the experimental mine and annual grant of Rs. 2 crores towards Fellowships. The Experimental Mine will call for annual expenditure of Rs.1crore towards maintenance. The conversion of an abandoned mine into an Experimental Mine will require a project duration of 3 years and will be a collaborative venture between CMPDI and CIMFR.

ENHANCING THE CAPABILITY AND CAPACITY OF THE EXISTING NATIONAL LABORATORIES

- Providing budgetary support to 2 premier National Laboratories to upgrade them to world class capabilities Rs.50 crores annually
- Develop a National Coal Research Center at Central Mine Planning & Design Institute to bolster R&D initiatives of coal industry- funding support of Rs.50 crores for 5 years

The Road Map, as unfolded above, is a suggestive model which can be implemented within the given time frames and will materially upgrade the Indian minerals sector's drive towards modernization, productivity enhancement and commitment to improved safety.

1.0 INDIAN MINERALS SECTOR – THE CONTEXT

Mining is a vitally important component of Indian economy and will continue to be the cornerstone of the nation's march towards a purposeful future. Before one can appraise the role of R & D and its impact on the minerals sector to configure a new strategy for R & D, it is necessary that we review the evolution of the sector and its current status of developments. Currently, the value of mineral production is estimated to be around Rs.206,000 crores (some US$ 40 billion), which constitutes about 2.5% of the gross domestic product. Indian minerals sector has the distinction of being the seventh largest mineral economy in the world. Sustainability of the minerals sector will be a critical issue in meeting the rising aspiration of its 1.21 billion population, who form the world's largest democracy. Equally critical will be the need for inclusive development and maintenance of the ecological and environmental integrity, issues which need to be addressed by the minerals industry proactively.

Indian minerals sector has had a hoary tradition dating back to 5000BC. Circumstantial evidences suggest that Rajasthan provided the earliest copper ores to chalcolithic India. Rajpura-Dariba near Udaipur provides the earliest C_{14} dated mine: 1260+/-160BC. Collating the various C_{14} data one can infer that Rajpura-Dariba mine was worked between 1260-1000 BC, and then again between 375 BC and AD 110; Rampura- Agucha lead-zinc and silver mine was operational between 370-200BC, and Hutti Gold mines in Karnataka around 760 BC. The mining industry's legendary past can be gauged from Kautilya's *Arthasastra*[1,2] (circa 330 BC) (Fig.1.1) which can rightfully lay claim to being the world's first mining tome.

India had a thriving gem mining activity in the past authenticated by traveller's accounts ranging from Al-beruni, Marco Polo and Ibn Battuta[3,4,5]. As one of the world's leading mineral producers, India today produces some 87 minerals which include 4 fuel minerals, 10 metallic minerals, 40 non-metallic minerals, 3 atomic minerals

Fig.1.1 A copy of Arthasasthtra *preserved at Oriental Research Institute, University of Mysore.*

and 23 minor minerals. Endowed with sizable mineral resources (Table 1.1), the nation is self-sufficient in resources of non-coking coal, lignite, bauxite, chromite, iron ore, manganese ore, titanium minerals, limestone, dolomite and India today is both a leading producer and exporter of a diverse range of minerals. Since Independence, India's mineral production has grown at a steady pace, from a level of total production valued at Rs.50 crores in 1950, it has attained a commanding height with a total production valued at Rs.200,609 crores. Fig.1.2 shows the rising trend of mineral production values by mineral groups in the recent past. Table 1.2 provides a snapshot of production from selected minerals in 2010-11 where the public sector continues to play a dominant role in coal and lignite, petroleum, iron ore, manganese ore, copper, chromite, and rock phosphate amongst others. India ranks 2nd in the global league table for chromite, talc/steatite/pyrophillite and barites, 3rd in coal and bauxite, 4th in iron ore and kyanite and 5th in respect of manganese ore. Table 1.3 highlights the contribution and rank of India in global production of principal minerals. Indian mineral industry presents today a

Table 1.1 Degree of self-sufficiency in respect of principal minerals and metals 2007-08 (P)

Commodity	Demand/domestic Consumption ('000 tonnes)	Supply/domestic supply ('000 tonnes)	Order of self sufficiency (%)
Minerals			
Asbestos	101	++*	%1
Barytes	126	1072	100
Bauxite	10628	23085	100
Chromite	1889	4798	100
Dolomite	663	5117	100
Felspar	312	411	100
Fireclay	534	460	86
Fluorite	71	7	10
Gypsum	6054	** 3055	50
Iron ore	81156	206452	100
Ilmenite	153	172	100
Kyanite	16	5	31
Limestone and Other calcareous Minerals	175419	*** 18860	100
Magnesite	254	248	98
Manganese ore	2496	2551	100
Rock phosphate (including apatite)	3885	1866	48
Rutile	19	19	100
Sillimanite	12	43	100
Silica minerals	1732	4280	100
Sulphur	1706	@ 486	28
Talc/steatite/pyrophyllite	303	1031	100
Metals#			
Aluminium	1315	1239	94
Copper (refined)	313	501	100
Lead (prime)	193	58	30
Zinc	482	457	95

Commodity	Demand/domestic Consumption ('000 tonnes)	Supply/domestic supply ('000 tonnes)	Order of self sufficiency (%)
Ferro-alloys$			
Ferro-chrome	151	933	100
Ferro-manganese	121	337	100
Ferro-silicon	46	83	100

Note: Although almost entire domestic demand is satisfied by domestic supplies, some quantities of certain special quality/types of minerals and metals/ferro-alloys are imported to meet the requirement in certain specific end-uses.

* Relates to chrysotile asbestos.

** Includes all the three forms of gypsum, viz. mineral gypsum, by-product marine gypsum and estimated production of by-product phosphor-, fluoro- and boro-gypsum.

*** Excludes production of limestone as a minor mineral.

@ Includes recovery of by-product sulphur from petroleum refineries and sulphur equivalent of by-product sulphuric acid recovered from copper and zinc smelters consuming indigenous ores and concentrates.

Apparent demand.

$ Excludes (++) negligible. (P) Provisional

Table 1.2: Mineral production, 2009-2011
(Excluding atomic minerals and minor minerals) – Mineral-wise

(Value in Rs. Crore)

	Unit	April 2009-March 2010		April 2010-March 2011	
		Qty.	Value	Qty.	Value
All Minerals			179384.01		200609.38
Fuel minerals			124088.33		135243.81
Coal	M.tonnes	532	49081.52	537	49011.64
Lignite	M.tonnes	34	3878.58	38	4240.19
Natural gas	mcm	47510	14780.03	58982	18488.83
Petroleum (crude)	M.tonnes	34	56348.20	38	63503.15
Metallic minerals			32274.29		41828.44
Bauxite	th.tonnes	13952	456.36	13363	502.66
Chromite	th.tonnes	3413	1183.41	3865	2089.76
Copper conc.	th.tonnes	124	362.54	161	486.34
Gold	Kg.	2106	331.39	2214	400.97
Iron ore	th.tonnes	218639	26864.84	212613	34852.37
Lead conc.	th.tonnes	136	174.34	136	181.70
Manganese ore	th.tonnes	2440	1269.54	2901	1428.49
Zinc conc.	th.tonnes	1277	1290.85	1342	1641.02
Other Met. minerals			341.02		245.12
Non-Met minerals			4286.94		4802.69
Ball clay	th.tonnes	898	18.88	1021	20.13
Barytes	th.tonnes	2138	234.97	1774	196.45
Diamond	crt	16810	11.59	71381	54.45
Dolomite	th.tonnes	5182	144.79	4724	154.22
Fireclay *	th.tonnes	410	6.62	285	5.02
Garnet (abrasive)	th.tonnes	1566	74.09	2724	144.78
Gypsum	th.tonnes	3422	95.86	4557	137.38
Kaolin	th.tonnes	2578	69.89	2488	56.64

	Unit	April 2009-March 2010		April 2010-March 2011	
		Qty.	Value	Qty.	Value
Laterite	th.tonnes	1221	17.32	915	10.36
Limeshell	th.tonnes	62	4.86	23	1.88
Limestone	th.tonnes	229	2986.23	240	3220.21
Magnesite	th.tonnes	286	42.26	291	42.17
Phosphate	th.tonnes	1547	312.01	1651	423.21
Pyroxenite	th.tonnes	279	15.39	303	14.61
Sand (others)	th.tonnes	2159	10.20	2457	11.86
Silica sand	th.tonnes	2283	29.82	3861	41.15
Sillimanite	th.tonnes	31	25.50	32	33.03
Steatite	th.tonnes	835	52.74	1006	66.16
Wollastonite	th.tonnes	132	11.19	200	16.74
Other non-met.min.			122.73		152.23
Minor minerals			**18734.45**		**18734.45**

Table 1.3 Contribution and rank of India in World Production of principal Minerals and Metals, 2008

Commodity	Unit of quantity	Production		Contribution %	India's rank in order of quantum of production
		World	India*		
Mineral fuels					
Coal and lignite	Million tonnes	6619	525	7.9	3rd
Petroleum (crude)	Million tonnes	3911	33.5	0.9	25th
Metallic minerals					
Bauxite	'000 tonnes	212000	15554	7.3	6th
Chromite	'000 tonnes	23300	3980	17.1	2nd
Iron ore	Million tonnes	2188	215	9.8	4th
Manganese ore	'000 tonnes	41800	2829	6.7	5th
Industrial minerals					
Barytes	'000 tonnes	9700	1682	17.3	2nd
Kyanite, andalusite and sillimanite	'000 tonnes	**440	38	8.6	4th
Magnesite	'000 tonnes	24000	246	1.0	10th
Apatite and rock phosphate	'000 tonnes	166000	1764	1.0	16th
Talc/steatite/pyrophilite	'000 tonnes	7600	1067	14.0	2nd
Mica	tonne	380000	1206 0.3		15th
Metals					
Aluminium	'000 tonnes	39400	1347	3.4	8th
Copper (refined)	'000 tonnes	18000	502	2.8	11th
Steel (crude/liquid)	Million tonnes	1329	54@	4.3	5th
Lead (refined)	'000 tonnes	9400	60	0.6	23rd
Zinc (stab)	'000 tonnes	11700	579	4.9	5th

Source: World mineral production data compiled from World Mineral Production, 2004-08, British Geological Survey
* Figures relate to 2007-08
** Mineral Commodity Summaries, 2010, US Geological Survey
@ Annual Report, 2009-10, Ministry of Steel

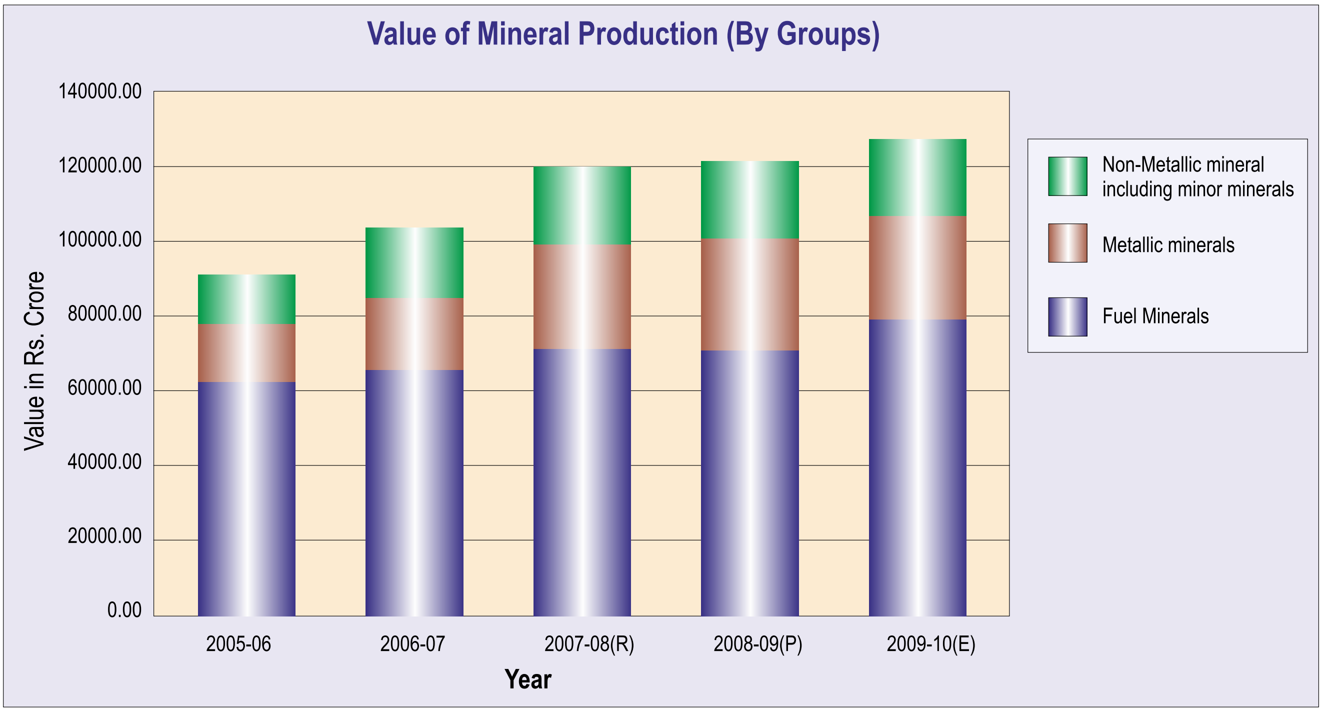


Fig.1.2

variegated picture of evolving technology development, from near-primitive mining practices to world-class technology and there has been kaleidoscopic changes in the policies espoused by the State vis-à-vis the minerals sector. The proposed amendments to the Mines and Minerals (Development and Regulation) Act will bring about radical changes in the mineral industry scenario which continues to be characterized by relative predominance of small-scale mining and low technology status with concomitant low productivity levels. Some 2628 mines reported mineral production in 2010-11 which included 574 coal and lignite mines, 608 metallic mineral and over 1446 non-metallic minerals. This was exclusive of operating mines for minor minerals and provided employment for nearly 1.1 million miners.

India is the third largest hard coal producing country in the world after China and the USA. With 114 billion tonnes of proven coal reserves out of a total geological resources of 285.86 billion tonnes, India accounts for about 9% of world coal reserves. Coal is the dominant mineral produced in India and its early beginnings can be traced back to 1774 when Sumner and Heatly sought the permission of Warren Hastings, President of East India Company for working coal mines and selling coal in Bengal. William Jones discovered the workings of Heatly in 1815 and was the first mining engineer to open a mine by sinking shafts. Carr, Tagore & Co was formed in 1835 which was later taken over by Gilmore, Homfray & Co and 1843 saw the birth of Bengal Coal Co. and witnessed the first organized attempt to exploit coal in the country. The Hyderabad (Deccan) Company Limited, was incorporated in 1920 with the name of Singareni Collieries Company Limited (SCCL), as the first government company under the Companies Act. The coking coal mines were taken over for public management on 16th October, 1971 and the non-coking coal mines on 1st May, 1972. Subsequent to this wave of nationalization, the Coal India Limited was formed on 1st November, 1975 which is the single largest hard coal producing company in the world and contributes today to about 81% of the total coal production in India. The nationalized sector (CIL and SCCL) contributes 90.6% of Indian coal output, where the share of opencast coal production is 90% and underground mines contributing only 10%. The coal industry's track record in technological progress has been somewhat dismal with focus on intermediate technology in underground mines; opencast coal production however is a "success" story with large capacity draglines (24 cub.m bucket size), shovels (42 cub.m shovels), 240 tonne dumpers and surface miners contributing to the coal production (Figs.1.3 &1.4). There is

Fig.1.3 An operating dragline in Northern Coalfields Ltd

scope enough for scaling up the equipment size for improved productivity. There are 5 truck dispatch systems in use and 11 more are to be commissioned shortly. In terms of innovative technologies, highwall mining is being tried out and for improving availability and utilization of equipment the concept of long term Maintenance and Repair Contract (MARC) is being explored. In underground sector, CIL has a fleet of some 722 Side Discharge Loaders (SDL), 304 Load Haul Dump (LHD) units, 5 Continuous Miners (Fig.1.5) 6 Roadheaders, and 5 powered support longwall faces (PSLW) while SCCL has 2 sets of Continuous Miners and 2 PSLW faces and at one site a Highwall Miner has been commissioned.

A state-of-the-art PSLW face is to be commissioned in Adriyala mine of SCCL in 2012. The assimilation of Information and Communications Technology (ICT) in Indian coal sector has been somewhat slow and halting. However, there are ambitious plans for implementing SAP in CIL to integrate all its units encompassing 473 units spread over 9 states.

In the non-coal sector, the mineral industry has made rapid strides in the production of iron ore, limestone, bauxite, dimension stone, lead and zinc, much of which is surface mined. Organized mining for gold was started by M/s John Taylor & Sons way back in 1880 in Kolar Goldfields and represents a new genre of underground mining. One of the mines of KGF reached a depth of over 3200 m and was ranked as the deepest mine in the world. Over its lifetime, KGF estimatedly produced over 820 tonnes of yellow metal. The first rock burst was experienced in Champion Reef mine in 1898 which triggered research into the causation of rock bursts[49,82]. Of the 85 underground mines in the non-coal sector, major mines include 6 mines of HZL, 3 mines of HCL, 5 mines of UCIL, 7 mines of MOIL, some 5 mines of chromite and 3 gold mines of Hutti Gold Mines Ltd. By and large, the underground mines in the non-coal sector are relatively small when benchmarked against the global scenario. In the iron ore sector, which has witnessed a massive production increase, 100% of the production of 218 million tonnes comes from surface mines, with an average mine size of 0.7 million tonnes; the largest mine at Kudremukh with a production capacity of 22.5 million tonnes had to be closed in 2006 arising from a Supreme Court verdict on environmental degradation. Mining for limestone also witnessed a significant jump with a

Fig.1.4 A surface miner in use in Mahanadi Coalfields

production of 240 million tonnes in 2010-11. Limestone mining has emerged as a proactive,mechanized and well managed mining sector where Surface Miners have made a major inroad as production system. The current population of surface miners in Indian minerals sector is around 125, which represents the largest deployment in the world.

The overview has provided the broad canvas of the context that the Indian minerals sector presents today and prompts a SWOT exercise to assess critically the strengths, weaknesses, opportunities and threats that confront the sector. Such a situational analysis would help in identifying and configuring the challenging and innovative goals for R&D to bridge the gaps, where they exist. A generic situational analysis leads to the following assessment for the Indian minerals sector:

Strengths

- Sizable resource endowment in a wide variety of minerals
- Availability of skills, both managerial and technical
- Large domestic market which can support resource-based industrialization
- Legal framework and enabling environment for orderly development are in place and there is no country risk in new investment
- The nation has a genuine competitive advantage in geological prospectivity, reasonable infrastructural base and a highly competent IT industry for future trajectory of growth

Weaknesses

- Because of low productivity and lack of state-of-the-art technology, often arising out of small-sized mines, the minerals sector is not competitive in the international arena
- The industry lacks foresight, long-term strategic planning and mineral intelligence

- The environmental performance of industry leaves much to be desired. The industry is looked upon as an environmental predator and invites increasingly stringent regulatory controls. The industry also has a legacy of past environmental damages
- The minerals sector lacks adequate infrastructure for research, design and development; there is also a critical skills shortage for research
- Lack of change agents in the minerals sector and the mindset is also archaic and obscurantist with neglect and lack of initiatives for R&D in the sector
- Poor overall image of the minerals sector

Fig.1.5 A Joy continuous miner at work

Opportunities

- India could emerge as a world-class mineral economy if major structural and economic reforms could be implemented. The realization of the full economic potential of the minerals sector would propel the nation to scale new heights
- With more positive and proactive stance, the minerals sector could unfetter itself and overcome the environmental and other road blocks to mineral development
- There are emerging opportunities for value addition to mineral commodities as mined through emphasis on mineral processing, thus enlarging the resource base and enhancing the sector's economic contributions
- Through technology upgradation and investment in R&D, the minerals sector could significantly reduce costs, improve safety performance and generate sustainable productivity improvements

Threats

- Unless the minerals sector could demonstrate its resource stewardship and launch green mining initiatives through R&D, the industry could face major constraints and roadblocks from an increasingly strident civil society
- High cost of energy input, scarcity of water and access to land for exploration or for waste disposal could be serious issues of concern for minerals sector's organic growth.

Cost cutting, productivity improvement, higher energy efficiency and improvement of environmental performance would all critically hinge upon new technology and innovations through R&D.

Indian mineral industry is on the throes of rapid changes, both in terms of overarching policies and technological developments. The primitive technology façade is being replaced by a focus towards high-tech though the industry is still regarded as insular and resistant to change. New winds of change are sweeping the mineral industry scene and development of new energy resources like coal bed methane open up new opportunities and challenges. It is in this backdrop that we need to examine the contributions of R&D in Indian minerals sector and its impacts in shoring up the industry's performance towards a vibrant future.

2.0 R&D IN INDIAN MINERALS SECTOR – AN OVERVIEW

Research is quintessentially a trigger for technological breakthrough and innovation which could help improve the competitiveness of the minerals sector, enhance safety, environment and productivity performance. While technology is a lever for amplification of human effort, innovations can range from "nuts and bolts" type of incremental advances, conceptual breakthroughs and to the design of large new systems. We examine in this chapter the evolution of R&D infrastructure in Indian minerals sector over the past and enumerate the R&D initiatives undertaken in coal and non-coal sectors for problem-solving in the industry. It needs to be clearly understood that the need for applied research was not well perceived, what with the small, fragmented and shallow mines which continued to be labour-intensive and largely devoid of any technology support. In the early 20th century, problems of mine safety, including fires, explosions, ground control and inundations merited the attention of professional societies and the Mining, Geological and Metallurgical Institute of India (MGMI)[6,7] launched some investigative/research studies in Indian mining. The work of the First and Second Subsidence Committees set up by MGMI (1913, 1927) could rank amongst the pioneering studies in the area of subsidence engineering in the world. Likewise, commendable work on problems of coal dust explosion was carried out under the aegis of MGMI, including laboratory and gallery studies at Indian School of Mines, Dhanbad. It is significant to note that some academic institutions also initiated research studies such as on coal preparation by Rev. E.H. Roberton at Shibpore engineering college (now Bengal Engineering and Science University, Shibpore) during the World War I and Dr. David Penman researched on the strength of Indian coals and problems of mine ventilation at Indian School of Mines. In his Presidential Address to the Mining, Geological & Metallurgical Institute of India in 1932, Dr.Penman highlighted the need for coal research and the role that Indian School of Mines could play. In the metalliferrous mining sector, the need for organized research was felt in the Kolar Gold Fields where problems of ultra-deep mining, and of rock bursts and heat stresses called for concerted research efforts to solve some of these vexed problems[49]. The first Special Committee to enquire into the problems of rock-burst was set up in 1936 and a major programme was launched under the auspices of the Rockburst Research Committee (1955) and the work was continued until 1972 with the guidance of Prof. E.L.J.Potts of the University of Newcastle upon Tyne.

2.1 Post-Independence: Organized R&D Initiatives

The Coal Mining Committee of 1937 and later the Indian Coalfields Committee of 1946 stressed the need for setting up an institution for initiating, organizing and directing research into the many and varied problems of coal mining industry. The Coal Mines Stowing Board undertook, in the interregnum, some useful studies on hydraulic sand stowing in early 1940s while private sector coal mining companies, Bengal Coal in particular, carried out limited research studies on mining methods, ground control, ventilation and hydraulic stowing for improving their operational efficiency.

2.2 Central Institute of Mining & Fuel Research (CIMFR), Dhanbad

The idea of setting up a central research institute finally took shape when the Council of Scientific and Industrial Research (CSIR) and the Coal Board constituted an Advisory Board for the proposed mining research station in 1954. The Central Mining Research Station (CMRS) came into being in 1955 and since then as a national institute provided a major impetus to research activities on a wide front. Dr.J.W. Whitaker, the first Director, was instrumental in giving the institute its shape and direction and CMRS has provided a propulsive thrust to five major R & D areas and missions, namely: Geomechanics and Mining methods for coal and metal mines, safety, environment and miners' health. As the premier national laboratory, CMRS has had an excellent track record in problem-solving and development of all aspects of technology for coal and non-coal mining. Currently, the Institute has been rechristened as the Central Institute of Mining and Fuel Research (CIMFR) with the merger of the Fuel Research Institute with the avowed mission "to be the world leader and path setter in Mining & Fuel Research". There are regional centres of CIMFR at Roorkee and Nagpur. Over the past 55 years, as a national laboratory, CIMFR has rendered yeoman's service to the minerals sector, especially through consultancy for problem-solving. Amongst the major contributions of the institute include:

- Development of safe mining methods and assessment of stability of workings
- Design of stowing systems for stabilization of mine workings
- Design of best practices in blasting and rock fragmentation
- Assessment of subsidence and ground movement due to mining
- Development of Environmental Management Plan for eco-friendly mining
- Investigations on methane emission and development of GHG inventories
- Evolution of methods and tools to combat mine fires and many "success" stories of controlling fires
- Design of support systems in mines
- Design and development of equipment for productive and safe mining

CIMFR also extends testing, evaluation, calibration and consultancy services for explosives and accessories, safety equipment, roof supports, measurement of in-situ stress, flameproof and intrinsically safe equipment, wire ropes, cage suspension gear, and monitoring of air, water, noise, vibration and other polluting agents and has a total complement of 100 scientists engaged in mining industry related R&D. There have been some change of course over the years with engagement in hydroelectric projects, and construction activities amongst others. The

Fig.2.2

research organization has also undertaken some mega network projects such as on coastal placer mining, development of refuge chambers, and development and application of robots for underground use. The Institute holds some 375 patents and made significant contributions in upgrading safety in Indian minerals sector. Even if it is invidious, a comparison with China Coal Research Institute (CCRI) might be appropriate here to benchmark CIMFR with an overseas research organization. CCRI is the only national institute for the coal sector in Peoples' Republic of China and was established in 1957. The institute has 17 branches, institutes, centres and companies located in 11 cities such as Beijing, Shanghai, Xi'an, Taiyuan, Nanjing and others with a total staff strength of 4800, amongst which 66% are technical/scientific staff, 3 Academicians and over 1030 senior engineers. Over the years, CCRI has transformed itself from a R&D Institute to a R&D Trading Institute launching the Tiandi Science and Technology Co. Ltd (TDTEC) in 2002 which channelises the consultancy, testing services and equipment sale of CCRI. The main research areas and industrial orientation of CCRI include geological exploration and mine surveying, mine construction and underground special construction technology, development of technology packages for mechanized mines, comprehensive prevention and control technology for mine safety, mine environment protection technology, coal mine economics research and information technology applications and others. Any comparison between CIMFR and CCRI reveals the differences in scale of operations, and the dispersal of research infrastructure across the country enabling focused areas of research and ready access to the coal industry. The concept of R&D Trading company also provides for improved marketability and access to industrial R&D. Figs.2.2-2.5 show views of the main building at CIMFR and its laboratories.

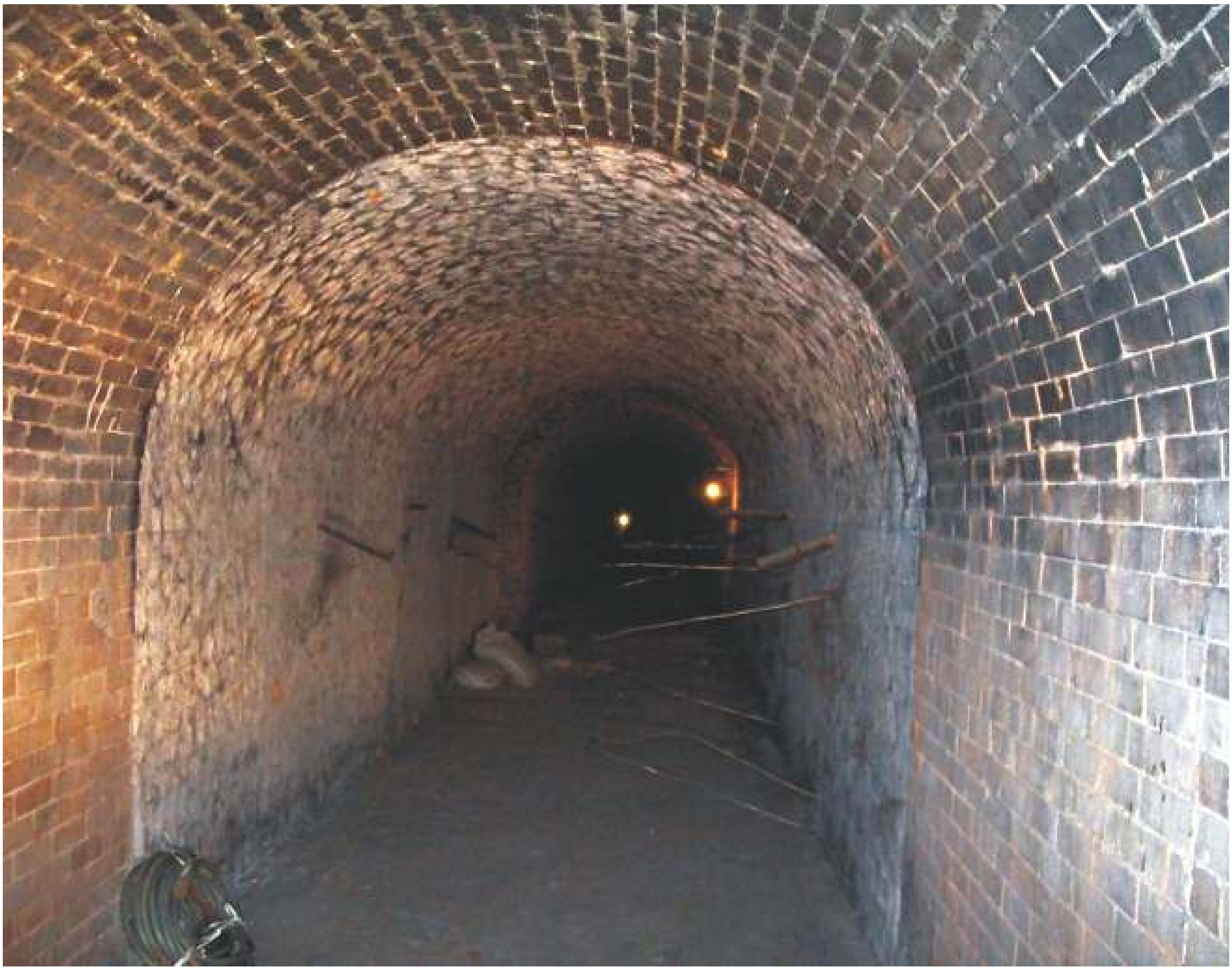


Fig.2.3 Fire gallery

Fig.2.4 Blasting gallery

Fig.2.5 Explosives laboratory

2.3 National Institute of Rock Mechanics (NIRM), Kolar

A premier centre for research in basic and applied rock mechanics, NIRM was set up in 1988 as an autonomous research institute under the Ministry of Mines. The Institute offers research and consultancy services to mining, civil and construction industry in India and abroad. Currently, the Institute has a staff strength of 80, out of which 54 are scientists and the areas of expertise span the disciplines of Engineering Geology, Engineering Geophysics, Engineering Seismology, Rock Fracture Mechanics, Numerical Modelling, Slope Engineering, Rock Blasting and Excavation Engineering, Ground Control and Mining Technology, Underground and surface mine design, Environmental Engineering and Dimensional Stone Technology. In the past two decades, the R&D activities related to non-coal mines conducted by NIRM include:

- Design of stope specifications for mines of HZL, HCL, MOIL, HGML and a few other mines using U-DEC or 3-DEC software packages and inputs from in-situ stress determinations
- On-site ground control investigations with instrument arrays to optimize stope parameters and to promote safety
- Pit slope stability and optimum safe slope angle mainly for iron ore and limestone mines
- Extensive studies on blast vibrations and air overpressure and development of predictive models
- Technical guidance and advise in several granite quarries

NIRM has diverted of late much of its R&D focus towards hydroelectric projects and geotechnical studies at nuclear power plant sites which have given sizable funding for such investigations. In consequence, the projects in mines have partly suffered by default. The Institute needs to focus on its core competency, namely geo-mechanics, and provide its problem-solving skills for the benefit of the minerals sector. The Institute must aggressively seek to garner large research funding for basic research in rock mechanics to justify its role as a national laboratory devoted to rock mechanics. Fig.2.6 shows a view of the NIRM building at Champion Reef, Kolar.

Fig.2.6 NIRM building at Kolar

2.4 National Institute of Miner's Health (NIMH), Nagpur

The Institute was established in 1990 as an autonomous body under the Ministry of Mines to address exclusively the occupational health problems of miners arising out of their long exposure to the mining environment. Some R&D studies have been conducted by the Institute in the areas of occupational health including airborne respirable dust monitoring, personal sampling near breathing zone of workmen, studies on noise, vibration and illumination. Investigations have been completed in two iron ore mines, and one limestone mine for evaluating prevailing work environment so as to be compliant to DGMS statutory requirements. Scientific studies currently under way include:

- Investigation of toxic contaminants of lead, iron and mercury in water samples near metalliferrous mines of Chhattisgarh
- Respiratory morbidity among miners in Rajasthan
- Vibration exposure due to heavy earth moving machinery in surface mines
- Risks due to vibrations in Indian mines

The Institute is still in a nascent stage of development and lacks adequate research manpower and laboratories.

2.5 National Environmental Engineering Research Institute (NEERI), Nagpur

This Institute, under the umbrella of CSIR, has completed some investigative studies in non-coal mines on reclamation of degraded land and waste dumps through revegetation and bio-technology. Revegetation was successfully accomplished in spoil dumps at Gurgaon Manganese mine, Iron Ore mines of Sesa Goa Limited and mill tailings of Zawar mines of HZL. NEERI is also credited with the development and application of Microbe Assisted Green Technology (MAGT) for accelerated reclamation of overburden dumps.

2.6 Mining Research Cell of Indian Bureau of Mines, Nagpur

The Mining Research Cell at Indian Bureau of Mines was set up in early 1972 as a part of TMP Division with a view to conduct applied mining research to serve the growing needs of the mining industry. Thus far, it has undertaken an assortment of medium-sized research projects on slope stability monitoring in wollastonite and calcite mines in Rajasthan, stability of tailings dam in Goa, monitoring of ground vibrations due to blasting at limestone mines, preparation of EMPs and mine plans besides contributing to the publication of specialized monographs on mining technology. The activities of the Mining Research Cell have been limited of late and recent studies have focused on study of pollution level in 19 asbestos mines and processing plants in Rajasthan and a S&T project on hexavalent chromium attenuation by bio-remediation. Under an Indo-French collaboration project with BRGM a study on "Development of Application Techniques in relation to Environmental Management of Mines and Waste Recoveries" was conducted between 1996-2000. Under this study, two Regional Environmental Impact Assessments were carried out in Iron Ore mines in North Goa and chromite mines of Sukinda Valley in Orissa.

2.7 R&D activities at Directorate General of Mines Safety, Dhanbad

R&D Cell at the DGMS is addressing a number of research areas which comprehend the *inter-alia* following:

(i) Explosive and blasting to study the characteristics of explosives with blasting parameters using latest technology and instruments

(ii) Illumination studies and the effects on mine workers

(iii) Dust analysis and its control measures

(iv) Slope stability and dump profile studies

(v) Strata control over longwall faces

(vi) Supports parameters and standards

(vii) Mine environment monitoring

(viii) Mine communication with tracking devices

(ix) Refuge chambers

(x) Develpment of new methods of mining

2.8 R&D in Public Sector Organizations – A Panoply of Projects

Since SMEs had reached commanding heights in Indian minerals sector, it was but natural that they would invest in creating a modicum of R&D infrastructure for in-house problem solving or for seeking external assistance, as and when necessary. We seek to collate here the research studies undertaken at the Public Sector Units and also in governmental organizations, if only to highlight the directions of such research initiatives. The Research and Development Centre at NMDC, Hyderabad started as a nucleus R&D Cell in 1970 and today has developed into a sophisticated R&D centre with research in the following areas:

- Upgradation of processing technology of existing process plants for better productivity and meet the customer requirement.
- Development of technology for utilization of mine wastes.
- Development of value added products.
- To extend its expertise to in-house projects of NMDC and other domestic and foreign organizations, in the field of mineral processing, hydrometallurgy, agglomeration, bulk solids handling, mineralogy and chemical analysis.
- Identification of new projects and development of cost effective process technology in tune with the long term objectives and strategic plans of the corporation.

The NMDC also has developed a Centre of Geostatistics, unique of its kind in India.

2.9 Centre for Applied Research and Development (CARD) at Neyveli Lignite Corporation (NLC)

Amongst the mining-related projects launched by CARD include:

- Land reclamation in mine spoil which was a pioneering and successful initiative of NLC
- Water conservation measures and artificial recharge of deep-seated aquifers

These apart, CARD has worked on the extraction of humic acid from lignite and utilization of fly ash and its disposal.

2.10 Central Mine Planning and Design Institute Ltd, (CMPDIL), Ranchi [10,11]

Organised research for facilitating and upgrading the research capabilities in coal industry started only after the adoption of "Coal Science and Technology Plan" by the Government in 1975. This has been the major stimulus for a plethora of R&D projects to be launched comprehending a spectrum of subjects from coal exploration to post-mining environmental issues. Central Mine Planning and Design Institute is the nodal agency for coordination and monitoring of Coal S&T and CIL R&D Board allocations for projects. The Coal S&T Programme is currently administered through an Apex body known as the Standing Scientific Research Committee (SSRC). CMPDIL is also the in-house research arm of Coal India Limited (CIL) and has developed excellent research and testing facilities for R&D. It has also undertaken a raft of projects in the areas of evaluation of explosives, rock blasting, strata control and ground subsidence besides projects in the area of environment and ecology such as remote sensing for assessment of vegetative cover in and around surface mines. Since inception in 1976-77, Coal S&T grants up to 2010 (December) aggregatively amounted to 194.47 crores, with annual investment in projects as given in Appendix 2.1. The allocation of R&D funds from SSRC for different research areas namely mining methods, strata control, blasting, ventilation and fires and development of new equipment are also given in the Appendix 2.2.

Since inception of organized research in the coal sector, 315 research projects were completed and 52 research projects, with outlay of Rs.236 crores, are under implementation by various academic and research institutes in association with coal and lignite producing companies. Out of this, 24 projects are under implementation by CMPDI alone or jointly with total outlay of Rs.134 crores.

R&D expenditure increased substantially by 127% during X Plan, compared to IX Plan and is expected to be significantly more by XI Plan end.

Many of these projects yield considerable benefits in operational improvement, safer working conditions, resource recovery and environment protection. While some research projects produced tangible impact on industry directly, there are others which strengthened more planning, design and technical services required by mines/projects. Design tools are now available for a variety of problems, like underground coal pillar design, analysis of roof cavability and stability of partings between multiple seam workings, surface subsidence prediction, optimum blast design for various rock conditions. CMPDI sponsored research studies for quantified assessment of roof strata – the "Rock Mass Rating" – which is in use for support design in underground mines. So far, over 600 underground workings in over 350 mines have been covered for assessment of roof rating.

Under R&D, trials of mining methods like 'blasting gallery and cable bolting' were conducted for coal recovery from thick seams. 'Shortwall mining', which was introduced at SECL with over 1000 tpd output, is being replicated in more panels at SECL. "Control blasting technique' is being used for excavation in opencast mines near surface structures without endangering safety of inhabitants. Over 125 Mt coal was extracted in over 100 mines which otherwise would have remained sterilized.

For safety of underground workings, significant progress through R&D has been focussed for introduction of modern techniques like ground penetrating radar for detection of old unapproachable water logged workings. This technology has provided a major tool for enhancing safety in underground mines close to water logged workings.

In India, the reserve of coal bed methane, a clean energy source, is around 3.4 trillion cubic meter. A research project, undertaken by CMPDI to recover CBM and its utilization, was completed and gas produced is being used to run gas generators for electricity generation.

Periodic opencast overburden excavation measurement by conventional method is time taking. A research project was undertaken by CMPDI to apply a new technique using airborne laser terrain mapper and ground based terrestrial laser scanner. Correlation between surface and underground mine survey is of importance to obviate risk of inundation, subsidence and fire. Conventional correlation method with manual Gyroscope (GAK-1) is time consuming besides being of lower accuracy. Under a CIL R&D project for developing a methodology for rapid and accurate correlation survey, the system and technique devised with automated gyroscope (Gyromat3000) was tested by CMPDI and it was concluded that method with Gyromat3000 is more accurate and rapid.

A number of research projects has yielded considerable gains in reclaiming areas after mining, fly ash utilization and humic acid extraction.

A number of research projects, taken up to integrate coal mining activities with ecological conservation and reducing hazardous impacts of mining, have resulted in adoption of proper environmental control.

New areas, like application of robotics and latest two-way communication systems for rescuing miners trapped in underground mines, CBM/coal mine methane/abandoned mine methane recovery and utilization, are also being addressed through ongoing research projects.

Future R&D efforts will address frontier areas like liquidation of developed pillars, slope stability in opencast mines, hydraulic mining, underground coal gasification, coal liquefaction, 'zero' emission coal combustion, carbon sequestration through bio-sequestration in coal mining areas, 3D seismic survey for coal exploration and CBM resources estimation.

Recently, CMPDI on behalf of the Ministry of Coal, has invited expression of interest for following 15 research topics:

1. Effective method to extract coal standing on pillars below infrastructure/developed area without stowing.
2. Safe parting between underground and opencast workings for simultaneous mining.
3. Design and development of procedure to assess safe barrier width for advancing benches in opencast mines.
4. Development of online remote field analysis and monitoring system for (a) optimal blast design (b) fragmentation measurement and (c) fly rock risk assessment.
5. Introduction of water jet cutting technology in coal mines for seams on fire.
6. CBM reserves estimation for Indian coalfields.
7. To produce 10% or less ash clean coal from washery slime.
8. Online washability analysis by using CT system.
9. To study the caving behaviour of roof rock due to presence of OB dump on the surface/quarry floor and suggest suitable support design as well as minimum hard cover for safe caving of roof rock.
10. Fugitive emissions of methane gas from opencast mines.
11. Early warning system for roof fall prediction in underground mines.
12. Early warning system for predicting dump or highwall failures in opencast mines.
13. High concentration fly ash slurry stowing in underground coal mines.
14. Shale gas estimation in coalfields.
15. Development of technology for remote operation in underground coal mines.

CIL R&D Board projects have been of a different scale with higher investment. Table 2.3 summarises the status of on-going projects under CIL R&D Board funding.

Table 2.3 Status of on-going CIL R&D Board projects (As on 04.09.2011)

	Project Name	Month & year of start	Month & year of completion	Total appr. cost, lakhs	Disbursment progressive
1.	Indigenous development of PLC based integrated control and monitoring system for conveyors in underground mines Project code: CIL/R&D/1/26/08 Implementing agency: RDCIS (SAIL) & CMPDI	August 2006	Feb 2011 Sep 2010 Mar 2010	182.00 RDCIS 145.50 CMPDI 3.50	75.00 RDCIS 145.50 CMPDI 30.00
2.	Development of immediate roof fall prediction system in UG mines using wireless network Project code: CIL/R&D/27/08 Implementing agency: IIT KGP & ECL	May 2008	Feb 2011 Oct 2010	216.95	115.00
3.	Development of CMPDI capacity for delineation of viable coal mine methane (CMM) /abandoned mine methane (AMM) blocks in the existing and would be mining areas having partly de-stressed coal in virgin coal seams Project code: CIL/R&D/28/08 Implementing agency: CMPDI	June 2008	Mar 2012 Mar 2011 Nov 2010	522.00	121.37679

	Project Name	Month & year of start	Month & year of completion	Total appr. cost, lakhs	Disbursment progressive
4.	Cost effective technology for beneficiation and recovery of fine coal Project code: CIL/R&D/8/03/08 Implrmrnyinh agency: CMPDI/BCCL	June 2008	May 2010	2714.50	Nil
5.	Development of a coal preparation plant simulator Project code: CIL/R&D/2/04/08 Implementing agency: CMPDI CIMFR & BHEL	Sep 2009	Mar 2012 Aug 2011	531.95	44.00
6.	Delineation of workings below railway lines near Ratibati colliery – stability analysis by numerical modelling and possible remedial measures	Feb 2009 Jul 2009	Jan 2010 Feb 2010 ECL 7.00	20,0518	20.422 CIMFR 13,422
7.	Analysis of in situ stress for CBM exploration in Jharia coalfields Project code: CIL/R&D/1/02/08 Implementing agency: CMPDI & ISM Dhanbad	Mar 2009	Aug 2012 Feb 2012	168,597 CMPDI 126.00 ISM 42,597	34.00 ISM 34.00
8.	GPS production reporting system in OCP Implementing agency: Systems Department, CIL HQ/BCCL	Sep 2009	Jun 2012 Dec 2011 Aug 2010	54.00	0.42
9.	Studies of techno-commercial efficacy of ANFO with low density porous aluminium nitrate for blasting over-burden in coal mines. Implementing agency: Blastrg Cell, CMPDI, DFPCL, Pune	Sep 2009	May 2012 Feb 2011	206.80	8.56
10.	Underground trapped miner location system Implementing agency: TCS, CMC, CMPDI, Ranchi	Jan 2000	Dec 2011 Jun 2011	489.7 TCS/CMC 450.72 CMPDI 30.18	346.65 TCS/CMC 339.00 CMPDI 7.65
11.	Generation/analysis of coalfield wise database of physico-mechanical characteristic of rock/coal and representative numerical models for appropriate solution to strata control problems Project code: CIL/R&D/1/06/10 Implementing agency: UMD Deptt. CMPDI	Feb 2010	Jan 2013	241.8	13.24

Project Name	Month & year of start	Month & year of completion	Total appr. cost, lakhs	Disbursment progressive
12. Establishment of correlation between phhysico-mechanical properties, chemical properties and bonding strength of chemical and resin capsule used in roof bolting Project code: CIL/R&D/1/07/10 Implementing agency: UMD Dept, CMPDI	Feb 201	Jan 2012	128.98	123.18
13. Development of guidelines for safe dragline dump profile under varying geo-engineering conditions in opencast coal mines of Coal India Project code: CIL/R&D/1/08/10 Implementing agency: BIT Mesra and CMPDI, Ranchi	Feb 2010	Jan 2013 Jul 2011	75.60 For BIT Mesra 59.00 For CMPDI 10.00	46.00 BIT Mesra 46.00
14. Studies on determination of fine silica (quartz) content fibre in air borne dust in coal mines and preparation of data bank of free silica and other minerals present in dust as well as in coal Project code: CIL/R&D/9/09/10 Implementing agency: CIMFR Dhanbad and S&R Dept of CIL, Kolkata	Feb 2010	Jan 2013 Jul 2011 S&R/CIL154.00	336.02 CIMFR 186.02	150.00 CIMFR 150.00

2.11 Public Sector Mining Companies in non-coal sector & R&D Initiatives

Funding of the R&D projects in non-coal sector started in 1978, essentially to encourage R&D in the sector. The projects are approved and monitored by a Scientific Advisory Group with Secretary (Mines) serving as the Chairperson of this Group. Since 1978 and right up to March, 2008 some 135 projects have been completed and the current annual budget is of the order of Rs.5.0 crores. Of these, mining technology related projects were 22 in number, including studies on blast vibrations in surface mines. Table 2.4 lists the projects up to 2004.

Table 2.4: S&T non-coal mining projects funded by ministry of mines (GOI)

Since 1978 the Ministry of Mines, Govt. of India is funding S & T Projects proposed by the industry, research institutions, educational institutions and approved/registered NGO's on case to case basis. The Standing Scientific Advisory Group of the ministry evaluate each project proposal on its merit and if found suitable/beneficial to the mineral industry it assists funds the project fully or partially depending on the availability of funds.

During the period 1978 up to March, 2008 the ministry funded about 135 completed projects, out of which only 27 projects were related to mining technology *per se*. These include:

	Project	Title Year	Impl. agency
1.	Seismic and micro-seismic monitoring project	1978	BGML
2.	Development of new mining methods with setting of concrete mats	1978	IBM
3.	Long hole raising in mines	1978	HZL
4.	Preliminary survey of leaching of sulphide ores by bacterial leaching	1978	ISM
5.	Improved steel support in mines	1979	HCL

	Project	Title Year	Impl. agency
6.	Vertical crater retreat method-introduction of	1981	HZL
7.	Development of method for improved fragmentation	1982	HZL
8.	Study of subsidence in coal mines	1983	CMRS
9.	Slope stability studies in non-coal mines	1983	CMRS
10.	Rock bolting – Introduction of	1983	HZL
11.	Rock mechanics study facilities-setting up of	1984	HZL
12.	Development of computer aided general system for opencast mine planning and its application to bauxite	1985	BALCO
13.	Development of computer programme for rock mechanics mines investigations mainly in respect of stress in pillars for extraction at Mochia Unit of HZL	1985	HZL
14.	Rock mechanics investigations in Khetri and Kolihan mines	1986	HCL
15.	Setting up of National Institute of Miner's Health at KGF	1987	DOM
16.	Setting up of National Institute of Rock Mechanics and Ground Control at KGF	1987	DOM
17.	Optimization of stope design and support in non-coal mines	1987	CMRI
18.	Optimizing the design of blasts in surface mines	1990	BHU
19.	Rock mechanics investigations at Rakha Copper Mines HCL for improved recoveries from in-situ reserves by NIRM, KGF	1990	NIRM
20.	Development of technology for delayed back filling of open stopes with high density cemented fill for extractions of pillars	1996	CMRI/DOM
21.	Application of pre-split blasting for production of dimensions/building stones in small scale mining	1996	CMRI/DOM
22.	Development of Engineering Classification system for design of jointed rock slopes	1996	NIRM/DOM
23.	Development of guidelines through investigation in granite mining to improve the recovery during mining operation	1996	NIRM/DOM
24.	Setting up of granite mining cell	1997	NIRM/DOM
25.	Laboratory method of estimating the in situ stress of rock mass by Kasiser effect (Rs.3.965 million)	2001	NIRM
26.	Investigations into the noise status of some selected non coal mining complexes with a view to developing abatment and control measures (Rs.1.3M)	2002	ISM
27.	Fly rock prediction and control in open cast metal mines in India for safe deep hole blasting near habitats- A futuristic approach (Rs.6.4M)	2004	CMRI

2.12 Uranium Corporation of India Ltd. (UCIL), Jaduguda

UCIL, a public sector enterprise under the administrative control of Department of Atomic Energy was formed in October 1967 with an objective to mine and process uranium ores in the country. Presently, it is operating 5 underground mines in Singhbhum district of Jharkhand state (Jaduguda, Narwapahar, Bhatin, Turamdih and Bagjata) and a surface mine (Banduhurang Opencast Mine). Another 2 underground mines are under development in Andhra Pradesh (AP) and one in Jharkhand. 2 Surface mines in AP and 2 Surface mines in Meghalaya are also planned. The first mine of UCIL was Jaduguda Mine which started production way back in 1968. Initially, the mine was developed up to a depth of 315m but later the shaft was deepened to 640m. However, the present workings have gone up to a depth of 905m as the mine was deepened to 905m by constructing an underground shaft at a depth of 555m. The mine has a tower mounted, multi-rope, double-drum

Koepe winder in use at Jaduguda which is the only one of its kind in the country with several built-in safety measures. The Narwapahar Mine is one of the few mines in the country having decline as the mine entry and using large trackless equipment right from the stope face to the surface.

Though different stoping methods including Shrinkage and Open stoping were used earlier in different periods of time in different mines of UCIL, a variety of cut and fill methods depending on different geo-mining conditions and machine availability are now widely practiced in all the underground mines for obtaining maximum ore recovery (around 92%) and minimum dilution. The innovative stoping methods developed through R&D include:

1. Cut and Fill Method with tramming drift in footwall
2. Cut and Fill Method with RCC arches for level protection
3. Cut and Fill Method with ramp/decline in footwall
4. Cut and Fill Method with main drive as tramming level
5. Trackless mining known as 'Step Mining Method'
6. 'In-stope Leaching' at Jaduguda Mine using barren ion-exchange solution

The minor amount of waste rock generated in the process of development and stoping are also disposed off in stopes as filling material. The void created by extraction of ore body is systematically filled with deslimed mill tailings. For design of stope parameters, the mine management normally takes the help of CIMFR, Dhanbad or IIT, Kharagpur. The deepening of the shaft up to a depth of 1200m from the present 905m is contemplated in near future. It is anticipated that the Jaduguda mine will encounter all the ground control problems related to deep mines including high rock temperatures. The mine management took the help of ISM, Dhanbad for designing the ventilation system of their mines, in particular deep mines, so as to reduce the radiation hazard. The advice of ISM helped the mines not only in improving the ventilation but also considerable saving in energy cost.

UCIL does not have any R&D Dept. for undertaking research projects related to 'Mining Technology'. However, they do have a full fledged Control R&D Department for monitoring the process parameters for the recovery of Uranium and by-products from the ore. As per the Annual Report of UCIL of 2008-09 the company spent Rs.18.62 million in R&D related to mineral beneficiation and optimization of process parameters. There was no R&D expenditure related to mining technology.[79]

2.13 Bharat Gold Mines Ltd. (BGML), KGF

The mines of BGML were closed after mining for nearly 130 years. Once upon a time the Champion Shaft was one of the deepest gold mines in the world when the depth of workings exceeded 3200m. They were the pioneer in introducing R&D in metal mines in India. They started maintaining records of rock burst in a scientific way from 1904 onwards and established a small R&D unit for rock mechanics investigation to develop new mining methods and to reduce frequency and occurrence of rock bursts[49]. Systematic rock mechanics investigations were started from 1955 when BGML established a full fledged R&D Department. Before 1955 investigations into the problems of rock burst and methods to reduce those including support and stope design were done by individuals. The incidence and severity of rock bursts and accidents considerably decreased as a result of investigations and implementing the recommendations of the R&D Dept. Some of the stoping methods developed and experimented chronologically include:

(a) Rill method of stoping with granite walls as support was used before 1955 but abandoned subsequently due to ground control problems

(b) Due to some drawbacks, at greater depth with rill stoping it was replaced by 'Stope Drive' system with granite wall built on concrete mats as support. The method was found to be most successful for extraction of ore at depths where other methods failed. In this method, the stope faces below the level lie always one stope length in advance of stope face immediately above the level.

(c) Shrinkage stopes used before 1955
(d) Flat back with crib set and granite support
(e) Flat back with cut and fill

For the first time in India a seismic network consisting of 15 geophones (8 on surface and 7 on underground) was established in 1978 to cover a mining area of 6 km × 3 km on the field[34]. The system yielded very useful results and helped in developing innovative mining methods to mine at great depths with lesser frequency of rock bursts. The seismic arrays helped in assessing the energy liberated by the rock bursts and to identify the source location. Unfortunately, the mines of BGML were closed in 2000-01 due to high cost of production because of mining at greater depths and problems associated with deep mines including the reduction in the efficiency of miners and unsafe workings.

2.14 Hutti Gold Mines Ltd (HGML)

The mine is a joint venture of State and Central Governments. HGML does not have a R&D Dept. for Mining Technology. However, the R&D activities are being looked after by Planning Dept. The mine has introduced in the past technological upgradation taking the help from research institutes including CIMFR and NIRM. The mining (stoping) methods tried by HGML include:

(a) Large diameter (152-165mm) blast hole stoping (LDBs)
(b) Vertical Crater Retreat mining (VCR) and Vertical Retreat Mining (VRM) with rock bolts
(c) Sub level stoping
(d) Mechanized cut and fill method
(e) Ventilation studies and optimizing the fan specifications in VRM and L DBJ stopes
(f) Optimized the stope parameters by scientific monitoring

The other R&D innovations of HGML are related to problems of deep mines as the present workings have already reached 1000m. They have conducted a 'Mass Blast' as a solution to destress high stress ground in which the explosive used was 232tons and the powder factor was 1.5tons/kg of explosive using i-kon system with electronic delays. This was the effective way of destressing the left-out pillars, regional pillars and crown pillars. For mining at greater depths HGML experimented with 'Pillar-less Pyramid Stoping' and 'Paste Back-filling'.

2.15 Manganese Ore India Ltd.(MOIL), Nagpur[62]

Mining of manganese ore started in India in late 18th century by the Central Province Manganese Ore Company in Balaghat district of M.P. However, since mid 19th century it is being mined by MOIL.

MOIL is operating 10 mines- 7 underground and 3 open-pits in the states of Madhya Pradesh and Maharashtra. They mine high to medium grade manganese ore. They do not have an exclusive R&D Dept. However, the R&D activities are co-ordinated by their Planning Department. They normally sponsor the work to research institutes including CIMFR and NIRM on payment basis for solutions to their mining problems.

The company in the recent years is spending about Rs.2 crores per annum on R&D. They sponsor the projects mainly to CIMFR, Dhanbad and its Regional Centre at Nagpur and implement their recommendations. The R&D work done and implemented by MOIL include:

(a) Introduction of fully grouted prestressed cable bolts as premining support of reinforcing the roof/back (1988)
(b) Optimization of rib pillar and post pillar size
(c) Introduction of large dia drilling for blast holes
(d) Introduction of air-deck blasting in Dongri-Buzurg open cast mine
(e) Design of stope pillar at Ukwa Mine

(f) Introduced sub-level stoping method, after detailed field observations and studies, in soft rock and weak ground conditions at Chikla Mine by using cable bolting from sub level drive. However, subsequently they switched over to sub level with post mining filling of stope with hydraulic stowing. In Balaghat Mine a saving of 65% in the cost of timber was achieved by adopting advance supporting and reinforcing the ore with cable bolting system of support.

It was observed that main advantages achieved by introduction of cable bolting in the mines of MOIL include

(a) Improvement in face OMS from 3 to 6.5 t and this is likely to increase to 10,

(b) Reduction in manpower in mines, and

(c) Increase in safety standard

In conclusion it can be said that the rock mechanics investigations along with instrumentation and scientific evaluation of mining techniques, production, productivity and safety have been increased due to mechanized operation.

As per the Annual Reports of MOIL[62] the R&D expenditure incurred by the company during the years 2003-04 to 2007-08 was as follows:

2003-04 - around Rs.17.00million

2004-05 - Rs.17.11million constituting 0.41% of total turnover

2005-06 - Rs.12.81million constituting 0.38% of total turnover

2006-07 - Rs.20.80million constituting 0.50% of total turnover

Rs.12.81million constituting 0.38% of total turnover

The R&D work conducted in each year during the above period includes:

(i) **Introduction of sub-level stoping method in soft rock and weak ground** conditions at Chikla Mine: The experiment has shown encouraging results with higher productivity and faster mining techniques and reduced cost of production. The cost of production was reduced up to 50%. New areas of the same mine were selected for continuing the experimental stoping before implementation in other mines.

(ii) **Introduction of SDL (Side Discharge Loader) for mechanical handling of ore in stopes**: At Balaghat Mine 3 SDL's are in operation. A system of mechanical loading is well established in this mine with increased production. Further one SDL has been introduced at Chikla Mine. This will enable switch over from manual to mechanized mining in phased manner in future

(iii) **Automation of Ventilator**: Deployment of ventilation fan operators have been saved to the tune of about 6 to 8 persons and the system is working smoothly

(iv) **Study of Geo-technical characteristics of Ukwa Mine**: Scientific studies for design and development of support system for Ukwa underground mine is being conducted by CIMFR. The studies include stress analysis of stoping operations and old pillars and to develop a support system applicable to Ukwa Mine underground. This will enhance the production capacity, safety and productivity of this mine considerably

(v) **Upgradation of low grade ore:** Beneficiation plant is under installation at Balaghat Mine where for the first time Air Pulsated jig is used for upgradation and improvement of recovery

(vi) **Rock Mechanics Instrumentation:** Rock mechanics instrumentation and monitoring of ground vibrations in underground mines are continuing.

(vii) **Blasting Studies:** Scientific studies to develop economical and environment-friendly ANFO explosive to achieve higher productivity with improved safety is being conducted by CMRI. The main features of this study consists of possible replacement of HSD with environment friendly bio-fuel/LDO in ANFO explosive and application of suitable ANFO explosive type with rock mass conditions for better fragmentation and for better rock – explosive energy interaction.

(viii) **Study of Pit Slope Stability:** The study is continuing specially in footwall rocks of Dongri Buzurg Mine where phyllite is posing threat to stability of benches

It is appropriate to mention that the research or academic institutions undertook the above investigations as consultancy projects which for the purpose of this report are considered as R&D projects.

2.16 Hindustan Copper Ltd (HCL), Khetri, Kolihan and Mosabani Mines

Khetri Copper belt was an area of intense ancient mining and smelting. The occurrence of numerous old workings viz. shafts and inclines and huge slag heaps throughout the belt are the best testimony to such activities. It is believed that the copper mining in Khetri area dates back as old as over 2000 years in the Mauryan period. However, the first recorded mention of copper mining in the belt is found in 'Ain-e-akbar' written by Abul Fazal, a courtier of the Emperor Akbar in the year 1590.

The in-situ copper reserves in India at the end of 20th century are of the order of 707million tonnes averaging 1.32% copper grade, distributed in 91 deposits all over the country. Out of these, only 17 deposits are being exploited; 11 by M/s HCL and 6 by other agencies. The known ore reserves in Khetri copper belt as on 01.04.2005 are 129 million tonne @ 1.2% copper, estimated in 16 main deposits. All operating mines in India, taken together, are just able to produce about 10% of the country's requirement of copper metal and the balance is met through imports. The well known Khetri Copper Belt in Rajasthan is considered to have large hidden copper deposits around and in the strike extension of existing mining properties of HCL. Presently, the company has 2 underground operating mine- Khetri and Kolihan and an opencast mine Malanjkhand in Balaghat District of MP. The opencast mine at Malanjkhand has already reached its limiting depth and steps are in progress to convert it to an underground mine. The R&D work conducted at Malanjkhand include:

(a) Optimization of drilling and blasting design to achieve the most suitable rock fragmentation to increase the performance of loading, transport and crushing machines. The studies were conducted by NIRM.

(b) Feasibility of leaching the low grade ores. The investigations were done by a Canadian Consulting firm to assess the techno-economical aspect of leaching.

HCL has given on lease the Surda underground mine in Singbhum district of Jharkhand to an Australian firm for production. The Indian Copper Complex, renamed as HCL, had 5 underground mines in Singbhum district namely Mosabani, Pathargora, Surda, Kendadih and Rakha. Leaving Surda the remaining 4 mines are closed due to various technical reasons. The present Khetri Mine has already reached a depth of 530 m. The ore bodies of both the underground mines are steeply dipping (60^{o} to near vertical) and their thickness vary between 5and 120m with competent foot and hangwalls. The underground method was started with 'shrinkage stoping' but quickly changed to 'sub-level open stoping' with ring hole drilling. Subsequently, the 'Vertical Crater Retreat' (VCR) method also known as 'Blast Hole Stoping Method' using 115 mm blast hole was introduced. The blast hole stoping method is at present the standard practice at both Khetri and Kolihan Copper Mines which has resulted in improvement towards production, productivity and ultimately cost reduction. It is appropriate to mention that Mosabani Mine of HCL was the first metal mine in the country which introduced rock bolting for stope support.

The R&D work conducted by HCL for their various mines in association with research institutes namely CIMFR and NIRM include:

(a) Optimization of stope parameters for room and pillar horizontal cut and fill, and post pillar mining at Mosaboni group of mines

(b) Monitoring of crown pillar stability using acoustic emission at Khetri mine.

(c) Introduction of trackless mining concept for the first time in India and development of mines through inclined ramps at Khetri Copper Complex enabling rapid development of mines with higher levels of production (1200 tonnes per stope per day on sustained basis) and productivity comparable to international standards

(d) 'Raising' forms one of the most difficult tasks of the mining operations. HCL has developed in-house and perfected the concept of 'Drop Raising' over 60m intervals. This has resulted in increased safety and higher progress. A pattern of five 150mm dia. holes has been standardized for the crater method of blasting the raises sequentially.

(e) Large diameter blast hole (162 mm) sub-level of stoping over level intervals of 60 m at Khetri and Kolihan Mines. Need to have intermediate sub-levels for drilling has been eliminated in this method. Excellent fragmentation was achieved. Benefits of the new stoping method include:

   (i) Reduction of upto 40% in quantum of development, drilling cost and explosive cost

   (ii) Overall reduction of about 30% in cost of mining

   (iii) Reduction in manpower

   (iv) 50% reduction in stope preparation time

(f) Post pillar stoping in wide ore bodies resulting in increase of production by over 7 times and the 'output per man shift' (OMS) to over 3 times

(g) Ventilation re-organization, network planning and optimization of fan specification for energy saving at Khetri and Kolihan Mines by ISM. It is pertinent to mention that in a mine about 40% of the total energy is consumed in ventilation alone. The investigations helped the mine management in saving significant amount of total energy requirement for ventilation

Towards R&D, HCL in collaboration with the Institute of Minerals and Materials Technology (IMMT), Bhubaneswar has taken up a project funded by DST on 'Bio-heap Leaching.' Further, to give thrust to R&D in other areas as well, HCL has signed MOU with IMMT to work on R&D programmes. The MOU also envisages framing proposals for funding from Govt. wherever applicable.

M/s Earth Resources Technology Consultants were engaged by HCL for optimization of blasting fragmentation at Malanjkhand Opencast Mine for productivity improvement. The recommendations given by the consultant have been implemented with good results.

2.17 Hindustan Zinc Ltd., (HZL) – now a part of Vedanta Group, Udaipur

Dariba mine perhaps represents the oldest mining and smelting operations in the world for the extraction of Zinc metal. All along the strike there are several open pits and a large number of openings providing access and ventilation to underground mines are noted in the upper levels which at places have gone as deep as 265m. Timber supports were also found dating back 2500 to 2800 years ago. HZL is one of the pioneering mining companies which introduced R&D in metal mines to improve working conditions of mines, increase production and productivity by optimizing mine and stope parameters. Mining of Lead-Zinc (Pb-Zn) ore was for the first time started by HZL way back in 1945 by 'shrinkage stoping method' producing about 500 tonnes/day. In 1960's the 'sub-level top slicing' method was introduced to increase the production to 2000 tonnes/day. Presently HZL is operating 4 underground mines in the Zawar Group of Mines namely Zawarmala, Mochia, Balaria and Baroi. HZL established in 1981 a separate Rock Mechanics Cell for design and development of new mining methods and introduction of appropriate technology tried elsewhere. The Rajpura-Dariba Mine was started in1984 for regular production. In the past, HZL has done pioneering work in underground mining by continuously developing and updating its mining technology through techno-economic considerations by maximizing the mine potential with sustained profitability through in-house R&D. The problems encountered were solved through in house rock mechanic studies, scientific/engineering knowhow and innovative ideas in stoping method leading to better ground stability, increased percentage of extraction, faster and safer mining methods and continuous improvement in productivity. Some of the R&D achievements at Rajpura-Dariba Mine include introduction of

- Long hole stoping methods
- Optimum drill design and its accuracy, use of spherical charge
- Vertical Retreat Mining (VRM) and VCRM techniques
- Non-electrical detonators for minimizing ground vibration
- Ground pre-reinforcement
- Engineered quality filling of voids
- Design of stable stope-geometry and analysis of ground stability with monitoring of ground response, and support design and its performance through numerical modeling, rock mechanics studies and ground instrumentation.
- 'Cut and Fill' Stoping Method up to 200 m depth and VCR method in lower levels (between 200 to 500 m depth) resulting in increased mechanization, production and productivity

Subsequently, another underground mine named Sindesar Khurd located about 6km north of Rajpura-Dariba Mine, was started. They also operate a large opencast mine at Rampura-Agucha. In addition, HZL also owns two lead mines namely Sargipali Lead Mine in Sundergarh district in Orissa producing about 500 tonnes of ore per day, and the other is Agnigundala Lead Mine in district Guntur, Andhra Pradesh producing about 240 tonnes of ore per day. Both of these mines are underground operations. HZL also owns Maton Rock Phosphate Mine at Udaipur, Rajasthan producing about 600 tonnes per day.

The R&D and the Planning Dept. of HZL, for the first time in India, introduced and successfully experimented 'Mass Blasting' of remnant crown, sill and rib pillars standing for 15 to 20 years under high stress conditions in October 1986, releasing some 130,000 tonnes of locked-up high grade ore, using latest blasting technology and accessories including electronic detonators and **i-con** system from M/s ORICA. They have successfully completed five such mass blasts in Zawar Group of Mines. On 14th December, 1987 the mine management conducted a mass blast of crown pillars which yielded 213,000 tonnes of locked-up high grade ore. Another Mass-blast was conducted in Mochia Mine of Zawar Group of Mines of the remnant crown pillars at a depth of about 500 m on 13th June, 1994 involving 145 tonnes of explosive and yielding 550,000 tonnes of locked up ore in crown pillars. Zawarmala Mine conducted 2 Mass-blasts between 2004 and 2006 each involving 36 tonnes of explosive thereby releasing 80,000 tonnes of locked-up high grade ore. The financial analysis of the Mass-blasts demonstrated that the drilling and blasting cost was reduced by 50% over the conventional method.

Presently, HZL involves in majority of cases either CIMFR or NIRM for optimization of 'stope' parameters using numerical modeling techniques and controlled blasting. A few of the innovations at HZL include:

(a) Introduction of Vertical Crater Retreat (VCR/VRM) method of stoping at various mines
(b) Design and optimize stoping parameters in various mines of HZL using numerical modeling and rock mechanics instrumentation
(c) Introduction of sub-level stopes with advance benches supported by cable bolts, large diameter blast holes of 115 and 165 mm size resulting in faster rate of extraction
(d) Mass-Mining of remnant pillars
(e) Long hole stoping method
(f) Prediction of surface subsidence due to underground stoping
(g) Introduction of cemented backfilling system for bulk filling of open stope and replacing rib pillars by cemented fills for maximum recovery of pillars and ore remnants with safety using mathematical models

(h) Introduction of pre-splitting blasting method for long term stability of final pit slope faces and thereby increased productivity and mineral conservation at Rampura Agucha open pit mine

(i) Introduction for the first time in India slope stability Radar at Rampura Agucha Mine for advance prediction and maintaining stability of slopes with high standard of safety.

(j) Ventilation analysing of mines and optimum design of mine fan specifications for energy saving and increasing productivity with safety

(k) Application of Six Sigma (Six Standard Deviation) Methodology in mines for providing the techniques and tools to improve the capabilities and reduce the defects in any process resulting in improvement in profits, product quality and customer satisfaction

It is appropriate to mention that during the year 2006-07 the total revenue of HZL was around Rs.87915 million and they spent a small amount of Rs.13 million (roughly 0.015% of the revenue) on R&D activities that too in the area of mineral beneficiation and metallurgy. Virtually, expenditure on mining technology R&D was nil.

Fig.2.7 Drilling jumbo in operation at Rajpura-Dariba

2.18 Chromite Mining in India

India has 2% of the worlds reserves of 6803 million tonnes of chromites. There are two chromite belts in India namely Boula and Sukinda in Keonjhar district of Orissa constituting 98% of the country's reserves. The main players include FACOR, IMFA, TATA STEEL and OMC (Govt. of Orissa). The mining of chromite was started in India in the year of 1943 by small to medium size open pits. There are 15 opencast mines and 4 underground mines. The production in 2009-10 was 3.4 million tonnes from these mines. Many of the open pit mines have already reached their economic limits for extraction by open cast mining. The economic depth of open pit mining is about 100 m. There are 4 open pit mines which have already exceeded their economic limit and therefore, they are being converted to underground mines. A 'cemented mat' was constructed to act as a barrier between the open pit and underground workings to save the rich ore. The overburden of the mine was dumped over the cemented mat. The Nuasahi Chromite Mine, in Boula-Nuasahi Belt, of M/s IMFA was the first underground mine which started production in 1998-99 by driving two inclines and introducing modified sub level stoping. The ore between sub levels was extracted by drilling ‘ring holes’ and or parallel holes. The other underground mines include Bangur Chromite Mine belonging to M/s OMC, Kathpal Chromite Mine belonging to M/s FACOR. Assistance of CIMFR, Dhanbad and IIT, Kharagpur was taken to design the thickness of mat and the stoping method.

2.19 The Singareni Collieries Company Ltd.(SCCL), Kothagudem

The SCCL established in 1980 a R&D Department to coordinate the formulation of S&T projects with the research organization and academic institutions and for specific problem-solving through consultancies. Limited in-house studies on ventilation planning, explosives and blasting trials, strata monitoring are also undertaken by this R&D Department. Since the inception of the research unit from 1980 to September 2009, 21 S&T projects were completed. The total cost of the projects was Rs.772.70 lakhs, out of which the S&T share was Rs.696.7 and SCCL share Rs.68.99 lakhs. Appendix 2.3 gives the details of the projects completed, including their perceived benefits.

2.20 Industry-Oriented R&D in Academic Institutions

Banaras Hindu University (BHU) and Indian School of Mines (ISM), Dhanbad were the only academic institutions in India offering mining engineering programmes prior to Independence. The rapid expansion of the minerals sector in 1950s created a skill shortage and today there are 17 academic institutions where undergraduate degree courses are taught. Of these Departments, 7-8 offer postgraduate courses at the M.Tech level. The total intake capacity at the B.Tech level is currently around 680 and at the M.Tech level about 20. With the support of the UGC, DST and AICTE since 1970s, the infrastructure and laboratories at the mining institutions have been vastly upgraded and their competence and capability to undertake R&D have been strengthened. The R&D areas thrust at these institutions could be best illustrated through the nature of work taken at the Ph.D level.

We shall briefly examine the contributions in R&D at 3/4 selected institutions for the minerals sector in India. It needs to be underscored that most academic institutions are also vying with premier national laboratories (CIMFR and NIRM) in getting increasing share of consultancy assignments.

2.21 Indian School of Mines(ISM), Dhanbad

The R&D focus has been on coal industry related problems including characterization of strength properties of coalmeasure rocks, abrasivity of coal and rocks, roof bolting, optimization of mining layouts, problems of mine fires, design of surface and underground blasts, ground vibrations due to blasting, monitoring of coal mine bumps, design of slopes, rock mass classification and its application, ground subsidence in Indian coalfields and ventilation design. In the non-coal sector, R&D studies have been undertaken on optimization of stope parameters, blast design, slope stability problems including waste dumps, ocean mining, design of optimum ventilation networks for energy saving, design of post pillars in copper mines and in-situ stress measurement.

In the area of mine environment, extensive studies have been undertaken on noise and air pollution in iron ore and bauxite mines, air quality monitoring in different coalfields, utilization of fly ash, reclamation strategy for mined out areas, environmental impact assessment methodology for mining projects etc.

2.22 Indian Institute of Technology (IIT-Kgp), Kharagpur

At the Department of Mining Engineering, the focus of R&D has been the metal mining sector and large number of consultancy assignments have been executed for UCIL, HCL, MOIL and HZL. The *forte* of the Department has been the research on safety, numerical analysis of mining excavations, ventilation analysis, wear of rubber and blind backfilling.

APPENDIX 2.1

UTILISATION OF COAL S&T GRANT OF MINISTRY OF COAL, SINCE INCEPTION OF S&T PROGRAMME IN 1975

(Rs. in Crore)

1	1976-77	0.78	19	1994-95	3.84
2	1977-78	0.97	20	1995-96	2.32
3	1978-79	0.69	21	1996-97	11.66
4	1979-80	0.84	22	1997-98	4.56
5	1980-81	0.75	23	1998-99	5.49
6	1981-82	0.39	24	1999-2000	2.74
7	1982-83	1.30	25	2000-01	4.92
8	1983-84	2.17	26	2001-02	7.26
9	1984-85	1.02	27	2002-03	6.04
10	1985-86	4.03	28	2003-534	9.82
11	1986-87	2.51	29	2004-05	12.73
12	1987-88	10.04	30	2005-06	14.74
13	1988-89	8.38	31	2006-07	8.09
14	1989-90	6.55	32	2007-08	12.48
15	1990-91	4.63	33	2008-09	10.52
16	1991-92	3.88	34	2009 -10	11.64
17	1992-93	3.71	35	2010-11(31.12. 2010)	7,66
18	1993-94	5.32		**Total**	**194.47**

APPENDIX 2.2

S&T PROJECTS ON MINING METHODS

	Title of the project	Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
1.	Study of adoption of sub-level caving at E.Katras and Kendwadih collieries	MT/18	BCCL & Sofremine(F)	1963	11.50
2.	Tests of sub-level caving from galleries in developed area in East Katras colliery	MT/37	BCCL	1990	141.00
3.	Optimisation of extraction of coal from pillars below surface structure using technique of partial stowing	MT/43	CMRS	1987	17.6
4.	Evaluation of new mechanized system performance using SDL, LHD and roof bolting	MT/49	CMRS	1989	33.74
5.	Development of method of mining for extraction of thick and steep seams of	MT/78	NEC	2000	120.00
6.	Hydraulic mining	MT/11	CMPDI & BCCL	1989	818.87
7.	Field trial of wide stall method	MT/44	CMRS	1991	19.45
8.	Induced caving of sub-level coal numerical evaluation of some geological and mining performance	MT/71	BHU	1993	2.00

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
9.	Mechnised depillaring of 6m thick seam III of Chirimiri with cable bolted support	MT/77	SECL & CMRI	1995	213.25
10.	Extraction of coal locked in pillars of multiple and thick seams	MT/107	NIRM &	2003	26.2 SCCL
11.	Application of ground penetrating radar (GPE) technique to locate water logged workings in coal mines	MT/110	NIRM & CMPDI	2003	47.00
12.	Scientific investigation on shearer longwall faces	MT/1	CMPDI & ECL	1982	3.00
13.	Stability of slopes in opencast mines	MT/10.3a	ISM	1982	13.18
14.	Evaluation of workability indices of coal seams and coal measure rocks	MT/18.3	ISM	1984	4.20
15.	Slope stability in pit walls dump stability ground monitoringin and around pit with geo-techniques studies	MT/40	CMRS	1987	11.00
16.	Workability indices of coal seams	MT55	CMRS	1989	24.11
17.	Mine accident analysis and control – a sociopsycholoical approach in coal mines	MT/57	BHU	1991	5.00
18.	Computerised mine planning for opencast coal mines	MT/50	ISM	1990	11.59
19.	Analysis of some time and cost overrun projects Ahmedabad	MT/75	ISM	1993	8.54
20.	Assessment of status of coal mining in the state of Meghalaya	MT/79	CMPDI	1994	15.00
21.	Underground coal gasification	MT/62	CMPDI	1995	322.00
22.	Development of integrated mine operation management system for a large opencast coal mine	MT/142	Ann. Unv.	2007	35.7029
23.	Feasibility study for the application of radar echnique for detection and mapping of geological faults and water bodies in UG coal mines	MT/144	IIT, Kharagpur & CMPDI	2007	20.445
24.	Optimisation of pillar parameters for development and final extraction highly inclined seams at SCCL mines	MT115	SCCL & NIRM	2008	24.90

S&T PROJECTS ON STRATA CONTROL

1.	Stata control	MT/3	CMPDI	1985	20.00
2.	Investigations into problem of rock bursts in deep coal mines	MT/8	ISM	1987	15.74
3.	Investigations into different strata control parameters in and around longwall mining	MT/9.1	CMRS	1982	8.12
4.	Physico-mechanical properties of coal measure rock	MT/9.2	CMRS	1981	3.89

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
5.	Control of massive and hard roof by water injection under high pressure	MT/86	CMRI	2006	49.55
6.	Assessment of control of ground movement around extraction perimeter in longwall and bord and pillar workings	MT/10.3(d)	ISM	1988	1.25
7.	Fracturing of massive sandstone roof	MT/15	CMPDI	1979	15.00
8.	Establishment of cavability parameters of coal measure strata of manuguru area (SCCL) for longwall caving	MT/31	KSM	1985	3.00
9.	Development of roof supports for mechanized bord and pillar workings and fast drivage and their field evaluation	MT/33	CMRS	1986	17.3
10.	Geo-mechanical classification of coal measure rock vis-à-vis roof supports	MT/34	CMRS	1986	3.45
11.	Stabilioty analysis of subsidence and strata behaviour using three dimensional analogue simulation and computer technique	MT39	BHU	1989	1.65
12.	Development of evaluation of norms for longwall support system in coal mines in India	MT/41	ISM	1987	10.2
13.	Design of support for mine roadways	MT/60	ISM	1989	25.4
14.	Simulation of large underground excavations in coal mines using numerical methods (finite element technique) with special reference to longwall face	MT/58	BHU	1990	2.33
15.	Development and application of acoustic emission technique in the mines of SCCL	MT/52	NGRI	1992	18.38
16.	A study of bump proneness of Indian coal seams and measures to alleviate the bump hazard	MT/72	CMRS	1994	3.7
	S&T PROJECTS ON MINE SUBSIDENCE AND STOWING				
1.	Surface subsidence in mining areas	MT/9.4	CMRS	1990	118.23
2.	Assessment of surface movement and structural damage due to mineral exploration	MT/10.3 (c)	ISM	1981	1.25
3.	Correlation of surface subsidence with deformation parameters in UG and intervening strata	MT/54	CMRS & IIT(K)	1989	90.64
4.	Subsidence studies for development of models with special reference to multi-seam mining in India	MT/89	CMRI	1999	4.40
5.	Experimental stowing plant to study flow characteristic of different stowing materials	MT/17	KSM	1988	24.64

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
6.	Stabilisation of water filled void through hydraulic sand stowing at Ramjeepanpur colliery	MT/36	ECL	1989	44.84
7.	Waste material stowing	MT/4	BCCL	1989	176.882
8.	Development of appropriate technology for removal of clayey material from overburden of the opencast mines	MT/82	CMPDI	1995	59.69
9.	Development of suitable subsidence prediction models for single seam working in South Eastern Coalfield area	MT/122	CMRI & SECL	2006	10.00
10.	Models studies on the efficiency of gravity and pack filling method and evaluation of pre-jamming indication parameters	MT/147	IIT(K)	2008	14.766
	S&T PROJECTS ON MINE VENTILATION				
1.	Methane drainage at Amlabad colliery	MT/2.1	BCCL	1978	16.56
2.	Sawing degasification	MT/2.2	CCL & CMPDI	1983	8.52
3.	Ghusick degasification	MT/2.3	ECL & CMPDI	1985	77.05
4.	Heat flow studies and problems of heat and humidity in coal mines	MT/8.2	ISM	1982	1.92
5.	Estimation of fire damp emission from different coal mines in the country and establishing the correlation with different controlling parameters	MT/10.1b	IIT(K)	1980	1.55
6.	Study of parameters affecting flow of air in mines and developing measuring instruments	MT/10.2b	BHU	1982	1.00
7.	Methane emission and control in mines	MT/10.3b	ISM	1981	2.60
8.	Determnation of ventilation co-efficient	MT/16	CMRS	1986	10.00
9.	In-situ investigations into feasibility of bacterial oxidation of methane	MT/32	CMRS	1987	7.56
10.	Development of sealants	MT/38	CMRS	1988	5.48
11.	Studies into heat and humidity in coal mines	MT/45	CMRS	1991	20.4
12.	Study of air leakage in coal mines	MT/84	CMRI	1995	3.5
13.	Virgin strata temperature and geothermic gradient measurement in Jharia coalfield	MT/48	ISM	1989	6.00
14.	Specific gas emission study to predict methane emission in mines	MT/65	CMRS CMPDI	1992	13.18
15.	Integrated monitoring and communication system for toxic and combustible gases in mines using ceramic sensors	MT/102	CG&CRI	2002	42.83

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
16.	Studies on simulation of open fires in mine galleries under varied air flow for separation of fire and fire damp explosions in underground coal mines	MT/101	CMRI	2003	145.35
17.	Study for early detection of the occurrence of spontaneous heating in blasting gallery method and to evaluate suitable measures to prevent and control spontaneous heating in thick coal seams	MT/118	CMRI & SCCL	2003	26.32
18.	Development of room temperature sensors for methane using carbon carbon nanotubes and nanofibres	MT/152	Jadavpur Univ. & ISMU	2009	84.634
	S&T PROJECTS ON ENVIRONMENT AND ECOLOGY				
1.	Study relating to noise arising out of coal mining activities	EE/2	CMRS	1985	0.99
2.	Study of effluents of coal washeries coken oven plants and evolve efficient and economical treatment processes	EE/3	CMRS	1985	2.79
3.	Reclamation and consolidation of worked out mine site and improvement of environment and ecology through scientific land management	EE/6	CMRS	1988	3.40
4.	Restoration and reclamation of abandoned Tikak opencast mine	EE/9	NEC	1995	75.00
5.	Environmental impact and management in and around opencast coal mining complex	EE/11	BHU	1995	4.00
6.	An integrated ecological study on revegetation of mine spoil	EE/8	BHU & Forest Dept of UP/MP	1996	48.71
7.	Soil environment and reclamation of backfilled areas of Neyveli opencast mines	EE/7	NEC & Anna Univ.	1997	44.47
8.	Envioronment management of OB dumps	EE/10	CMRI	1997	35.00
9.	Study of green belt regarding its noise attenuation and dust arresting capacity in coal mining areas	EE/12	ISM	1998	12.47
10.	Development of technology for conversion of backfilled areas in Ballarpur area for agriculture	EE/13	WCL & IISc	1999	7.00
11.	Geoplant ecological and aerobiological studies of coal mine areas	EE/17	Vinobha Bhave Univ. Hazaribagh	2000	6.09
12.	Beiological method of employing VAM fungi nitrogen fixing bacteria	EE/14	NLC Madras	1999	13.96

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
13.	Environment and eco-system studies in Godavari Valley coalfield – a geo-chemical and biological appraisal and redressal	EE/15	Osmania Univ.	2000	12.23
14.	Bio-restoration of dumps through the plation of selected efficient photo-synthetic/soil conserver species in Eastern Jharia, BCCL	EE/20	CFRI	2004	43.08
15.	Frequency analysis and modelling of noise pollution for an opencast project	EE/23 SCCL	KREC &	2004	6.30
16.	Pond ash reclamation and possibilities of utilization of industrial waste for revegetation and developing green cover	EE/18	NLC & AMU	2005	112.7
17.	Field studies on application of lignite humic acid on various crop response in different agro climatic conditions	EE/21	TNAU & NLC	2005	58.68
18.	Reclamation of mining wastelands and restoration of native vegetation through microbiology technology in Rajmahal coalfield area of ECL	EE/24	TM Bhagalpur Unv. ECL	2005	11.2066
19.	Characterisation and leaching studies of Indian fly ashes for evaluation of their suitability as mine fill material	EE/25	CMRI, BCCL & SCCL	2005	19.92
20.	Bio-processing of lignite and bio-remediation of its sulphur rich wastes for development of environment friendly value added products	EE/22	NLC & IIT Delhi	2006	74.45
21.	Air pollution resistance and filtering capacities in trees and shrubs of surround opencast coal mines areas	EE/26	Vinobha Bhave University	2006	9.45
22.	Development of cost effective high performance highway using fly ash composite	EE/19	NLC & Anna Univ.	2008	38.10
23.	Studies on the impact of atmospheric biotic/abiotic particulates on the environment of Jharia coalfields and their abatement strategies	EE/29	CFRI	2008	33.90
24.	Studies on the use of bottom slag in crop production	EE/32	NLC &	2008	92.3244
25.	Development of emission factors for various mining machineries and operations in opencast mines	EE/27	CMPDI	2009	78.01
26.	Environmental impact of subsidence movements caused due to caving on groundwater and forest cover in Godavari Valley coalfields	EE28	CMRI & SCCL	2009	72.03

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
S&T PROJECTS ON MINE FIRES					
1.	Application of CO_2 in combating mine fires	MT/9.6	CMRS	1981	5.30
2.	Chemical eradication of green growth	MT/20	ECL	1979	0.60
3.	Coal stack heating	MT/22	CMPDI	1982	4.25
4.	Study of spontaneous heating of coal	MT/23	CMPDI	1985	4.65
5.	Nitrogen infusion	MT/26	CMPDI	1988	43.00
6.	Development of fire extinguishing foam including application technology for use in mines and allied industries	MT/42	CMRS	1987	3.00
7.	Thermal infrared imager	CE/16	CMPDI	1982	1.00
8.	Assessment of status and control of u/g coal mine fires	MT/46	CMRI	1996	7.00
9.	Development of suitable fire protective coating for preventing spontaneous combustion in the benches of opencast/underground mines vis-à-vis consolidation of dust	MT/83	CMRI	1996	7.00
10.	Development of a mechanized spraying system for spraying the fire protective coating material for industrial application in the coal benches of large opencast projects	MT/100	CMRI	1999	5.27
11.	Handy method of coal categorization and prediction of spontaneous risks in mines	MT/90	CMRI, CFRI & ISM	1999	28.06
12.	Study of problems of spontaneous heating of coal pillars and development of techniques for its prevention and early detection and control	MT109	CMRI, ISM & ECL	2006	36.10
13.	Studies on the advance detection of fires in coal mines with special reference to SCCL	MT/130	Andhra Univ. & SCCL	2009	166.5088
S&T PROJECTS ON EQUIPMENT DEVELOPMENT					
1.	Development of water spray and log nozzles and dust suppression studies	MT/10.1a	IIT(K)	1983	0.56
2.	Remote sensing of Damodar flow level	AE/5	CMPDI	1985	1.85
3.	Goaf temperature monitoring system	AE/6	CMPDI & SIRDO	1985	0.20
4.	Run-away coal tub alarm and protection system	AE/7	CMPDI & SIRDO	1985	0.70
5.	Coal tub weigher and counter system	AE/8	CMPDI & SIRDO	1985	1.54
6.	Developoment, trial and evaluation of Auger-cum-drill	AE/27	CMPDI	1987	33.00
7.	Improvement in the life of mine implements through tribological studies	AE/30	RRL Bhopal	1997	36.79

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
8.	Failure analysis of certain cage suspension gear components and standardization of ultrasonic testing technique for examination of suspension gear components	AE/31	CMPDI	1995	8.91
9.	Development of sensors and microprocessor based switching system for intrinsically safe power supply for u/g use	AE/28	CMRS	1990	23.50
10.	Improve track system	MT/68	ECL	1991	11.5
11.	Development of instrument for coal mine stability monitoring	MT/76	NIRM	1994	10.39
12.	Powered support characteristics recorder	MT/70	CPRI & CMPDI	1997	25.15
13.	Shearer performance optimization by drum design and speed control	MT/74	ISM	1997	63.80
14.	Development and application of continuous strata monitoring system for evaluating roof stability in coal mines	MT/85	NIRM	1997	13.30
15.	Development of processed continuous mining equipment condition monitoring for maximum machine available time in mines	AE/32	CMRI	1997	11.00
16.	Development of hydraulic roof bolt drilling equipment and drilling accessories for mechanized bord and pillar workings and fast roadway drivages	MT/91	NIRM	1998	25.00
17.	Development of an instrument for prediction of roof falls in the goaf area in coal mines	MT/98	NIRM & SCCL	1998	14.50
18.	Development of instruments for continuous recording of methane	MT/7	BCCL	1980	8.00
19.	Field trial of data acquisition system developed by CMRI	MT/97	CMRI	2000	7.10
20.	Development of micro-processor based solid state controller for improving hauler's efficiency	MT/113	NIRM & SCCL	2002	17.50
21.	Development of a micro controller based system for monitoring of longwall powered supports and its application for continuous automatic evaluation of strata behaviour	MT/111	SCCL & NIRM	2004	47.236
22.	Corrosion research	MT/5	ISM	1968	13.02
23.	Study of corrosion problem due to mine water – its causes and prevention	MT/29	BHU	1984	2.16
24.	Pipeline transport of sand and coal	MT/6	CMPDI	1979	1.50
25.	Preparation of DPR for demonstration of coal slurry pipeline project	MT/66	WCL	1992	93.00

Title of the project		Project Code	Implementing agency	Year of completion	Total approved cost (in lakh)
26.	Design and development of wireless multi media monitoring system for coal mines	MT/136	IISc Bangalore	2005	12.985
27.	Development of high strength corrosion resistant roof bolts and guidelines for selection of bolts and accessories	MT/140	RDCIS & CMPDI	2007	72.912
28.	Development of an experimental subterranean robot(SR) for feasibility	MT/148	CMERI, Durgapur, CMPDI & CMRI	2009	89.168

APPRENDIX 2.3

IMPACT OF R&D PROJECTS ON PRODUCTION AND PRODUCTIVITY IN SINGARENI COLLIERIES CO LTD

Details of S&T projects completed in SCCL and the benefits to the industry

01. Design and experimentation of cable bolting for adverse ground conditions in thick seams containing clay bands.

- Project code : WIT/ 87/94
- Implementing and sub-implementing agency: SCCL and NIRM
- Total cost: Rs 13.78 lakhs
- S&T share: Rs. 13.78 lakhs
- Date of starting : March 1995
- Date of completion: May 1997
- Site of implementation of the project: RK New Tech Incline, SCCL

Advantages to the mining industry

- After successful completion of the project in SCCL, it was replicated to other mines.
- By using cable bolting at PK.2 Incline, Manuguru, haulage dip roof problems have been solved. Roof falls were prevented and the performance is good.
- At present, cable bolting is done at GDK.6B Incline (IGM) and there is improvement in roof conditions.

02. Design and experimentation of cable bolting for adverse ground conditions in thick seams for longwall gate roads and face dips.

- Project code : MT/105
- Implementing and sub-implementing agency: SCCL.
- Total cost: Rs 3.30 lakhs
- S&T share: Rs. 3.30 lakhs
- Date of starting: December 1998
- Date of completion: November 2000
- Site of implementation of the project: Padmavati Khani, SCCL

Benefits to the mining industry

- By implementing the project in SCCL it is established that cable bolting can also be used in LW panels particularly in the face dip, which has to be widened up to 6 m for installing LW machinery safely.
- Cable bolting system is useful in the seams with more than 6 m. thick and it has to withstand for a longer period during developmental stage of bord and pillar method. While in longwall, all gate roads and face preparation for installation of longwall machinery, this system of cable bolting is regularly used with success.

03. Development of roof bolting equipment and drilling accessories for mechanised bord & pillar workings and fast roadway drivages.

- Project code: MT/91/95
- Implementing and sub-implementing agency: NIRM and SCCL.
- Total cost: Rs 25.00 lakhs
- S&T share: Rs. 25.00 lakhs
- Date of starting : March 1996
- Date of completion: June 1998
- Site of implementation of the project: GDK No 8 and 10 A Incline, SCCL

Benefits to the mining industry

- This project was implemented with a view to develop roof bolters indigenously as the coal industry is switching over to roof bolting support system on large scale. This attempt is the first step towards developing fast bolting technology, which has numerous benefits on safety, production and productivity.
- A couple of attempts were made to re-design the roof bolting machine viz. tyre mounted roof bolter, modification of tyre mounted, roadheader mounted roof bolter, etc.
- In view of the practical difficulties experienced in the roof bolting machine developed under this project, the technology could not be replicated and SCCL is procuring roof bolters of other firms.

04. Evaluation of Explosives' performance through in-the-hole detonation velocity measurement.

- Project code : MT/ 96/96
- Implementing and sub-implementing agency: NIRM and SCCL.
- Total cost: Rs 23.84 lakhs
- S&T share: Rs. 14.60 lakhs
- SCCL share: Rs 7.24 lakhs
- Date of starting: November 1996
- Date of completion: August 2001
- Site of implementation of the project: RG OC I and OC III, SCCL

Benefits to the mining industry

- This project has established that the VOD values quoted by manufacturers can be verified in the field.
- Measurement of VOD will be useful for assessing the strata wise requirement of VOD in the field to optimise the blast and to maintain the required fragmentation.
- It is advisable to check VOD for each batch of new explosives and also as and when the strata changes in the quarry to optimise blasting.
- SCCL has made arrangements to check VOD of permitted explosives periodically for ensuring quality and informing the firms in case of any deviations from the nominal values.

05. Development of micro-controller based solid state controller for improving hauler efficiency.

- Project code: WIT/113
- Implementing and sub-implementing agency: NIRM and SCCL.
- Total cost: Rs 17.50 lakhs
- S&T share: Rs. 12.50 lakhs
- SCCL share: Rs 5.00 lakhs
- Date of starting: May 1999
- Date of completion: May 2002
- Site of implementation of the project: GDK 9 Incline, SCCL

Benefits to the mining industry

- NIRM in association with NRDC has conducted an industrial meet on 19.12.03 at Singareni Bhavan, Hyderabad, for commercializing the MBSC system.
- Pranay Enterprises, Hyderabad, accepted to license this know-how. ¦ SCCL proposes to procure 5 Nos. of MBSC systems for replication.

06. Investigations to optimise blast design and charge loading parameters in coal for ring hole blasting and in stone for induced blasting in degree-1 seams for blasting gallery method in underground mines of the SCCL.

- Project code : MT/125
- Implementing and sub-implementing agency: CMRI and SCCL.
- Total cost: Rs 38.30 lakhs
- S&T share: Rs. 23.25 lakhs
- SCCL share: Rs 15.05 lakhs
- Date of starting: February 2001
- Date of completion: January 2003
- Site of implementation of the project: VK 7 Incline, GDK 8 Incline and GDK 10 Incline, SCCL

Benefits to the mining industry

The technique developed in the project (patterns for ring hole blasting, & charge per hole, patterns for induced blasting & charge loading) is being widely followed in all the blasting galleries of Singareni Collieries (VK.7, GDK.6B IGM, GDK.8 and GDK.10 Inc) and results are satisfactory.

07. Development of micro controller based system for monitoring of longwall lowered supports and its application for continuous automatic evaluation of the strata behaviour.

- Project code : MT/111
- Implementing and sub-implementing agency: SCCL and NIRM.
- Total cost: Rs 47.236 lakhs
- S&T share: Rs. 38.836 lakhs
- SCCL share: Rs 8.40 lakhs
- Date of starting: May 1999
- Date of completion: May 2003
- Site of implementation of the project: GDK 10 A Incline, SCCL

Benefits to the mining industry

The micro-controller based system for monitoring LW powered supports developed in this project is proved to be useful for continuous monitoring the health of supports and strata behaviour. This system being used in some LW faces in SCCL.

08. Optimal extraction of coal locked in pillars of multiple and thick seams.

- Project code : MT7 107
- Implementing and sub-implementing agency: NIRM and SCCL.
- Total cost: Rs 29.70 lakhs
- S&T share: Rs. 24.20 lakhs
- SCCL share: Rs 5.50 lakhs
- Date of starting: June 1999
- Date of completion: December 2003
- Site of implementation of the project: RK 8 Incline, SCCL

Benefits to the mining industry

This project proved that extraction of thick seams or contiguous seams is possible in more than two sections simultaneously. This is advantageous both in term of safety and production and productivity. This method of extraction will be replicated wherever geo-mining conditions are feasible.

09. Study of occurrence of spontaneous heating in blasting gallery (BG) method and to evaluate suitable measures to prevent and control spontaneous heating in thick coal seams

- Project code : MT/118
- Implementing and sub-implementing agency: CMRI and SCCL.
- Total cost: Rs 26.32 lakhs
- S&T share: Rs. 23.72 lakhs
- SCCL share: Rs 2.60 lakhs
- Date of starting : May 2000
- Date of completion: April 2002
- Site of implementation of the project: VK 7 Incline and GDK 10 Incline, SCCL

Benefits to the mining industry

The following recommendations of the project are being implemented in the BG Panels in SCCL

- Regular thermo compositional monitoring of goaf edges return of the panel for early detection of spontaneous heating;
- Application of fire protective coating/sealant in the remnant coal left in the goaf, barrier pillars;

Measurement of air quantity and pressure drop at regular intervals;

Probe gallery for application of N_2/CO_2 has been very much useful for early detection and control of spontaneous heating in BG panels.

10. Frequency analysis and modelling of noise pollution for an opencast coal project

- Project code : MT/EE-23
- Implementing and sub-implementing agency: KRCE, Suratkal and SCCL.
- Total cost: Rs 6.30 lakhs

- S&T share: Rs. 6.30 lakhs
- SCCL share: Nil
- Date of starting : August 2001
- Date of completion: March 2004
- Site of implementation of the project: RG OC II

Benefits to the mining industry

- Noise analysis at different operating conditions of the machine revealed that proper maintenance of machines can bring down the noise level considerably thereby reducing the operators' exposure to noise. SCCL is taking measures to bring down the noise in the machinery.

11. Development of a model vis-a-vis study of parameters influencing abutment loading of pillars at a depillaring face of shallow depth cover and under massive roof strata.

- Project code: MT/112/98
- Implementing and sub-implementing agency: CIVIRI and SCCL.
- Total cost: Rs 40.45 lakhs
- S&T share: Rs. 40.45 lakhs
- SCCL share: Nil
- Date of starting: May 1999
- Date of completion: March 2003
- Site of implementation of the project: SRP 1 and SRP 3 & 3A Incline, SCCL

Benefits to the mining industry

Based on the data generated in this project, empirical formulation has been attempted to estimate the ultimate value of mining induced stress and the range of influence ahead of the face for different geo-mining conditions. These formulae are useful in estimating the ultimate value of mining induced stress and range of influence ahead of the face.

12. Optimisation of production from underground coal mines by achieving longer pull (Phase-1)

- Project code: MT/135
- Implementing and sub-implementing agency: CMRI and SCCL.
- Total cost: Rs 13.61 lakhs
- S&T share: Rs. 13.61 lakhs
- SCCL share: Nil
- Date of starting: May 2003
- Date of completion: October 2004
- Study conducted at: PK OC II, Manuguru (As the objective of the study is to determine maximum safe air gap between explosive cartridges, DGMS advised to carryout experiments in coal bed confinement in OC mines only before doing trials in underground. Hence, tests of air gap sensitivity, continuity of detonation, velocity of detonation were carried out at PK OC II)
- Site of implementation of the project: GDK 5 Incline.

Benefits to the mining industry

- Production and productivity in underground solid blasting faces largely depends upon the efficiency of blasting operations. In spite of best efforts the pull in solid blasting face is around 1.0m only. This is due to the weak P5 explosive composition.

- In this project efforts are made to develop strong P5 explosives for use in solid blasting with out sacrificing the safety characteristics.
- A new explosive named Pentadyne (HP) was developed in this project. The field trials proved that the performance is good with average pull of about 1.5m.
- SCCL is planning to introduce this explosive in solid blasting operations for increasing production and productivity.
- 13. Study into extent of abutment loading trend and design of advance support during pillar extraction by stowing in a coal mine.
- Project code : WIT/133
- Implementing and sub-implementing agency: SCCL and NIRM.
- Total cost: Rs 35.79 lakhs
- S&T share: Rs. 35.79 lakhs
- SCCL share: Nil
- Date of starting: September 2002
- Date of completion: August 2005
- Site of implementation of the project: GDK 5A Incline, SCCL

Benefits to the mining industry

- The study was carried out to optimize the advance supports in depillaring panels with sand stowing. Coal Mines Regulations requires advance support to be carried out in depillaring panels upto two pillars or 30m which ever is more irrespective of whether it is caving or stowing panel.
- Based on the strata monitoring observations and numerical modeling with FLAC 3D, it was seen that the influence of the extraction of the pillars was felt up to one-and-a-half pillar distance from the pillar under extraction.
- It is suggested to conduct some more field trials under difficult geo-mining parameters before reducing the distance for advance supports.

14. Role of blast design parameters on ground vibration and correlation of vibration level to blasting damage to surface structures

- Project code: MT/134/02
- Implementing and sub-implementing agency: NIRM, WCL and SCCL
- Total cost: Rs 37.60 lakhs
- S&T share: Rs. 29.60 lakhs
- SCCL share: Rs. 3.00 Lakhs
- Date of starting: October 2002
- Date of completion: September 2005
- Site of implementation of the project: RG OC II and Medipalli OCP, SCCL.

Benefits to the mining industry

This study was conducted to provide technical justification for the revision of DGMS vibration limits and suggest a proper strategy to contain ground vibrations.

The study revealed that the existing DGMS levels of ground vibrations are very conservative i.e. factor of safety is very high and there is ample scope for revising the current limits without defeating its basic purpose - adequate safety of surface structure.

If the recommendations of the study are accepted by DGMS, mining industry would be benefited by increasing the maximum charge per delay and increasing the blasting area and reducing the frequency of blasting.

15. Development of integrated mine operation management system for a large opencast coal mine

- Project code: WIT/142
- Implementing and sub-implementing agency: Anna University and SCCL
- Total cost: Rs 35.70 lakhs
- S&T share: Rs. 32.13 lakhs
- SCCL share: Rs. 3.57 Lakhs
- Date of starting: July 2004
- Date of completion: June 2006
- Site of implementation of the project: RG OC II, SCCL

Benefits to the mining industry

In this project effective integrated mine management system (IMMS) for large scale opencast mining operations is developed for continuous monitoring of key performance indicators. The system is successfully being implemented in some OC projects of SCCL.

16. Development of mining method for final extraction of critically thick coal seams standing on pillars and the development made along roof horizon mines.

- Project code: MT/141
- Implementing and sub-implementing agency: CMRI and SCCL
- Total cost: Rs 24.30 lakhs
- S&T share: Rs. 21.87 lakhs
- SCCL share: 2.43
- Date of starting: November 2003
- Date of completion: October 2006
- Site of implementation of the project: GDK 6B, SCCL Benefits to the mining industry

The objective of the project is to develop a mining method for final extraction of thick coal seams of less than 9 m thickness, standing on pillars and the development made along roof horizon and superimposed bottom section development is not possible due to critical thickness of the seam. This method can be applied in critically thick seams.

17. Development of support guidelines for depillaring panels in Indian coal mines.

- Project code: MT/126
- Implementing and sub-implementing agency: CMRI
- Total cost: Rs 21.78 lakhs
- S&T share: Rs. 21.78 lakhs
- SCCL share:
- Date of starting: October 2001
- Date of completion: April 2006
- Site of implementation of the project: GDK 5A, SCCL

Benefits to the mining industry

In this project attempts were made to develop empirical equations for estimating the support load density at different places of the face, which helps in designing of support system properly at the face. Equations for support load densities for slice junction, within slice, in the split gallery and for goaf edges were developed. This will help the mining industry to design the supports, which are adequate for site-specific conditions.

18. Studies on the advance detection of fires in coal mines with special reference to Singareni Collieries Company Ltd.

- Project code : WIT/130/101
- Implementing and sub-implementing agency: Andhra University and SCCL.
- Total cost: Rs 166.50 lakhs
- S&T share: Rs. 166.50 lakhs
- SCCL share:
- Date of starting : September 2002
- Date of completion: November 2007
- Site of implementation of the project:

Benefits to the mining industry

In this study it is investigated that the presence of following parameters influences the proneness of coal for spontaneous combustion, which would be helpful for assessing the coal for spontaneous heating.

- Concentration of free radicals in coal
- Rate of weight increase or weight loss.
- Energy released for exothermic reaction
- Concentration of C4 - C12 hydrocarbons.

19. Environmental Impact of subsidence movements caused due to caving on ground water and forest cover in Godavari Valley coalfields.

- Project code: EE/28
- Implementing and sub-implementing agency: CMRI and SCCL.
- Total cost: Rs 72.03 lakhs
- S&T share: Rs. 60.83 lakhs
- SCCL share: Rs. 11.20 lakhs
- Date of starting: October 2003
- Date of completion: September 2007
- Site of implementation of the project: 5B and MK 4 Incline.

Benefits to the mining industry

- The project is implemented to assess the environmental impact of subsidence movements caused due to caving on groundwater and forest cover to generate the safe limits of ground movements for caved workings below forest land.
- The study revealed that the transmitivity and hydraulic conductivity of aquifer were almost unaffected due to mining at 5B incline, whereas they become almost doubled at MK 4 Incline due to multi seam extraction in 4 panels at a time.

- Subsidence movements caused accumulation of fine textured soil in the trough area and increased soil moisture.
- Ground movements have also increased soil organic carbon, total nitrogen and phosphorous.
- Subsidence movements have no impact on phyto-sociological characters of forest cover over all the subsided sites having up-to 1m wide cracks and 23.74 mm/m tensile strain.
- This study is useful to the mining industry in predicting the subsidence impact over the caving depillaring panels.

20. Optimisation of pillar parameters for development and final extraction of highly inclined seams at SCCL mines.

- Project code: MT/115/99
- Implementing and sub-implementing agency: SCCL and NIRM.
- Total cost: Rs 24.96 lakhs
- S&T share: Rs. 19.60 lakhs
- SCCL share: Rs. 5.00 lakhs
- Date of starting: December 1999
- Date of completion: December 2007
- Site of implementation of the project: KTK 5 Incline,

SCCL Benefits to the mining industry

- This study was carried out to optimize the chain/rectangular pillars parameters for highly inclined coal seams.
- It is found that factor of safety of rectangular pillars of 26 × 10 m size is 2.3. This has eased the working conditions for the workers and removed drudgery during loading in the steep seams, which has resulted in the improvement of OMS from the panel.

21. Direct sourcing of coal for value added chemicals.

- Project code: CU-51
- Implementing and sub-implementing agency: CMRI, IICT, Hyd and SCCL.
- Total cost: Rs.70.30 lakhs
- S&T share: Rs.70.30 lakhs
- SCCL share: Nil
- Date of starting: November 2004
- Date of completion: July 2008
- Site of implementation of the project:

Benefits to the mining industry

- The objective of this study is to explore commercial utility of non-coking coal for sourcing them for value added chemicals.
- The study revealed that mixture of chemicals (coal derivatives obtained after nitric acid oxidation) has a gross property, which can be utilised as a value added product like organic semi-conductor. This particular behaviour is a new information to the world of coal science and technology. This would create new vista in utilization of coal as a source of high value product.
- The acetone extract can be used as a material for removing statical electricity from a surface and can be used in different types of inks.

3.0 IMPACTS OF R&D ON THE PERFORMANCE OF THE INDIAN MINERALS SECTOR

The preceding chapters have underscored the evolution of R&D initiatives and the size of investment in R&D made in Indian minerals sector since the beginning of the 20th century. In assessing the aggregative contributions of the past R&D initiatives, it is necessary to resolve some definitional issues vis-à-vis "performance", "impacts" and "relevance" to appraise the outcome of the initiatives in concrete terms. Performance of the minerals sector can be adjudged holistically only on multiple criteria which include inter alia three major metrics: productivity of the industry, track record in workplace safety and environmental stewardship. One could also benchmark other parameters such as international competitiveness, and quality of governance. Some of these are at times intangible and the mining industry offers little scope for benchmarking these parameters because of confidentiality on organizational performance. It is only of late that in striving for transparency and accountability major mining companies are circulating their annual social and environmental review. For the assessment of research relevance and impact, the contributions of R&D have been examined using a modified five-point scale originally evolved by the National Academies in the United States as given in Box 1. Relevance could be evaluated in terms of the priority of work carried out which bear upon the upgraded performance of the industry while impact is evaluated in terms of the contributions of research to technology

BOX 1

Five-point scales used for the rating of relevance and impact

Rating of relevance

5. = Research is in highest-priority subject areas and highly relevant to improvements in workplace protection; research results in, and transfer activities at a significant level (highest rating).
4. = Research is in high-priority subject area and adequately connected to improvements in workplace protection; research results in, and transfer activities.
3. = Research focuses on lesser priorities and is loosely or only indirectly connected to workplace protection.
2. = Research programme is not well integrated or well focused on priorities and is not clearly connected to workplace protection and inadequately connected to transfer activities.
1. = Research in the research programme is an ad hoc collection of projects, is not integrated into a programme, and is not likely to improve workplace safety or health.

Rating of impact

5. = Research programme has made a major contribution to worker health and safety on the basis of end outcomes or well-accepted intermediate outcomes.
4. = Research programme has made a moderate contribution on the basis of end outcomes or well-accepted intermediate outcomes; research programme generated important new knowledge and is engaged in transfer activities, but well-accepted intermediate outcomes or end outcomes have not been documented.
3. = Research programme activities or outputs are going on and are likely to produce improvements in worker health and safety (with explanation of why not rated higher).
2. = Research programme activities or outputs are going on and may result in new knowledge or technology, but only limited application is expected.
1. = Research activities and outputs are NOT likely to have any application.

NA Impact cannot be assessed; programme is not mature enough.

upgradation, enhanced productivity levels reached and improved safety records of the industry. Much of the research work undertaken so far by the major research establishments have led to incremental improvements in production and productivity and in any case establishing a causal relationship between research outcomes and productivity can at best be tenuous. No major projects barring the demonstration of shortwall mining for extraction of developed pillars have been implemented thus far. Amongst new technology trials mention can be made of blasting gallery method in Singareni Collieries, adopted from the French mining technique in Blanzy coalfield by Charbonnage de France (CdF), where production and productivity levels have exceeded the original trials made in France. This has been possible through a raft of R&D projects including development of suitable explosives for ring hole blasting, optimising blasting patterns, and development of measures for prevention and control of spontaneous heating. Large demonstration projects for extraction of thick seams such as hydraulic mining have failed to deliver the expected outcomes and had to be aborted. Despite surveillance and monitoring of strata control parameters in longwall faces, including sophisticated instrumentation and seismo-acoustic monitoring, the production and productivity of major longwall faces could not be scaled to higher economical levels. In fact, the collapse of longwall faces at Churcha and Kottadih, have eroded the confidence in longwall system per se and the applications have largely been slow and halting. One would look forward to the results at state-of-the-art longwall face at Adriyala longwall project in Singareni Collieries Co.Ltd which will go into production in 2012. The project has received inputs from CSIRO, Australia for geotechnical characterization for the design of the face. A pervasive problem faced in underground coal mining is that of cavability of hard and massive roof rocks overlying coal seams and R&D efforts in this direction have been fragmentary and have not yielded so far any usable methodology which could be of assistance in selecting the capacity of longwall powered supports. Caving Index, proposed and touted by the Central Mining Research Station is (CMRS), is overly empirical in nature and does not take into cognizance some essential parameters affecting caving behaviour such as the face length or the state of stress. So far, the Ministry of Coal have assigned two projects in this area and a consortium of the CIMFR, NIRM and ISM are involved, in an on-going Coal S&T project with substantial funding to come up with definitive answers on the evaluation of cavability of roof rocks.

Indian coal sector has dominantly been labour-intensive in its underground operations and even after the nationalization of the coal sector, intermediate technology using side discharge loader(SDL) and load-haul-dump (LHD) systems have formed the backbone of such semi-mechanised systems. In consequence, the labour productivity has been dismally low, when compared with coal industries around the world, including even China. Fig.3.1 demonstrates the growth trajectory of labour productivity in surface and underground coal mines, of Coal India and SCCL (Fig.3.2) where the overall improvement in labour productivity has been higher in mines of SCCL.

In the metalliferrous mining sector, where technology developments have been marked, the R & D projects have been diverse and have led to the implementation of new mining methods such as Vertical Crater Retreat (VCR) at Rajpura Dariba mine of HZL, introduction of cemented backfill in open stopes and replacing rib pillars by cemented fills, demonstration of techniques of mass mining of remnant crown and sill pillars under high stress conditions by using state-of-the-art blasting techniques and application of Slope Stability Radar GroundProbe at Rampura Agucha mine of HZL. There have been some successful development of mining techniques as research outcomes at Hutti Gold Mines (development of Vertical Retreat Mining), large diameter blast hole stoping, optimization of stope parameters through ground control monitoring, post-pillar stoping at Hindustan Copper Ltd (HCL), and the development of new cut and fill methods at underground mines of Uranium Corporation of India Ltd (UCIL). The levels of productivity, however, remain dismally low when benchmarked against overseas figures. Overall productivity in terms of OMS during 2009-10 at mines of UCIL were: Jaduguda mine – 0.8 tonnes; Narwapahar- 2.0 tonnes). This is especially striking when one reflects on the productivity levels in coal sector. Fig.3.3 shows the trend of coal mining productivity in the United States for 1949-2006 which demonstrates the abysmal gap in the productivity between Indian coal industry and that of the United States; for a productivity level of 13.8 short tons per miner hour in surface mines in 2006 and 3.9 short tons per miner hour in underground

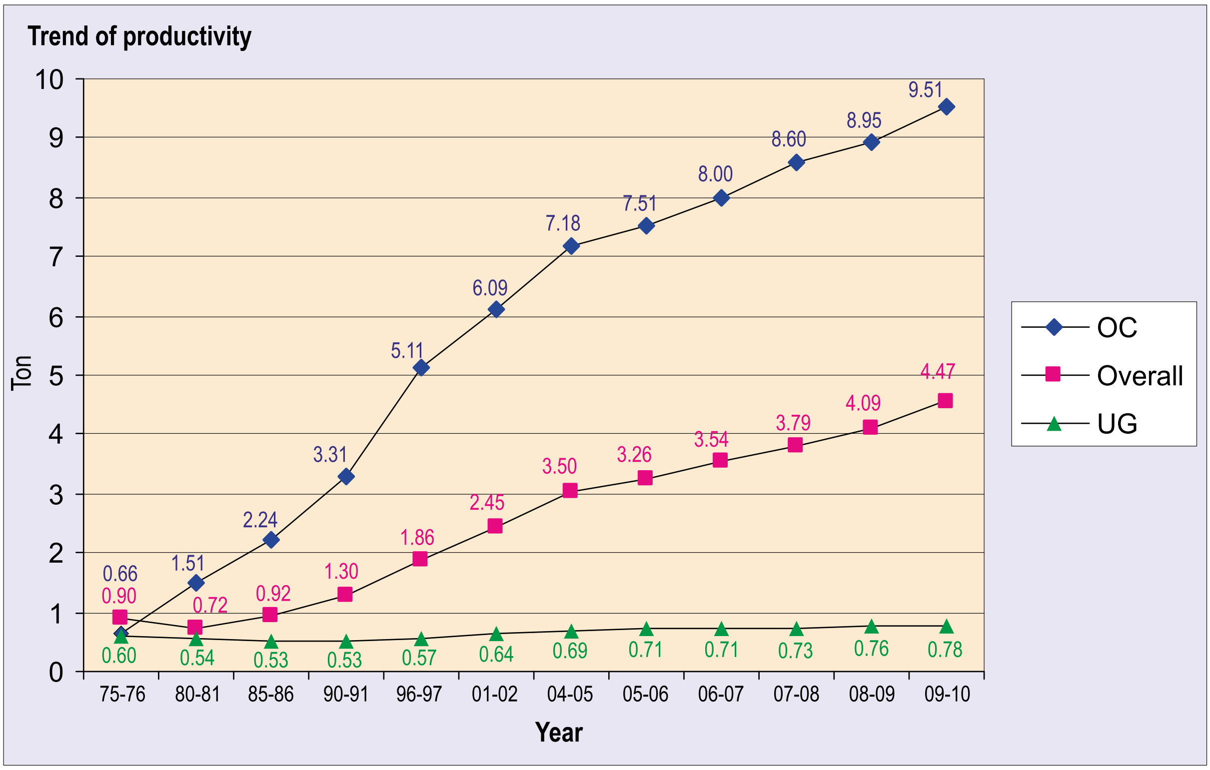

Trend of productivity
Ton
Year
OC
Overall
UG
75-76
80-81
85-86
90-91
96-97
01-02
04-05
05-06
06-07
07-08
08-09
09-10
0.66
1.51
2.24
3.31
5.11
6.09
7.18
7.51
8.00
8.60
8.95
9.51
0.90
0.72
0.92
1.30
1.86
2.45
3.50
3.26
3.54
3.79
4.09
4.47
0.60
0.54
0.53
0.53
0.57
0.64
0.69
0.71
0.71
0.73
0.76
0.78

Fig.3.1

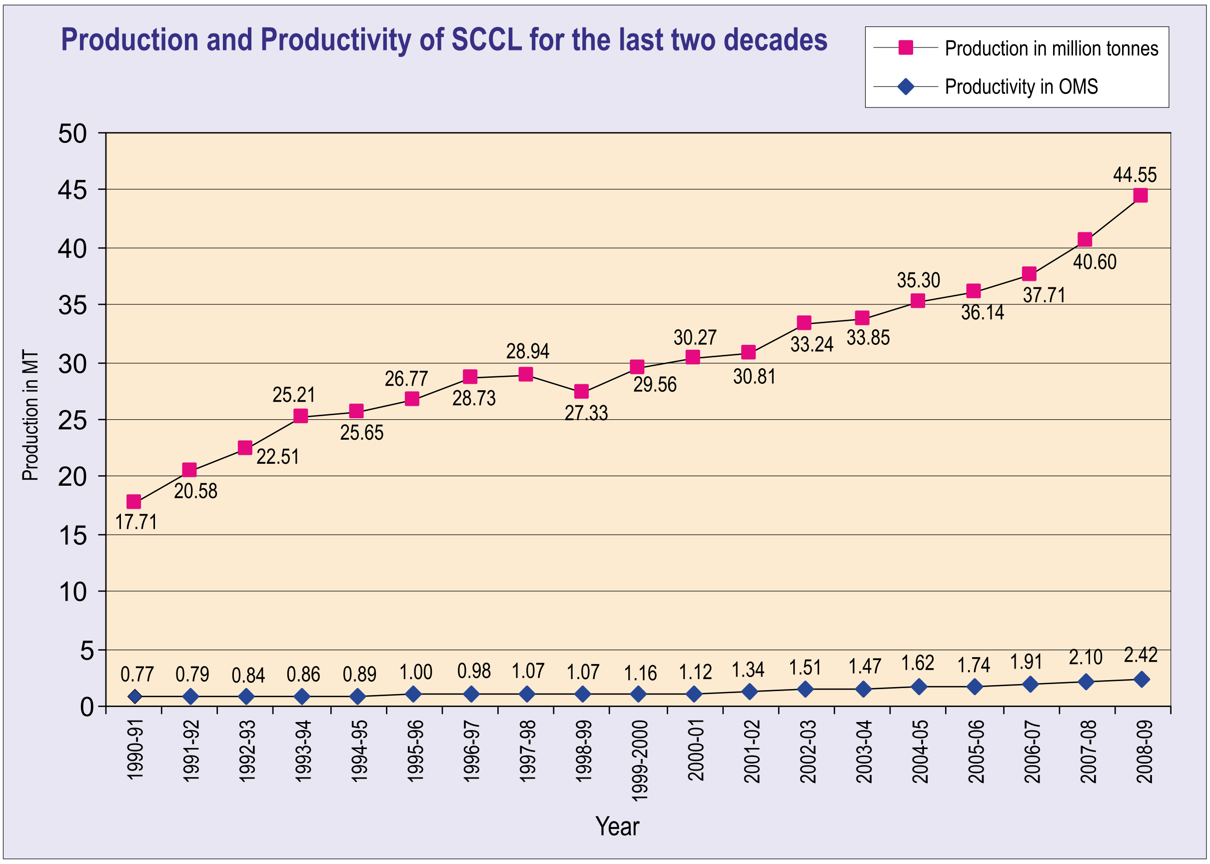

Production and Productivity of SCCL for the last two decades
Production in million tonnes
Productivity in OMS
Production in MT
Year
1990-91
1991-92
1992-93
1993-94
1994-95
1995-96
1996-97
1997-98
1998-99
1999-2000
2000-01
2001-02
2002-03
2003-04
2004-05
2005-06
2006-07
2007-08
2008-09
17.71
20.58
22.51
25.21
25.65
26.77
28.73
28.94
27.33
29.56
30.27
30.81
33.24
33.85
35.30
36.14
37.71
40.60
44.55
0.77
0.79
0.84
0.86
0.89
1.00
0.98
1.07
1.07
1.16
1.12
1.34
1.51
1.47
1.62
1.74
1.91
2.10
2.42

Fig.3.2

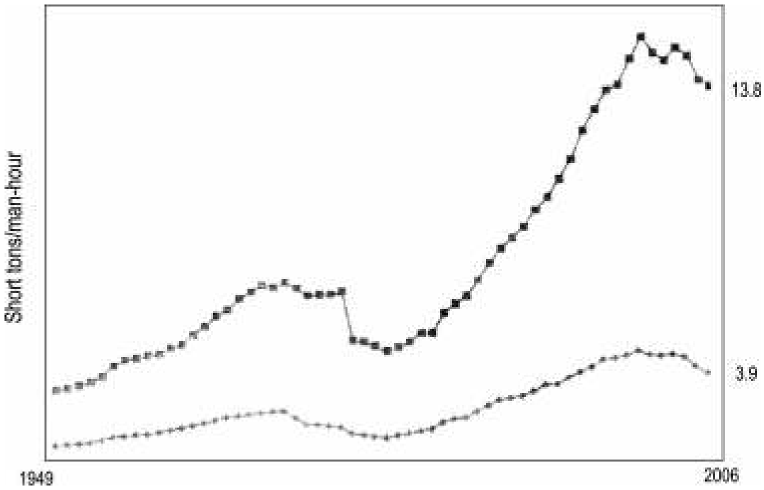


Fig.3.3 Coal mining productivity, 1949-2006 by mining type in USA

mines, the corresponding figures for Indian coal industry for surface and underground mines were 9.51 and 0.78 tonnes per manshift respectively.

Whilst much of the differences could be attributable to larger and more reliable equipment in both surface and underground operations in the United States, the fact remains that Indian minerals sector has only Inched ahead in its productivity performance. Technological change which could have been possible through R&D was largely thwarted by obsessive focus on intermediate technology and lack of awareness of improvements in equipment technology world-wide. If one critically scans the projects funded by Coal S&T on equipment development, one comes across projects like development and trial of auger-cum-drill, and development of roof bolting machine, which could hardly be categorized as R&D projects and fail on the score of being relevant and in terms of impact gets the lowest score as applications were few and far between. On the other hand, reasonably large-sized network projects like coastal placer mining would score high both on impact and relevance.

In terms of safety performance, Indian minerals sector has had a reasonable track record in terms of fatality rates as shown in Fig.3.4, which provides a comparative landscape for mine safety in major coal producing countries of the world.

The diminishing trend of accidents as well as improved safety performance, which is inversely proportional to technology growth and R&D efforts, is discernible. Table 3.1 presents the trend in fatal accidents and fatality rates per 1000 persons employed in coal and non-coal mines (on a ten-yearly average basis) while Table 3.2 shows the trend of incidence of accidents in mines between 2000-2009. Tables 3.3 and 3.4 show the trend in fatal and serious accidents and death and serious injury rates in coal mines and metalliferrous mines, place-wise. It is significant to note that in the recent past, death rate per 1000 persons in opencast mines has surpassed that of below underground rates. The occurrence of mine disasters, which often mar the safety track record is an area of major concern. However, precise contribution of R&D to improvements in safety would be difficult to delineate as continuous legislative and regulatory actions have had overarching impact on safety records. The scale of R&D activity in the area of mine safety *per se* has been abysmally low in the country. The following table summarises the disasters (death toll exceeding 10) in Indian minerals sector over the past decade and underscores the fact that accidents due to inundation and explosions still account for a large number of fatalities:

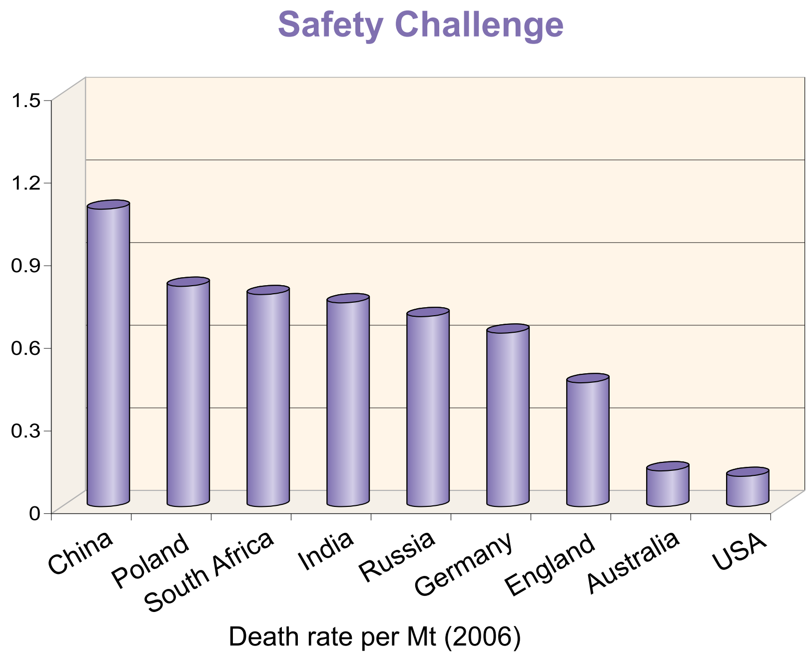


Fig.3.4

Mine disasters since 2000

Date	Mine	Fatalities	Cause
24.06.2000	Kawadi opencast, WCL	10	Fall of side
02.02.2001	Bagdigi, BCCL	9	Inundation
16.06.2003	Godavari Khani, SCCL	17	Inundation
7.10.2003	Godavari Khani 8A, SCCL	10	Fall of roof
15.06.2005	Central Saunda, CCL	14	Inundation
06.09.2006	Bhatdee, BCCL	50	Explosion
06.05.2010	Anjan Hill, SECL	14	Explosion

Safety research initiatives that have been mounted in the recent past include development of robots for access to difficult and risky environments, use of ground penetrating radar for evaluating the barrier thickness against water bodies and development of refuge chambers in the event of a disaster.

Best practice environmental management is still a far cry in the minerals sector and the quantum of research undertaken so far fall short of the needs[25]. Critical issues include water and waste water management, solid waste management, development of bio-reclamation techniques amongst others.

Table 3.1 Trend in fatal accidents and fatality rates per 1000 persons employed (Ten yearly average)

	Coal mines				Non-coal mines			
	Av No. of acc.	Acc. rate	Av. No.of fatalities	Fatality rate	Av. No. of acc.	Acc. rate	Av. No. of fatalities	Fatality rate
1901-10	74	0.76	92	0.03	16	0.47	23	0.67
1911-20	139	0.94	176	1.29	29	0.57	37	0.73
1921-30	174	0.99	219	1.24	43	0.54	50	0.66
1931-40	172	0.98	228	1.33	35	0.41	43	0.51
1941-50	226	0.87	273	1.01	26	0.24	31	0.19
1951-60	223	0.61	295	0.82	64	0.27	81	0.34
1961-70	202	0.49	264	0.55	66	0.27	74	0.30
1981-90	162	0.30	185	0.34	65	0.27	73	0.51
1991-00	140	0.27	170	0.33	65	0.31	77	0.36
2001-09	86	0.21	107	0.27	55	0.35	66	0.42

N.B.: Data for the period 2001-2009 are provisional and figures for 2009 are up to 31.12.09

Table 3.2 Trend in incidence of Accidents in Mines

	Coal Number of accidents			Metal Number of accidents			Oil Number of accidents		
Year	Fatal	Serious	Total	Fatal	Serious	Total	Fatal	Serious	Total
2000	117	661	778	50	160	210	1	27	23
2001	105	667	772	62	178	240	9	21	30
2002	81	629	710	50	174	224	2	31	3
2003	83	563	646	51	147	198	1	21	2
2004	87	962	1049	55	150	205	2	38	40
2005	96	1106	1202	47	93	140	1	15	10
2006	78	861	939	54	63	117	4	15	10
2007	77	923	1000	54	63	117	3	16	10
2008	85	687	772	56	63	119	8	20	28
2009	78	487	565	32	65	97	6	15	2

N B. Figures for the years 2007 to 2009 are provisional and figures for 2009 are up to 31.12.09

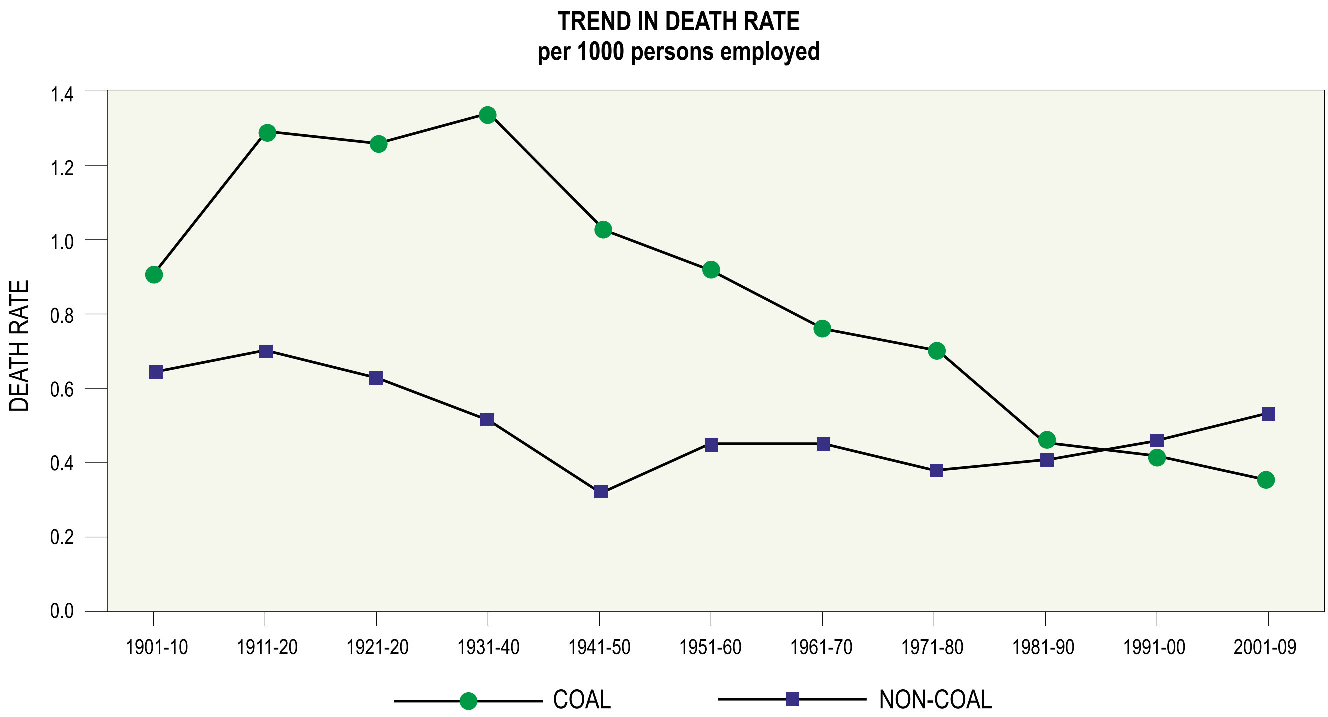


Table 3.3: Trend in Fatal and serious accidents and death rate and serious injury rates in coal mines

	No. of accidents			Accident frequency rate/lakh Manshifts	Number of persons		Rate per 1000 persons employed		Death rate per Million tonnes
Year	Fatal	Serious	Total		Killed	Seriously S/injured*	Death rate	Serious inj. rate	
2000	117	661	778	0.54	144	707	0.31	1.54	0.43
2001	105	667	772	0.54	141	720	0.32	1.64	0.41
2002	81	629	710	0.54	97	665	0.23	1.57	0.27
2003	83	563	646	0.50	113	590	0.27	1.42	0.30
2004	87	962	1049	0.82	96	991	0.24	2.45	0.23
2005	96	1106	1202	0.96	117	1138	0.29	2.85	0.28
2006	78	861	939	0.76	137	891	0.36	2.31	0.32
2007	77	923	1000	0.81	79	951	0.20	2.47	0.18
2008	85	687	772	0.63	98	710	0.25	1.84	0.23
2009	78	487	565	0.46	88	513	0.23	1.33	0.20

Note: Data for the years 2007 to 2009 are piovisional. Figures for 2009 are up to 31.12.09

• Includes seriously injureds from fatal accidents also.

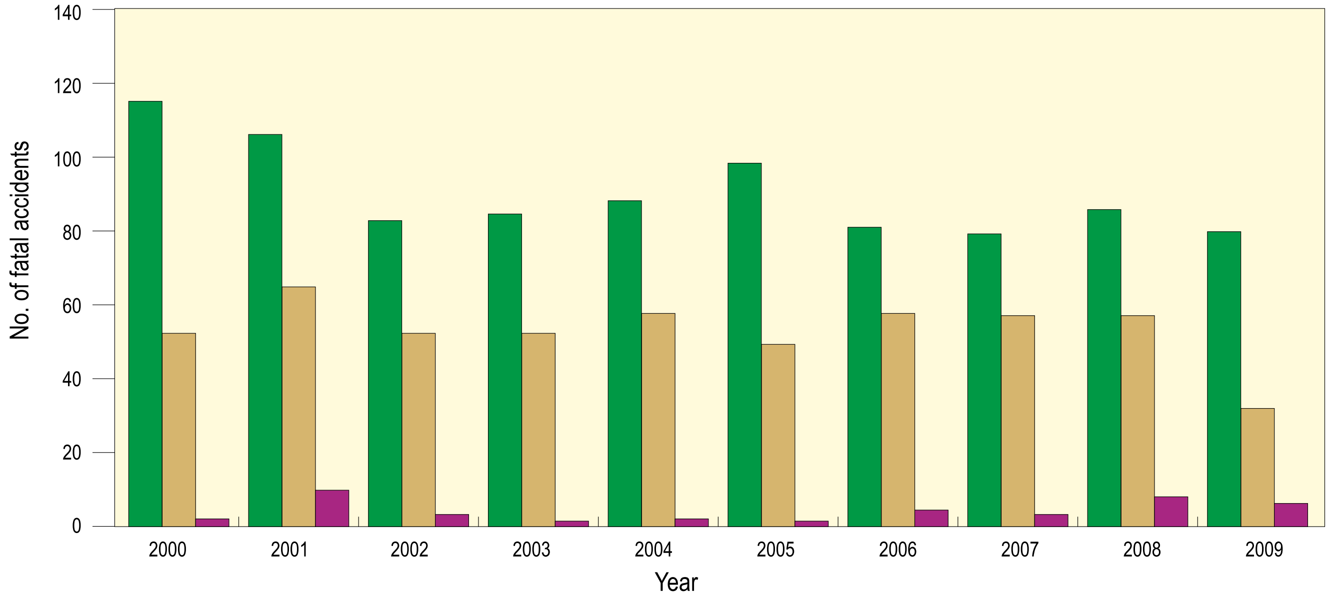
Table 3.4 : Trend in Fatal and serious accidents and death and serious injury rates in metalliferous mines - placewise

	Number of fatal accidents				Number of serious accidents				Death rate per 1000 persons				Serious injury rate per 1000 persons			
Year	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall
2000	7	30	13	50	66	38	56	160	0.49	0.37	0.25	0.34	4.65	0.46	1.12	1.06
2001	5	45	12	62	59	37	82	178	0.46	0.63	0.36	0.53	5.57	0.53	1.82	1.36
2002	5	33	12	50	52	40	82	174	0.49	0.54	0.28	0.45	5.07	0.53	1.89	1.30
2003	3	31	17	51	57	25	65	147	0.52	0.45	0.42	0.45	7.36	0.43	1.56	1.19
2004	5	36	14	55	54	34	62	150	0.62	0.47	0.32	0.43	6.70	0.52	1.36	1.14

Year	Number of fatal accidents				Number of serious accidents				Death rate per 1000 persons				Serious injury rate per 1000 persons			
	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall
2005	3	34	10	47	27	22	44	93	0.38	0.43	0.23	0.36	3.41	0.30	0.99	0.70
2006	3	42	9	54	24	13	26	63	0.38	0.62	0.19	0.47	3.20	0.25	0.55	0.51
2007	3	39	12	54	19	14	30	63	0.38	0.58	0.26	0.46	3.84	0.34	0.66	0.63
2008	3	40	13	56	15	20	28	63	0.51	0.56	0.49	0.54	2.05	0.35	1.11	0.69
2009	4	23	5	32	28	14	23	65	0.51	0.34	0.15	0.29	3.71	0.20	0.55	0.51

Note: Data for the year 2007 to 2009 are provisional. Figures for 2009 are upto 31.12.09
Serious injuries from fatal accidents are also considered for computation of serious injury rates.

TREND IN INCIDENCE OF FATAL ACCIDENTS in mines



TREND IN DEATH RATES AND SERIOUS INJURY RATES in Coal Mines

Table 3.5 : Trend in Fatal and serious accidents and death and serious injury rates in coal mines - placewise

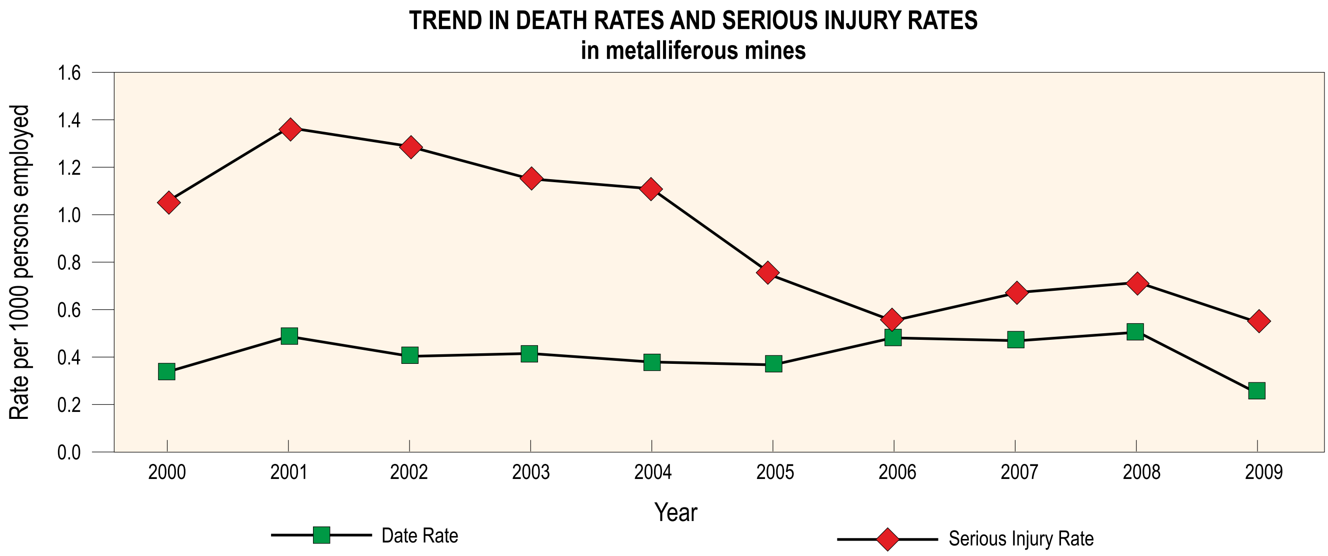
Year	Number of fatal accidents				Number of serious accidents				Death rate per 1000 persons				Serious injury rate per 1000 persons			
	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall	Below ground	Open-cast	Above ground	Overall
2000	62	38	17	117	444	108	109	661	0.30	0.74	0.13	0.13	1.92	1.67	0.82	1.54
2001	67	26	12	105	464	73	130	667	0.43	0.38	0.10	0.32	2.10	1.12	1.07	1.64
2002	48	22	11	81	434	92	103	629	0.27	0.32	0.11	0.23	2.07	1.43	0.80	1.57
2003	46	23	14	83	380	82	101	563	0.33	0.35	0.13	0.27	1.85	1.30	0.77	1.42
2004	49	32	6	87	757	82	123	962	0.27	0.47	0.05	0.24	3.69	1.24	1.02	2.45
2005	50	28	18	96	843	98	165	1106	0.34	0.42	0.15	0.29	4.23	1.45	1.37	2.85
2006	44	24	10	78	646	88	127	861	0.52	0.33	0.09	0.36	3.40	1.30	1.11	2.31
2007	25	36	16	77	717	83	123	923	0.13	0.50	0.14	0.20	3.75	1.16	1.12	2.47
2008	34	31	20	85	517	74	96	687	0.21	0.49	0.18	0.25	2.74	1.00	0.85	1.84
2009	32	34	12	78	375	39	73	487	0.20	0.49	0.11	0.23	2.00	0.58	0.68	1.33

Note: Data for the year 1007 to 2009 are provisional. Rates for the years2007 to 2009 are provisional. Figures for 2009 are upto 31.12.09 Serious injuries from fatal accidents are also considered for computation of serious injury rates.

Table 3.6: Trend in Fatal and serious asccidents and death rate and serious injury rates in metalliferous mines

Year	No. of accidents			Accident frequency rate per 1000 person employed	Number of persons			Rate per 1000 persons employed
	Fatal	Serious	Total		Killed	Seriously injured*	Death rate	Serious inj. rate
2000	50	160	210	1.34	54	166	0.34	1.06
2001	62	178	240	1.76	72	186	0.53	1.36
2002	50	174	224	1.64	62	178	0.45	1.30
2003	51	147	198	1.45	61	163	0.45	1.19
2004	55	150	205	1.43	62	163	0.43	1.14
2005	47	93	140	0.99	51	98	0.36	0.70
2006	54	63	117	0.82	67	73	0.47	0.51
2007	54	63	117	0.82	66	91	0.46	0.63
2008	56	63	119	0.83	77	99	0.54	0.69
2009	32	65	97	0.68	41	73	0.29	0.51

Note: Data for the years 2007 to 2009 are piovisional. Figures for 2009 are up to 31.12.09
* Includes seriously injureds from fatal accidents



4.0 GREEN MINING – NEW R & D INITIATIVES ON INDIAN MINERAL INDUSTRY HORIZON

4.1 Introduction

Although the concept of rather politically correct "green" mining has been bandied about for quite sometime, the consensus in the usage of the term is still emerging. To start to explore the labyrinths of green mining it is now important to address the environmental issues of mining with improved efficiency, conservation, restoration and sustainable perpetual use of the natural resources on which mining was conducted or more practically, will be conducted in the future.

To put forward a working definition Green mining can be considered as a modern mining exercise where the mineral resource depletion would be simultaneously compensated by growth and restoration of natural capital of water resource, land, trees, biodiversity as well as possibilities of agriculture. It aims to make sure that the efficiency of minerals mining is optimised with the natural resource productivity of the environment and brings in coordination to the benefit of enterprise and society to foster perpetual return.

The focus thus far has been placed on five main research pillars:

- Footprint reduction by enhancing procedural and material efficiency.
- Innovation in waste management and re-use.
- Ecosystem risk management by enhanced disaster preparedness and system sensitization.
- Mine closure, rehabilitation and regeneration.
- Sustainable use of mined out land and surrounding resources

The need for research to support the pillars, especially the need for research for finding alternatives to tailings placement and reclamation is a compelling one. While much research and development and demonstration is currently under way in Indian minerals sector to reduce the footprint of ravages wrought on the environment, waste management continues to be a neglected and contentious area. Likewise, there has been only a modicum of research on issues of mine closure or that of rehabilitation of the mined land and restoring the abandoned or orphaned mine sites. Remediation measures are essentially site-specific and call for research and demonstration over a period of time. Neyveli lignite mines, and opencast mines of Coal India, have also implemented best practices in environmental management in striving for "green" mining goals. The Center for Mining Environment at Indian School of Mines,CIMFR and IIT,Kharagpur have initiated important research projects including management of solid wastes, utilization of industrial wastes such as fly ash, stabilization and control of waste dumps, development of fugitive dust dispersion model for mining areas, new bio-remediation method development amongst others.

In Chinese coal industry, the concept of green mining is taking shape as the research capacity and infrastructure in the key areas are better than that of India, where the preservation of water in mining areas, coal mining under surface structures with bed separation spaces grouted to retard surface subsidence, partial extraction and mining with backfill, besides underground disposal of rock waste are resorted to in order that the relationship between mining and the surrounding environment could be harmonious as it existed prior to mining. Much of the environmental problems are related to mining-induced strata movement, especially the fracture of the key strata in the overlying rocks. The crux of the theory as foundation for the "green" mining concept is: (i) the development and distribution of joints, fractures and bed separation in overburden after mining, (ii) the influence of mining on the movement of rock strata and surface subsidence; (iii) the seepage and flow of gas and water in the broken rock strata; and (iv) the distribution of the stress field in the rock mass. The theory of "key stratum" has been advanced based on the study of how the thick and strong rock strata in overburden control the distribution of fractures, the methane drainage, the prevention and mitigation of water irruption, and surface subsidence. Fig.4.1 shows a conceptual scheme of "green" mining, where the surface structures could be protected by grouting the bed separation voids or by partial backfilling. Since grouting techniques cannot prevent the initial break of the key strata, based on bed separation developing dynamically below the key strata, Chinese specialists have advanced the concept of "section-grouting" for the overburden bed separation spaces (Xu et al,2004[15]).

Green Mining

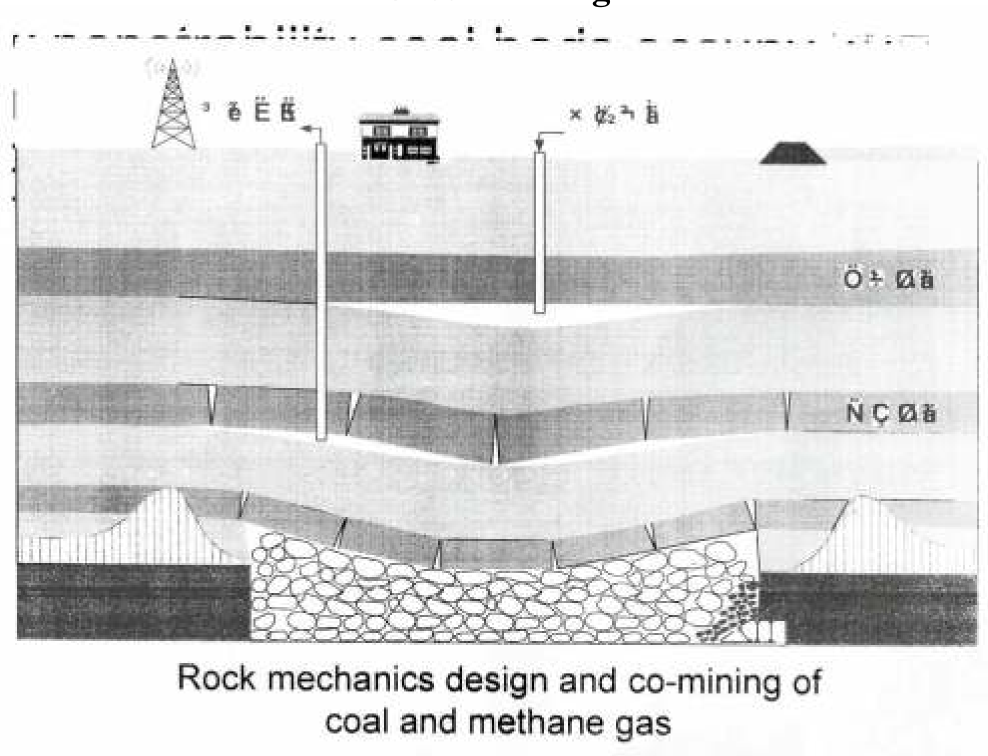


Fig.4.1

The disposal of the mounting volume of wastes in the mining process safely and in an environmentally-compatible manner continues to be the key area of concern in implementing green mining. The current volume of wastes for a total minerals output of 1.3 billion tonnes in India could be, based on a back of the envelope estimate, of the order of 1 billion tonne of solid waste while the effluent volumes are difficult to estimate reasonably. "Green Mining" could be feasible, if and only if, the footprints of mining processes which are being enlarged due to the aggregative impacts of air pollution, of mine fires, impacts on mining water regime, noise and vibration and on land and ecology could be contained. Under the "India- Environmental Management Capacity Building Technical Assistance Project" between 1997 and 2004, 16 R&D proposals were funded in the area of environment. Of these projects, in terms of impact and relevance the studies on airborne dust concentration at work place in Chromite mines of Sukinda belt and the assessment and prediction of groundwater contamination in and around chromite mine dump and its management, closure plans for the selected SECL coal mines deserve special mention. Very little work has been undertaken in Indian minerals sector on waste disposal or for that matter on ecosystem risk management or on mine closure. Post-mining landscaping could be a fit area for R&D; water treatment at mine closure is also a fit area for R&D for sustainable mining.

4.2 Stumbling blocks

For the research in green mining to fructify in India, structural and regulatory changes are necessary: government allowing industry to attain higher leverage on the mined land by means of clarity in regulation and at the same time, making the industry more responsible. Unless the industry sees the attainable economic benefit in terms of mined land restoration, at moderate risk, it will not be enthusiastic in green mining. And so would suffer research and good results.

Just a case in example, many abandoned underground and surface mines, with time, have become reservoir of water.It is now more or less accepted that such water reservoirs bring back ground water level at a pre-mining level, work towards bringing equilibrium in confinement pressure. In a water deficit country like India such fresh water reservoir can also be an important source of supply for civil and agricultural use. While supply and demand exist, the research can be the plug that will bring in such potential to effective use.

4.3 Technological Constraints

As mining is distinctly different from manufacturing (set up) the site specificity brings about many varieties of technological challenge. Through the mechanical systems of green mining concepts like use of surface miner have a certain maturity in development, geological complexities make every situation salient and thus complex.

The technical innovation in mining processes require long periods of technological and field trials and thus needs sustained effort to obtain satisfactory performance and economic results. Infrastructural and capacity building support is thus very important Therefore, government should offer the fund to support mine technological progress, and popularize and introduce the advanced methods of green mining at home and abroad as much as possible, to enhance and capture newer markets for green mining systems.

The main technology of green mining includes water preservation, simultaneous extraction of coal and coal-bed methane, bed separation grouting to reduce surface subsidence, coal roadway supporting and underground discharge of partial rock refuse, underground coal gasification, etc. There are many aspects to be considered in coal green mining technology, such as control and prediction of mining subsidence and quantitative design method of mining under constructions which are based on the strata movement and key stratum theory, backfill coal mining methods and process systems which suit mine characteristics. Of course, the research and development, including mining research and mining institutes should be encouraged to develop capacity and to offer enough technical support to coal enterprises.

4.4 Community Acceptance

While a minority of the local community benefits from the mining activity, the majority suffers due to disproportionate lack of income and sustainable opportunities. Mining industry remains inseparably attached to the community surrounding its activities. This condition cannot be any truer in India due to its populous nature, than in any other country of the world. Green mining would need gradual societal acceptance. Considerable research input is needed to understand the community requirements and their fit and alignments with the mining process for long term solutions.

4.5 Research Agenda

The following research agenda could be identified as the need of the hour:

1. Structure protective mining, minimizing the use of explosives.
2. Flexible belt and other conveying technologies to reduce the use of small and medium sized dump trucks in surface mines.
3. Improved ground control.
4. Reduction of fugitive dust

5. Progressive land filling and reclamation.
6. Abundant use of plants and trees to use them as carbon sinks.
7. Recovery and reuse of substances from tailing impoundments.
8. Use of low fixed carbon coal in efficient combustion process.
9. Enhanced traffic control, occupational health and safety.
10. Safe mining process development with high reliability, accident reduction and disaster avoidance measures in place.
11. Corporate Social Responsibility

The above should be a part of the immediate research agenda for green mining. While community will sure be in the mind, profit or building surplus by saleable products and innovation will be required for sustained interest.

5.0 ICT AND ITS IMPACTS ON MINERALS SECTOR PERFORMANCE – WHERE DO WE GO FROM HERE?

Introduction

Despite the apparent euphoria on ICT as a magical tool for transformation of the industry, the role of ICT has thus far been only marginal in Indian mining industry setting. Regrettably, what remains unrecognized is the critical role of ICT as a source of solutions for the entire gamut of problems in the minerals sector in a game changing way. The minerals sector operates in a massive, inter-connected supply chain where ICT provides a range of tools to model, manage and optimize this supply chain. This section of the report seeks to provide an overview of the usage of ICT in the minerals sector so that a programme of research could be seeded to address the many facets of the mineral's sectors problems with a range of computing technologies including (but not limited to): optimization technologies, supply chain management technologies, business process management/process improvement technologies, virtualization technologies, ICT-enabled collaboration technologies amongst others. The contours of this new and exciting space for R&D for the ultimate benefit of the minerals sector opens up new vistas for development where the policy dimensions of these issues call for a massive input from industry-academia consortium to drive the agenda forward. The continuing impact of the diffusion of ICT revolution on mineral sector performance is understood but rarely utilized fully because of an innate conservative mindset of the industry. The ICT revolution involves what is generally referred to as a "general purpose technology", characterized by scope for improvement, applicability across a broad range of uses and potential for use in a wide variety of products and processes, and strong complementarities with existing or potential new technologies. The lack of purposeful R&D in the area of ICT in minerals sector or even the range of applications reflect the disconnect between the industry's thinking and the potential for high pay-offs through ICT usage on a large scale. There is lack of efforts to introduce underground personal communication systems which could be of benefit in the effective deployment of machines and personnel and could be of vital importance in dealing with emergencies that may involve evacuation from the mine. There have been significant advances in developing intrinsically safe communication and tracking technologies for underground mines, while applications are also scarce in the surface mines where large pay-offs are possible from use of truck dispatch systems which provide a backbone for an ERP system.

R&D Initiatives in ICT

As the 21st century unfolds, the pivotal role of ICT in mining, and especially surface mining, needs to be underscored offering as it does unimaginable opportunities for change. Using ICT in innovative ways the industry could look forward to a step change in productivity levels and ultimately to digital mining systems. The sector-specific R&D on ICT in the minerals sector, as already noted, has been a miniscule in relation to the existing needs. There are currently 5 truck dispatch systems operating in the minerals sector, of which at least 2 can claim to be the outcome of indigenous development efforts. Installation of 12 more such imported systems are contemplated in the coal sector. It needs to be pointed out that some R&D initiatives have been taken in the mineral industry milieu in the area of ICT. These include DIT funded projects at CIMFR for development of wireless communication systems for underground mines (including trapped miner communication) with a total funding of Rs.32 lakhs between 2004-2007. Likewise, a DIT funded project valued at Rs.70.00 lakhs at CIMFR between 2007-10 led to the development of wireless information and safety system for underground mines, tracking and monitoring system for opencast mines and a proximity warning device for heavy earth moving machinery. With venture capital from the industry, Indian Institute of Management, Kolkata[19,20,21,22] has developed software and hardware for managing enterprise resource and environment through real-time tracking, monitoring and actuation of enterprise objects on the internet using RFID tags. IIM, Kolkata has also developed an effective alarming system for moving vehicles using GPS and a wireless communication module, which could contribute to avoidance of vehicular collision in surface mines. While these systems have been patented and commercialized, the applications have been somewhat limited. A subterranean robot has been developed at Central Mechanical Engineering Research Institute (CMERI, Durgapur) with the assistance of CMPDI using Coal S & T funds.

Agenda for research

The minerals sector, as noted earlier, has taken some hesitant steps in R & D for ICT applications and much remains to be done in massive application of software for planning and scheduling from the global shelf of softwares. While world-wide the evolution of real-time health monitoring of equipment has reached a new high with a wide assortment of systems available from original equipment manufacturers, the industry is yet to take a bold and purposeful stride in this area. Machine health-monitoring systems can provide in-depth diagnostic analysis, long-term trending and predictive capabilities in real-time to the operator and a central control station. Such systems minimize unscheduled downtime, improve the management of assets and alert the operator with a warning message. The minerals sector needs to demonstrate the utility of such Vital Information Management Systems (VIMS) through standard fitments in dumpers and there is a wide array of available systems such as Mine Star (from Komatsu), Litronic Plus diagnostic system (from Liebherr), Mine Care (from Modular)and Maintenance Monitor (from Wenco) amongst others. P&H mining's PreVail system is a new breed of highly advanced remote machine-health monitoring system whose potential for demonstration in Indian minerals sector needs to be actively explored. Given substantial R&D support, one can look forward to a new wave of creative breakthroughs in IT applications in surface mining sector, including automation and remote control in 21st century Digital Mines.

There are certain areas that need urgent attention:

1. Geographic Information System (GIS) enablement of all kinds of mining activities in the country.
2. Mine wide measurement and data transfer of roof convergence, failure and utilization of support system.
3. Computer image based delineation of old mine workings in Asansol and Jharia coal belts.
4. Development of automated mining with external remote control.
5. Computer aided production, measurement and control.
6. Promotion of paperless and verified transactions.
7. Progressive measurement of mine environment and reclamation.

Requirement of a nodal agency/institution

In the absence of a nodal agency or an institution only ad-hoc developments have so far been possible in the area of ICT application in the mineral sector. Without having a long-term perspective and framework based development, much of the existing efforts have happened without any complementary actions and benefits. Considering the diversity of the mineral sector it is important to have a nodal agency, a CRC, National Informatics Center (NIC), to look after the various requirements and aggregation to a holistic ICT development that would aim at transparency.

We propose the formulation of a national agency to look after the research and developmental requirement of ICT for the total minerals sector including research and development, reliability and quality control, testing, standardization, system integration, technology transfer across sectors, and human resource development.

Such an agency will require a starting capital budget of Rs.30.00 crores and annual budget of Rs.10 crores in the first 10 years. It will be allowed to form corpus from external funding and services to be completely self-reliant in 10 years,or to be run on a PPP model after the said period, as per norm.

6.0 IDENTIFYING R&D THRUST AREAS – A POLICY DELPHI EXERCISE

Identifying the areas of thrust called for a policy Delphi exercise to synthesize and distil the views of an expert group from the industry, academia and research. Delphi has been characterized "as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem." As the problem area does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis, the use of a conventional Delphi was thought to be appropriate[8].

This pilot study was an attempt to discover through the process of summarizing the views, judgments and opinions of a group of informed respondents if there has been a discernible impact on mineral sector's "performance" through investment in R&D over the recent past and to identify the future directions of such R&D. The first round questionnaire (Table 6) was disseminated in January, 2010. A list of more than one hundred selected potential respondents was developed from amongst the most notable "experts" and invitations to participate in the study were sent to them. Only 37 responded. The questionnaire was again widely circulated by publishing it in two mining journals which elicited 2 more responses. In what follows, an analysis of the responses is presented.

6.1 Rank ordering of R&D thrust areas:

6.1.1 Underground mining

- Development of new mining methods – 45% respondents ranked 1
- Development of methods for faster liquidation of pillars – 33% ranked 1
- Development of methods for improvement of face productivity in conventional Bord and pillar workings – 20% ranked 1

TABLE 6 : DELPHI QUESTIONNAIRE

This Delphi exercise is being undertaken as a part of a study to assess the impacts of R&D in performance of Indian mineral sector. The study has been commissioned by the Office of the Principal Scientific Adviser to Government of India. Your response to the following set of questionnaire, to the extent possible, in your perception, would be of considerable value in this assessment. Your response should not take more than 10 minutes of your valuable time but your inputs would considerably impact on the outcome of the study.

1. Given below is a list of thrust areas for R&D which predominantly are focussed on coal. Would you kindly rank order them in terms of priority as you perceive? You can give same numeric value to 2-3 projects, which in your judgment deserve equally high priority.

R&D Thrust areas for Underground mining

- Development and trials of new mining methods including thick seam mining
- Development of methods for faster liquidation of developed pillars
- Development of methods for improvement of face productivity in conventional bord and pillar workings
- Development of techniques/systems for monitoring underground mine environment
- Location of trapped miners
- Alternatives to sand for stowing
- Stabilization of worked out areas
- Replacement of timber
- New methods of combating mine fires

Opencast mining

- Haul-road dust suppression
- Slope stabilization/optimization studies
- Development of methods for selective mining

Equipment development

- Development of machines suitable to Indian geo-mining conditions
- Development of efficient tele-monitoring, communication and control system

Underground coal gasification :
Environment and ecology

- Development of compatible bio-reclamation and hydro-reclamation systems for rehabilitation of degraded land and mined out areas for each coalfield
- Development of efficient dust suppression measures specially for dust generated on haul roads/transport roads and in CHPs
- Identification of suitable flocculating agents for reducing high level of suspended solids in the mine effluent, specially opencast mines. Collection of environmental data in different coalfields and interpretation/assessment of likely impact level due to varied level of mining operations
- Impact of leaching due to fly ash on water resources
- Bio-rehabilitation and gainful utilization of abandoned mines
- Sequestration of CO_2 and control of greenhouse gases

Others

- Strata behaviour in PSLW face
- Development of light weight support
- Development of backhoe type SDL to take the coal which is being lost in goaf
- Disaster management in mines and mining areas

2. Would Indian mining industry need to be compliant with Equator Principle and are there any requirement for R&D in the area of social issues of mining?

   YES NO

3. The value of GIS as a spatial in terms of decision making tools in environmental impact assessment is well-recognised. Could you agree with the mining industry needs to mount some R&D in this area?

   YES NO

4. During 2009-2010 the total value of minerals produced in the country will be around 1,30,000 crores. What percentage of this value do you think should be directed on R&D funding?
   a. Less than 0.5%
   b. 1-2%
   c. 2-5%
5. The handling of minerals industry waste will be a major challenge for the industry in the coming years. Would you agree that we need to mount major R&D projects on minimization of the volume of waste and their suitable reuse?

   YES NO

6. The productivity in Indian mineral industry is abysmally low when benchmarked with other industries in developed countries. Would higher level of investments and technological breakthroughs help uprate the productivity level?

   YES NO

7. The priorities for R&D in Indian mineral industry today would be
   a. long-term research
   b. short-term research
   c. no research at all
8. The structure facilitating R&D to deliver results in the Indian mining industry is
   a. Non-existent
   b. Existent but not sufficient
   c. More or less existent and sufficient
   d. Highly existent and sufficient

9. R&D investments bring tax benefits to the companies. However, there is little clarity and there are substitute channels to divert the cost and obtain higher benefits. Which one of the following you think is true:
   a. No clarity and no substitute channels
   b. No clarity and there are substitute channels
   c. There is clarity but substitute channels are more encouraging
   d. There is clarity and substitute channels are not encouraging. There is, however, an avoiding tendency
10. What can best describe the condition of academic and research establishments in India
    a. High manpower but lacking skill and motivation
    b. High manpower and full of skill but lacking motivation
    c. Low manpower, lacking in skill, and full of motivation
    d. Low manpower, lacking in skill, and low in motivation
11. How will you best describe - out of the following – the situation of coal mining?
    a. Indian mining has not at all followed global research in engineering
    b. Indian mining has been more of a arbitrary pick and choose mode in terms of global research
    c. Indian mining has modified global research to its requirement
    d. Indian mining has blindly followed global research without understanding its own need
12. Which of the following mining engineering areas do you think Indian research has proved fruitful for Indian mining?
    a. Ground support
    b. Drilling and blasting
    c. Materials handling and transport
    d. Design of mining methods
13. Competence and skill development are the keys for industrial survival. How will you describe the Indian mining industry:
    a. Indian mining industry has a short-term view on competence and skill
    b. Indian mining has skill and competence but localized and cannot be replicated organization wide
    c. Indian mining has organization-wide skill and competence but not exploited in terms of skill and competence due to lack of management structure
    d. Indian mining industry has a long-term view on competence and skill
14. Giving an industrial status to any economic activity brings in structure conducive for accepting research and development. What can best describe the status?
    a. Industrial status would have helped somewhat
    b. Industrial status would have helped moderately
    c. Industrial status would have helped well
    d. Industrial status would have helped very much
15. Underground coal mining is getting increasingly difficult. India has a soaring demand for coal. Increase in R&D expenditure should bring results. Which of the following, you think, is appropriate:
    a. Investment in R&D will yield results in 5 years
    b. Investment in R&D will yield results in 10 years
    c. Investment in R&D will yield results in 15 years
    d. Investment in R&D will yield results in 20 years
16. Whatever money is invested in research is not monitored well to bring to on-field application. Which of the following you think appropriately describes the situation?
    a. There is no clear cut goal or objective in the research portfolio
    b. Frequent changes in the nodal agencies impair decision-making
    c. The objectives of researchers and the requirements of practicing engineers do not march
    d. All of the above
17. There is very little research done in India on safety and analysis, monitoring and instrumentation. What do you think is the main reason behind it?
    a. We have invested more on safety policy than on safety research
    b. We have not built enough infrastructure and research manpower in this area
    c. We have more or less depended on the prescriptions by overseas research
    d. All of the above

18. Indian mining research has been impeded by the lack of encouragement provided to people with Masters or PhD degrees. This has resulted in:
    a. Inadequate trained manpower for research
    b. Lack of development of specialized skills in addition to basic skills
    c. Lack of development of research culture and its appreciation
    d. Dilution of mining research by persons from other disciplines
19. In most countries, research is complementary to design and engineering. In India with almost non-existent industrial design and manufacturing base for mining, industry could not provide the complementary support.
    a. Domestic industrial design and manufacturing base is sufficient
    b. Domestic engineering base is all about borrowed drawings and manufacturing
    c. The above complementarities are not necessary
    d. The above complementarities are necessary
20. Indian mining industry is more or less a user industry rather than builder and user variety as found in the West.
    a. I agree fully with the statement
    b. I do not agree with the statement
    c. I agree partially but we have also developed a few but significant engineering variety
    d. I agree partially but in the recent years we are also moving towards the build and use variety.
21. Indian mining research has never been mission driven. India has obtained significant benefits in Mission on mode research as in space research and development and also in nuclear technology. Please select your choice from the following:
    a. Mission driven research would have surely produced better results
    b. Mission driven research would build better research structures and institutions
    c. Mission driven research always does not produce good results
    d. Research need not be mission driven at all
22. Largely non-existent and, wherever present, lack of government policies have produced ad-hocism, encouraged politics and profiteering, and at their best produced some trained manpower who are not motivated.
    a. I fully agree
    b. I agree to some and I do not agree on the others
    c. I do not agree at all
    d. Policies need to be consistent
23. Indian government is in the process of disinvesting stakes in the public sector mining companies. This will bring in higher efficiency. Which one of the following do you think will be seen in the future.
    a. It will encourage off the shelf buying of equipment and systems from abroad
    b. It will encourage the government to promote domestic research to build competence
    c. Disinvestment will augur well for the corporations but not engineering per se
    d. Disinvestment will not augur well for the industry
24. Acquisition of land for the mining industry is already a contentious problem. On the other hand, habitations like towns and cities are coming very close to potential mining areas and the problems have just been surfacing. To which one of the following, you agree:
    a. Research towards developing technologies for sustainable mining by complete back-filling should be vigorously followed
    b. Complete back-filling is impractical and sustainable underground mining is impossible
    c. Requirement of coal will always be put before the upkeep of environment
    d. In the future too, like in the past, caving method of mining will be the only practicable technology
25. Disinvestment will surely act to push de-regulation and decontrol of administered price mechanism applicable in the coal sector. Do you agree in a way, higher market price actualization will help the coal mining to adopt cost-intensive mining particularly in underground mining.

    Yes   No   Can't say
26. Does the Indian minerals sector need any focused R&D initiative in artisanal mining sector, which is now sizable in terms of production volume?
27. Economic competitiveness is the main driver of mineral industry research. There is scant regard paid today oh cost-effective solutions, and the industry is hamstrung by past legacies. How can the industry breakthrough this mould? Your views:

28. Research infrastructure for the minerals sector in India is a miniscule compared to the demand. In the last 20 years research and academic personnel dedicated to mining has actually gone down. Is there any need to replicate/establish new research centres?

Yes No

29. Indian mining industry favours kinds of job to be done by the R&D personnel that help them obtain clearance and some certification to carry on the job as usual. Do you think this mentality will serve the industry any longer in the future:

Yes No

6.1.2 Opencast mining

- Blast-free mining – 20% ranked 1
- Haul-road dust suppression – 15% ranked 1
- Slope stabilization/optimization studies – 33% ranked 1
- Equipment development – machines suitable for Indian geo-mining conditions – 50% ranked 1
- Environment and ecology Rehabilitation and resettlement of project affected people – 33% ranked 1
- Development of compatible bio-reclamation and hydro-reclamation systems for rehabilitation of degraded land and mined out areas for each coalfield – 25% ranked 1

6.2 Others:

- Disaster management in mines and mining areas – 33% ranked 1
- Support behaviour in PSLW faces – 20% ranked 1
- Query 2 on equator principle – 100% Yes
- Query 3: Need for research on GIS: 92% Yes
- Query 4: on the required level of R&D funding as a percentage of value of minerals produced:
  (a) Less than 0.5% - 13% of respondents
  (b) 1-2% - 39% of respondents
  (c) 2-5% - 46% of respondents

  Query 5: Need for R&D on waste minimization: 100% of the respondents -Yes
- Query 6: on opinion as to whether higher level of investments and technological breakthroughs help upgrade productivity levels? 97% Yes
- Query 7: Time horizon for research: Both short and long-term – 42%; long-term – 15%, and short-term – 12%
- Query 8: Infrastructure for delivery: Existent but not sufficient 90%; non-existent - 7%
- Query 9: R&D investments and tax benefits – no clarity – 15%; no clarity and substitute channels – 24%; substitute channels are more encouraging – 24%
- Query 10: Status of academic and research establishments in India – large manpower lacking skill and motivation – 27%; large manpower, skilled but lacking motivation – 18%; low manpower, lacking skill and motivation – 40%
- Query 11: Indian mining has not followed global research – 9%; more of an arbitrary pick and choose – 57%; Indian mining has modified global research – 15%; blindly followed global research – 18%
- Query 12: Areas of research which have been fruitful – ground support – 36%; drilling and blasting – 51.5%; materials handling – 9%; design of mining methods – 15%

- Query 13: Short-term view on competence and skill – 21%; localized skill and competence – 39%; Indian mining has organization-wide skill and competence but not exploited because of management – 27%; long-term view on skill and competence – 6%
- Query 14: R&D support if industry status is given to mining: Helped somewhat – 9%; helped moderately – 33%; helped well – 15%; helped very much – 33%
- Query 15: Yield results in 5 years – 21%; results in 10 years – 70%; results in 15 years – 0%; results in 20 years – 3%
- Query 16: Monitoring of research for application – no clear cut goal – 24%; changes in nodal agency affect decision-making – 3%; mismatch in objectives of researcher and practicing engineers – 48%; all of the above – 24%
- Query 17: Research on safety and analysis – investment more on safety policy – 18%; lack of enough infrastructure and manpower – 39%; dependent on overseas prescriptions – 9%; all of the above – 30%
- Query 18: Mining research impeded by lack of encouragement for people with Masters and Ph.D – inadequacy of trained manpower – 33%; lack of development of specialized skills – 18%; lack of research culture – 51%; dilution from other disciplines – 12%
- Query 19: Lack of industrial design and manufacturing base – domestic base sufficient – 3%; domestic base on borrowed design – 55%; above complementarities not necessary – 6%; above complementarities necessary – 24%
- Query 20: Indian mining industry is a user industry - agree – 515%; do not agree – 0%; partly agree – 15%; we are moving towards build and use – 24%
- Query 21: Indian mining research has never been mission-driven – it would have produced better results – 60%; it would have built better research institutions – 54%; research need not be mission-driven – 3%
- Query 22: Lack of government policies has contributed to adhocism – agree – 33%; partly agree – 42%; do not agree – 0%; needed consistent policies – 18%
- Query 23: Higher efficiencies may result from disinvestment – will encourage off the shelf buying of equipment from abroad – 27%; promote domestic research -21%; does not augur well for engineering – 30%; disinvestment will not augur well for industry – 6%
- Query 24: Acquisition of land is becoming a contentious problem – research for complete backfilling a must – 54%; complete backfilling impractical – 15%; coal requirement will have higher priority to environmental demand – 18%; caving will be the only practicable technology – 9%
- Query 25: Disinvestment will help coal mining to adopt cost-intensive mining underground – fully agree – 45%; do not agree – 12%; not sure – 12%
- Query 28: Need for establishing more research centres – 57% Yes; 12% No
- Query 29: Indian mining industry's requirement for R&D is only to obtain clearances and certification for carrying on the job as usual. Will this mindset help the industry? – 15% Yes; 52% No

A second round questionnaire was circulated in July after the responses were hammered out in a Workshop at Kolkata where some 36 participants refined the overall responses. The second round of questionnaire elicited only 3 responses and were not analysed. A brief report on the Brainsteering Workshop held on July 3, 2010 at Kolkata is given in Appendix 8.6.

R&D is necessarily a continuous improvement journey. While new technology underpins long-term progress in the industry, it requires adventurous ideas offering step improvements and considerable strategic support.

7.0 BARRIERS TO R&D – SKILL DEFICIT IN MINING INDUSTRY

The increasing shortage of skills in many areas of the mining industry has impacted significantly on mining industry R&D initiatives. This has exacerbated in recent years due to the migration of mining engineering graduates to greener and more lucrative job opportunities in the IT sector. We need to address this major concern of the mining industry as the underlying pillars of engineering skills provision are education and research, where a crisis situation prevails today because of the very low availability of research workers (and that of quality faculty) in the discipline of mining engineering. The national research laboratories (CIMFR and NIRM) are currently facing acute shortage of eligible mining engineers who could man a vast array of mining industry projects and often have to make do with inputs from geology and other disciplines. The issue needs to be viewed from both the short and long term perspectives to ensure the regular supply of the necessary skills for future mining R&D. There is no gainsaying the fact that academic research could make substantial contributions to the minerals sector now and in the future ranging from graduates at all levels trained in modern research techniques to fundamental concepts and key ideas based on basic and applied research to the development of tools, prototypes, and marketable products.

We shall examine here the status of mining engineering education in India and the role played by the academe in mining research in terms of overall contributions to research, development and innovations. We need to appraise the quality and content of mining programmes, the adequacy of research infrastructure and the involvement of academics in R&D and the thrust and orientation of basic and applied research. It is necessary to recall that some of the pioneering research for the minerals sector in India was undertaken in early years of the last century(when no organized research infrastructure existed in the minerals sector) in academic institutions. Rev. E.H. Roberton conducted studies on coal washing at Bengal Engineering College during World War I and Dr.David Penman undertook studies on the strength of Indian coals and problems of mine ventilation between 1926-31 at Indian School of Mines. In his Presidential Address before the Mining and Geological Institute of India in 1932, Dr. David Penman highlighted the need for research and the role that Indian School of Mines could play.

Mining engineering education received a significant fillip in the post-independence era in keeping with the escalating mineral production and expanding career opportunities. From a mere two mining engineering programmes, prior to 1957, the number of mining engineering degree awarding faculties have gone up to 17 as of present with a sanctioned intake capacity of over 680 as highlighted in Table 7.1. On an average, barring some fluctuations, the mining programmes have been turning out some 350-400 graduates every year and about 20 M.Techs. Research, however, had been a sorely neglected area for lack of adequate faculty and lack of any impetus for R&D. The first M.Sc in Mining Engineering was awarded by Indian School of Mines in 1958-59 and the College of Mining & Metallurgy, Benares Hindu University awarded the first Ph.D degree in mining in 1964. In the past three decades, some 180 Ph.D degrees have been awarded in mining engineering in Indian universities and Table 7.2 provides a snapshot of the diversity of topics dealt in the dissertations whose impact and relevance is dubious. The lack of any incentive for mineral industry research was reflected in the number of Fellowships available in the Mining Departments from the University Grants Commission or the AICTE and other Governmental organizations. There was a sea-change however with the nationalization of coal industry when the programmes were infused with significant funding from Coal S&T and S&T grants from the Ministry of Mines from 1978. To create a cadre of research workers within the coal industry, the CMPDIL sponsored 4 research fellows at

ISM for M.Tech and Ph.D programmes in 1980, while the infrastructure for research was refurbished/upgraded with the support of S&T grants at the leading mining institutions. The then Ministry of Ocean Development created in 1980 a Fellowship at Indian School of Mines in a frontier area of research for a project on sea bed mining. Even a cursory evaluation of the Ph.D topics would exhibit the predilection of the academic guides without any specific industry or even purpose orientation. In any case, a large majority of external Ph.D candidates from research and academic institutions were motivated to complete Ph.D in their own area of work largely to advance their career prospects. Academic research in many cases was relegated to irrelevance with academic institutions turning into" factories" to prepare or "qualify" potential faculty for fitness of purpose and to facilitate promotional prospects for scientists working at research institutions! Be that as it may, research trained students and graduates at all degree levels can play a critical role in the development, transfer, diffusion, and application of new knowledge and technology both within and between industry and academia.

Table 7.1 Degree Awarding Institutes in Mining Engineering in India with 2010 Intake

• Indian School of Mines, Dhanbad, Jharkhand	109
• Indian Institute of Technology, Kharagpur, West Bengtal	160
• Institute of Technology, Benaras Hindu University, Varanasi, U.P.	47
• Bengal Engineering and Science University, Shibpur, West Bengal	20
• National Institute of Technology, Surathkal, Karnataka	26
• College of Engineering, Guindy, Chennai, Tamil Nadu	25
• National Institute of Technology, Rourkela, Orissa	18
• Visvesvaraya National Institute of Technology, Nagpur, Maharashtra	29
• National Institute of Technology, Raipur, Chhattisgarh	50
• Mughneeram Bangur Memorial (MBM) Engineering College, Jai Narain Vyas University, Rajasthan	44
• Kothagudem Institute of Technology and Mining, Kakatiya University	30
• Birsa Institute of Technology, Sindri, Jharkhand	49
• Government Engineering College, Koni, Bilaspur, Guru Ghasidas University, Chhattisgarh	20
• Rajiv Gandhi College of Engineering, Research & Technology, Chandrapur, Maharashtra	40
• College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan	20
• Golden Valley Institute of Technology, Kolar Gold Field, Bangalore University, Karnataka	40
• Orissa School of Mining Engineering, Keonjhar, North Orissa University, Orissa	60
The total annual intake in B.Tech degree courses in mining engineering in 2010	687

Table 7.2 Ph.D. Theses at ISM in the area of mining engineering

Title of Ph.D. theses submitted to the Department of Mining Engineering over the past 30 years (from 1980 to 2009), including the names of the Ph.D. candidates

	Name of the candidate	Title of the thesis	Year
1.	Tribhuwan Nath Singh	A study of the behaviour of ground due to mining thick coal seams by equivalent material models	1981
2.	N M Raju	Design of roof bolting systems – investigations in Indian mines	1981
3.	S K Ghosh	A study of air pollution including toxic trace elements in an Indian coalfield and its likely impact on incidence of diseases	1984
4.	R T Deshmukh	Optimal plan for exploitation of iron ore in India by 2000 AD	1984
5.	M N Das	A pillar strength approach employing a new triaxial failure criterion for rock masses	1985

	Name of the candidate	Title of the thesis	Year
6.	Vellanky Venkateswarlu	Geomechanics classification of coal measure rock vis-a-vis roof supports	1987
7.	Chiranjib Bandopadhyay	Analysis of stability of parting between contiguous pillar working	1988
8.	N K Khandelwal	Spoil dump behaviour in opencast mines	1989
9.	Pramod Kumar Arya	Studies into the biodegradation of methane and its application for degasification in coal mines	1990
10.	Mohammad Jawed	Optimization of coking coal mining system - under Indian environment	1991
11.	Bijay Kumar	Mechanism of ground subsidence in Indian coalfields	1992
12.	Chandra Nath Ghose	Improved coal mine roadway support design investigations on prediction of roof conditions and support efficiency through observational approach	1994
13.	Parijat De	Planning strategies for coking coal development in India - systems design for underground coking coal mines	1994
14.	Durga Charan Panigrahi	Simulation of heat and moisture transfers in mechanised longwall faces in Indian coal mines	1994
15.	Phalguni Sen	Computer aided design of open pit slopes	1995
16.	M M Bhattacharya	Studies on fume characteristics of explosives under laboratory and field conditions	1996
17.	V M S R Murthy	Priorities for roadways development in Indian coal industry - a systems development approach	1997
18.	Manoj Kr. Singh	Simulation of environmental conditions in mine ventilation networks using linearised flow equipment	1997
19.	Vinod Kr. Saxena	Investigation into spontaneous combustion characteristics of coal seams with special reference to Jharia coalfield	1999
20.	P K Rajmany	Development of empirical models predicting rock mass failure around open stopes and their application in extracting marginal grade deposits	2000
21.	A K Mishra	Evaluation and design of blast using high-speed video camera in coal measure rocks	2000
22.	Rajendra Yarpude	Techno-economic appraisal of underground coal mining projects	2000
23.	H R Anireddy	Development of selection methodology of rock reinforcement systems for coal measure strata	2001
24.	Debi Pd. Tripathi	Environmental quality assessment in some fire areas of Jharia coalfield	2002
25.	A K Chakraborty	Development of predictive models for optimum blast design in mine roadways and tunnels under various rock mass conditions	2002
26.	Asim Kr. Sinha	Development of design guidelines and strata control standard in multiple-seam working with thin parting in Indian coal	2003
27.	Jagdish Kr. Mahnot	Formulation of optimum investment decision model for economic evaluation of mining venture	2003
28.	Ram Madhab Bhattacharjee	An investigation into pillar fire problem in bord and pillar method of mining in Ranigani coalfield and categorization of pillars with respect to their proneness to spontaneous heating	2004

	Name of the candidate	Title of the thesis	Year
29.	H B Sahu	Investigation into spontaneous heating characteristics and an approach for classification of coal seams with special reference to Mahanadi Coalfields	2004
30.	B K Sah	The effects of chemicals on the rheology of coal water slurry and its transportation through horizontal pipelines	2005
31.	Harsh Vardhan	Assessment of machine generated noise in opencast mines and development of suitable maintenance guidelines for its attenuation	2006
32.	J K Pandey	A study of chromium contamination in opencast chromite mine environment and development of a method of control	2007
33.	C Sawmliana	An investigation into the blast design parameters for ringhole blasting and induced blasting in blasting gallery method of underground coal mines	2007
34.	M D Yadav	A study of different fire retardants and sealants for preventing and controlling fire in Indian coal mines	2007
35.	Goutam Banerjee	Numerical modelling studies for prediction of longwall roof behaviour	2008
36.	Gauri Shankar Prasad Singh	Cavability assessment and support load estimation for longwall workings in India	2008
37.	Kaushik Dey	Investigation of blast-induced rock damage and development of predictive models in horizontal drivages	2008
38.	Mangalpady Aruna	Evaluation of illumination system in opencast mine and development of optimum design parameters	2008

Ph.D Degrees awarded at ISM in the area of mine environment

Year	Name of Awardecs	Title of Ph.D Thesis
2009	Papiya Roy	Air quality assessment and its impacts on social spectrum in Talcher coalfield, Orissa, India.
2009	Soma Giri	Distribution of radionuclides and heavy metals in environmental components around the Bagjata and Banduhurang uranium mining areas, East Singhbhum, Jharkhand India
2008	Manab Das	Bioremediation of copper mine tailing with special emphasis on metal accumulation, distribution and tolerance in plants
2007	Jyoti Prabha	Development and validation of emission factor equations for the estimation of fugitive dust from some select opencast coalmines in India
2007	Manas Kumar Mukhopadhyay	Strategies for environmentally compatible land use zoning in a power grade coalfield in India
2007	Ashutosh Roul	Investigation into the environmental impacts of noise in mines and refinery complex of NALCO
2007	Amit Kumar Gorai	Investigation into the environmental impacts of noise in an iron ore mining complex in India
2007	Anurag Tiwary	Investigation into the air quality status and its impacts on social spectrum of the coal mining areas of Korba industrial belt of Chhattisgarh
2006	Uday Chand Kumar	Investigations into the socio-economic status of a rural community for assessing their QoL (Quality of Life) and for suggesting measures for improving the same
2006	R.N.Tripathi	Investigations into the development of a model for community development planning for coal mining complexes

Year	Name of Awardecs	Title of Ph.D Thesis
2005	Ritesh Kumar	Environmental assessment of coal combustion residuals from a few thermal power stations
2005	Sumana Banerjee	Biodegradability of phenol in coke oven effluent in laboratory and bench scale studies.
2005	S K Puri	Investigation on air pollution with special reference to particulate trace elements and their effect on population in Korba area
2003	Gurumurthy Vijayan Iyer	Environmental effects of chrome rollers used by cotton roller ginning Industries and design and development of eco-friendly alternative
2003	E Saranathan	Resource evaluation and development of strategies for pollution management of Dhanbad district of Bihar through remote sensing and GIS application
2003	Vinod Prasad Sinha	Investigations into the environmental impacts of noise in TISCO Collieries Jharia Division
2002	Biswajit Paul	Investigations into utilisation of fly ash in economic management of mining degraded land with special reference to TISCO leasehold area in Jharia coalfield
2002	V N Sharma	Studies on the effect of fly ash on growth and nutrition of vegetable and flower crops and tree species
2002	Kanwal Krishan Malhotra	Design of a reclamation strategy for the wastelands created by coal mining
2000	I N Sinha	A study on the appropriate environmental impact assessment methodology for mining projects
2000	B N Singh	Changes in vegetation index and soil moisture in India
1998	Ravi Kumar Gupta	Characterisation and clarification of coal washery liquid effluents through coagulation/flocculation
1998	Abhay Kumar Soni	Integration strategy for development and exploitation of natural mineral resources of ecological fragile area.
1998	Pravir Kumar Sen	Environmental impact assessment studies due to the disposal of tailings from iron ore mines and their management.
1998	Aniruddha Roy	Study on the environmental impacts of limestone mining and slope stability using remotely sensed and ancillary data- case studies from southern Himachal Pradesh.
1998	Kumar Nikhil	Vegetation succession on coal mining O/B dumps for sustainable ecological development
1997	Bipul Kumar	Characterisation and treatment of spent pot liner for environmental compliance
1996	Nishit Kumar Kundu	Studies on the shelf life of topsoil in coal mining areas
1996	Mallu Venkata Reddy	Study on water quality determination in coal mining areas of some Indian coalfields
1995	Subodh Kumar Maiti	Some experimental studies on ecological aspects of reclamation in Jharia coalfield
1995	Subrata Sinha	Characterisation and control of haul road dust in opencast mines
1992	Bably Prasad	Studies on characterisation and abatement of coke-oven liquid effluents.
1991	Praveen Kumar Sharma	Investigation on air quality assessment in some coal mining areas of Raniganj coalfield of India
1991	Deep Shankar Chatterjee	Land reclamation around Raniganj, Raniganj coafield. Eastern India, with special stress on its water potentialities and its management.

Ph.D THESES AT BHU

YEAR	NAME	Topic
1964	B.S. Verma	N.A.
1972	Ramesh Kumar	N.A.
1974	N.C. Saxena	Investigations into the behavior of support surrounding strata in longwall workings
1981	J.P. Dixit	N.A.
1982	T.N.Singh	Investigations into feasibility of inclined slicing coal seams by equivalent material modelling
1983	R.Nath	Creep and time dependent strength of rocks
1986	B.K.Srivastava	Design of underground rock excavations based incremental approach using FEM
1987	K.V. Shanker	N.A.
1988	K.K.Gupta	Stability of slopes over old underground working in multi-seam mining by equivalent material modelling technique
1989	Rama Sastry Vedala	A study of the effect of some parameters on rock fragmentation due to blasting
1989	S. Ratan	Effect of thermal pre-treatment on comminution characteristics and leaching behaviour of Mosaboni copper ore
1989	Arif Jamal	Environmental impact of opencast mining on air, and water quality and its management
1989	V.K. Singh	Investigations into the strata control parameter in and around underground working for optimal exploitation of thick coal seams
1990	K.P. Yadav	ABEM elastostatic evaluation of the effect of some parameters on the displacements and stresses around a shallow seated wide opening
1990	A.K. Singh	Removal of Fe(II) from water using fly ash, wollastonite and china clay
1991	Trilok Nath Singh	A study of opencast slope stability in the ground disturbed by earlier workings by equivalent material modelling technique
1991	R.S. Vishwakarma	N.A.
1991	H.L Jaiswal	Prediction of stresses and ground movement over longwall face using finite element method
1991	Angad Kushwaha	The study of stress distribution around openings by photo-elastic technique
1991	K.B. Singh	Influence of petro-fabric of coal measure formations on strata movement due to mining
2002	M.Monjezi	Slope stability study in open pit mines
2002	N.R.Thote	Analysis of post blast fragmentation of opencast mines
2002	Piyush Rai	Evaluation of effect of some blast design parameters on fragmentation in opencast mine
2004	Nawal Kishore	Planning of dragline operations in opencast mine
2005	B.P. Sinha	Effect of rock mass parameters on ground vibration due to blasting
2007	Ashok Jaishwal	Design of structures of underground coal mine
2008	Sharad Kumar Singh	A study of slope stability in and around magnenite mines, Pithoragarh district, Uttaranchal
2009	Rajesh Rai	Stability of mine waste dump and its numerical simulation
2009	Sanjay Kumar Sharma	Numerical simulation of underground structures in coal mines

Ph.D THESES AT IITKGP

	Year	Name of the Authors	Titles
01.	1971	Golak Bihari Misra	Model studies on the resistance of rectangular airways supported with timber sets.
02.	1976	Janakiran Sudaram	An approach to optimal planning and scheduling of equipment maintenance in open cast mines.
03.	1978	Paithankar Anand Govind	Drilling ability of some Indian rocks with regard to percussive drilling.
04.	1978	Tapan Kumar Chattopadhyay	Model studies on the influence of certain blasting parameters on rock fragmentation
05.	1983	Hari Ram Patel	Laboratory studies on ploughability of some Indian coals
06.	1986	Suendra Mohan	Studies on spontaneous combustion of some coals from Jharia coalfield
07.	1989	Pramod Kumar Arya	Studies into the biodegradation of methane and its application for degasification in coal mines.
08.	1993	Braja Bandhu Rath	Influence of slope parameters on the location of the critical toe circle
09.	1993	Jayanta Bhattacharya	Coal mines systems availability and reliability-a design and performance assessment based on failure data
10.	1994	Sadananda Dattatryaya	Investigation on spontaneous heating of some Indian coals
11.	1994	K. Umamaheswar Rao	Experimental and theoretical investigation of drilling of rocks by impregnated diamond core bits
12.	1994	Ajay Kumar Lokanand	Influence of rock properties and mining factors on ground subsidence
13.	1995	S. B. Srivastava	An investigation into the design of post pillars in cut and filled method mining.
14.	1995	K. S. Rao	Experimental and theoratical investigations of heat flow from surrounding rock into mine roadways.
15.	1996	B. K. Pal	Studies of spontaneous heating of some Indian coals from Chirimiri and Talcher coalfields
16.	1996	Indrajit Roy	Influence of the geo-engineering parameters on the stability of dumps
17.	1999	N. C Karmakar	Applications of polymeric flocculants for solid-liquid separation in mineral fines with a special reference to coal
18.	1999	J. Maity	An investigation of multivariate statistical models to evaluate mine safety performance
19.	1999	Ch. S. N. Murty	Experimental and theoretical investigation of some aspects of percussive drilling.
20.	2000	John Loui P.	Finite element simulation and experimental investigation of drag cutting in rocks
21.	2001	Samanta	An investigation of geostatistical and multivariate statistical quality control model in surface mines
22.	2001	D. Chakravorty	Image and texture analysis of rocks and their classification using artificial intelligence techniques
23.	2002	S. K. Pal	Experimental investigation on wear of rubber by rocks

	Year	Name of the Authors	Titles
24.	2003	Dheeraj Kumar	Experimental and FEM analysis of floor bearing characteristics of weak coal measure strata
25.	2004	Manoj Kumar Mishra	Experimental and numerical analysis of behaviour of model pillars with reinforced fly ash composites
26.	2004	Suprakash Gupta	Development and evaluation of fault tree of a longwall mining system with hybrid data
27.	2004	Sushmita Mishra	An evaluation of the adsorption characteristics of shorea robusta leaf litter for phenol removal from waste water and its potential for biological treatment.
28.	2004	Apurna Kumar Ghosh	An epidemiological investigation to evaluate the rate of some personal and impersonal varieties in coal miners' injuries.
29.	2005	Manish Kumar Jain	An investigation into the engineering properties and hydraulic transportation aspects of fly ash as medium for mine void fill.
30.	2007	Ravi Krishnarap Jade	Prediction of shock losses in mine aerodynamics.
31.	2008	Kaushik Pal	Speciality elastomer blends for abrasion resistant tyre tread of dump-trucks
32.	2008	Bijay Mihir Kumar	Impact of occupational hazards and individual characterisrics in underground coal miners injuries
33.	2008	Gnananandh Budi	Experimental and finite element analysis of shear behaviour of rock joints

Ph.Ds theses in Department of Mining engineering, BESU

	Name	Title of the Thesis
1	Provat Kumar Mondal	Development of a methodology for underground extraction of contiguous and thick contiguous coal seams/sections under weak and laminated parting
2	Surajit Chakraborty	Assessment and management of groundwater resource for English bazar block, Malda dstrict: of West Bengal using rmote sensing and G!S
3	Patrtha Sarathi Paul	Mine safety management-the synergic role of persona! and socio-technical characteristics on work injuries in mines.
4	Sujit Kumar Mandal	An investigation on the effect of geotechnical and blast design parameters on blasting
5	Sudipta Mukhopadhyay	A techno-economic study on beneficiation of Indian power grade coal".
6	Pratik Dutta	Analysis and applicability of environmental impact assessment methods for opencast mining projects in India.
7	Suranjan Sinha	Economic analysis of environmental impact of surface iron ore mines in eastern India
8	Muktipada Dikshit	Strata-support interaction in thick seam longwall extraction in India.
9	Ratnadeep Saha	Physiological assessment of occupational stress in selective underground coal mining operations.
10	Netai Chandra Dey	SDL-based underground mine production system in India

Department of Mining Engineering, NITK – Surathkal

List of Ph.Ds produced

Name of scholar	Topic
Vijaya Kumar	Ventilation network planning
Govinda Raj	Scheduling of equipment in OC mines
H.S. Venkatesh	Ground vibrtations caused due to blasting
M.S. Venkatramajah	Strata control in longwall mines
Roshan Nair	Barrier pillar design in longwall mines
Shranappa	Utilisation of bio diesel in HEMM

Some generic conclusions can be drawn on the basis of the above on the contributions of academic institutions to R&D in the mining industry:

- Lack of research workers constitute a barrier to R&D and could perhaps be partly bridged by the current dual-degree programmes that have been launched. There is an imperative need for training of at least 50-60 M.Tech students per year to meet the minimum requirement of research manpower. A major programme of fellowships should be established to attract and support graduate students in mining engineering;
- The minerals sector and academic institutions need to explore mechanisms and pathways for bringing the benefits of academic research to industry;
- Much of the funding made available as of present to R&D projects in academic institutions is small, if not meagre, and fail to impact significantly on the performance of the industry;
- There is a large disconnect between the industry and the academia on the areas of research at the academic institutions;
- S&T projects undertaken at mining faculties do not logically lead to any innovation in product or processes;
- Despite large funding presently available under S&T grants, the academics are averse to supplicate for grants;
- Overall, the impact of research and development undertaken in mining faculties on Indian mineral industry have been very marginal and they have not been able to germinate the seeds of a band of capable research scientists and instill a research culture amongst the faculty and students.
- Academic research in mining engineering programmes have been largely devoid of any innovative content and failed to provide a leadership to the industry in terms of "blue sky" research projects or providing "hot spots" for innovation.
- The absence of a synergistic interface between the industry, research and academe has been glaring.

Finally, information technologies are critical to the performance of the mining industry and will continue to be so in the future too. The industry's need for the continued development, diffusion, and effective application of ICT presents major opportunities for academic research, especially in the joint development of powerful softwares for mine design and mine scheduling by mining and computer science faculties.

8.0 IDENTIFYING RESEARCH AND DEVELOPMENT PRIORITIES – NEEDED A RADICAL STRATEGY SHIFT

Much remains to be done in formulating a grand strategy for R&D for Indian minerals sector which needs to address the key areas of concern for the industry in the next 10 years. What we need to evolve is a truly Indian minerals sector's vision for the future of R&D which could help strengthen the scientific and technological bases of industry and encourage its competitiveness. The R&D vision must foster scientific excellence, competitiveness and innovation through the promotion of improved cooperation and coordination between relevant actors at all levels. In hindsight, as we evaluate the past R & D initiatives, we find that instead of tackling the "grand challenges" of the minerals sector, the projects have been far too small in size, often fragmented and nebulous in terms of projected outcomes; the projects have not solved nor have they responded even limitedly to the major issues and challenges that the minerals sector has faced. To ensure focused effort and maximizing R&D outcomes, we need to assemble a critical mass of resources and integrate research efforts by pulling them together. The emphasis must be on new instruments of R&D initiatives based on Integrated Projects and Networks of Excellence.

For effective R&D outcomes, it is proposed that thematic research priorities will have to be identified to increase the impact of the programmes with significant funding on "mega" national projects which will seek to achieve the following objectives:

- Creating Centres of Excellence with collaboration between research centres, universities and industrial companies. One could adopt the model of Australian Cooperative Research Centres
- Launching mineral industry technological initiatives bringing together different stakeholders to define a common research agenda and create technology platforms which could mobilize a critical mass of public and private resources, a PPP model
- Developing world-class research infrastructure by liberally funding the premier national research institutes
- Improving the coordination of national research programmes
- Effective peer-review of all research programmes
- Funding selected academic institutions liberally for basic research
- Creating a National Experimental Mine for real-life testing
- Funding CMPDIL to become a full-fledged research arm of the coal industry

In working out the outlines of the "mega projects", the R&D initiatives will have to address the following challenges faced by the industry:

- improving performance and operational effectiveness
- addressing environmental concerns
- ensuring workforce safety

ICT will provide a common thread in meeting the challenges as above and will have to be woven into the fabric of all the mega projects.

Actionable Items as Outcomes of the Study

This INAE Study has underscored the risk the country faces due to a very weak and fragile mining industry. It pinpoints the need for augmented R&D initiatives and rapid capacity building, the efforts and resources towards that have been miniscule in R&D and the visible skill deficit in minerals sector for R&D. In the light of the above findings, and the imperative to bridge these gaps, the study team would like to recommend substantial investments to overcome the near-moribund and lackadaisical state that prevails in the arena of R&D in the minerals sector. For overcoming skill deficit, a major effort is called for capacity building in R&D manpower by creating high-value Fellowships/Scholarships in selected post-graduate institutions in mining which can help attract and create a R&D talent pool. Substantial R&D investments are also needed in the areas of ICT, rock excavation engineering, and sustainable development issues affecting the mineral industry. Through this project, the INAE study team seeks to strengthen the institutional capabilities to make informed policy decisions through a suggestive roadmap comprehending the following:

1. Creation of focused efforts through national centers of excellence in specific areas;
2. Launching mission-mode projects of relevance for the minerals sector's future and sustenance of mineral supply and
3. Enhancing the capability and capacity of the existing National Laboratories.

The components of the roadmap may be elaborated in the following:

Creation of National Centers of Excellence in the Gap Areas

Center of ICT for Mineral Industry

Objective: To help develop and refine appropriate application areas of ICT in the minerals industry for which aggressive and radical research only can provide solutions beyond the current scientific and technological framework. The Center will also provide guidance to different institutions on the current developments in Management Information Science and Technology.

Location: The Center should come up within or in the proximity of a reputed Institute

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is IIT, Kharagpur.

Budget : The Center will be initially funded with Rs.30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 crores for the 5 subsequent years. From the 7^{th} year, grant should be on the basis of internal resource generation and the central matching grant.

Center of Rock Excavation Engineering

Objective: Center of Rock Excavation Engineering shall exist to cater to the many problems of blasting and development of mechanical rock excavation systems for which there is a crying national need as of present The Center will provide research inputs to mineral and construction industry as well as the machine and cutting tool manufacturing units of the country

Location: The Center will come up within or in the proximity of a reputed Institute

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is ISM, Dhanbad.

Budget : The Center will be initially funded with Rs.30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 Crores for the 5 subsequent years. From the 7^{th} year, grant should be on the basis of internal resource generation and the central matching grant.

Center of Sustainable Mineral Development

Objectives: Center of Sustainable Mineral Development will help to mount defensive research on regulatory and policy requirements on environmental issues and innovations that could safeguard national and mineral industry's long-term interests on sustainability through research on best practices.The Center will also advise the industry on the Global best practices.

Location: The Center will come up within or in the proximity of a reputed Institute. The ideal candidate is Indian School of Mines, Dhanbad.

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is ISM, Dhanbad.

Budget: The Center will be initially funded with Rs.30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 crores for the 5 subsequent years. From the 7^{th} year, grant should be on the basis of internal resource generation and the central matching grant.

Center of Mine Environment and Reclamation

Objectives: The Independent Center of Mine Environment and Reclamation that would conduct researches integrating environmental issues of mine development and mine closure, landform reconstruction and ecosystem development – primarily focusing on technology development, testing,implementation and field engineering besides research on management of mineral industry waste.

Location: The Center will come up within or in the proximity of a reputed Institute having proven skills.

Mentor Institute: An institute having existing and multidisciplinary capability including mining engineering. The ideal candidate is IIT, Kharagpur or ISM, Dhanbad.

Budget : The Center will be initially funded with Rs.30 crores for land acquisition,construction and basic manpower in the first year. It shall also receive an annual Capacity Building and Seed R&D fund of Rs.10 Crores for the 5 subsequent years. From the 7^{th} year, grant should be on the basis of internal resource generation and the central matching grant.

The Centers will be developed on the campus of a mining university or institution where post-graduate programmes in mining are being offered and could cooperate on areas of short-term research and training of manpower for future of mineral industry R&D. The CRCs will provide a multidisciplinary overview in research areas for the greater good of the minerals sector.The likely candidates will be Indian Institute of Technology, Kharagpur and Indian School of Mines.

Launching mission-mode projects of relevance for the minerals sector's future and sustenance of mineral supply.

In terms of immediate research relevance, the minerals sector needs to launch a number of mission-mode projects in specific areas. These include:

- Ventilation on demand for large underground mines in coal and non-coal sectors where payoffs could be substantial- Research funding of about Rs.5 crores at a modest level would be adequate. Project duration will be 3 years.
- Demonstration project on thick seam mining using Longwall Top Coal Caving (LTCC) system. In view of the large national endowment in thick seam reserves the project is of great relevance. The project investment will be of the order of Rs.200 crores and the time frame would be 5 years. The project will be based on a networked synergy of coal industry and research establishments like CIMFR, and the DGMS amongst others.
- Demonstration project on partial pillar extraction using the Duncan Method is also of seminal importance and the rationale for the project is the existence of over 2000 million tonnes of coal in developed

pillars.Besides the coal industry, the project will be conducted on the synergy of CIMFR, the CMPDI and DGMS with a project investment of Rs.60 crores and will be completed in 4 years

- Demonstration of a green mining project reclaiming a worked out surface mine back to reformed contours and economic use. The project investment will be Rs.75 crores and participating players will be CMPDI, a CRC and a coal/metal open pit mine. The project duration will be 5 years.
- Demonstration of a green mining concept in an underground mine with progressive control of subsidence for preventing surface damage and underground aquifer. This will call for a networked project with the coal industry, CMPDI, CIMFR and an academic institution as partners. The project cost will be Rs.75 crores and will be completed in 5 years.

  Demonstration of new and innovative technology in surface mines in the following areas:
  - Application surface miners for overburden removal
  - Use of International Rock Excavation Data Exchange Standard, IREDES, in surface mining industry
  - Demonstration and evaluation of techniques of highwall displacement monitoring using Ground Probe Slope Stability Radar(SSR) and Reutech
  - Remote Health Monitoring of excavating equipment (PreVail). Overall, the project investment for R&D will be Rs. 50 crores and the project duration will be 5 years.

Additionally, the mining industry needs to develop an Experimental Mine for live demonstration and testing of safety techniques and new equipment and for capacity building in R&D manpower support at mining institutions with attractive Fellowships. The total project cost will be Rs. 20 crores for the experimental mine and annual grant of Rs.2 crores towards Fellowships. The Experimental Mine will call for annual expenditure of Rs.1crore towards maintenance. The conversion of an abandoned mine into an Experimental Mine will require a project duration of 3 years and will be a collaborative venture between CMPDI and CIMFR.

R&D thrust areas and industry focused R&D programmes for the next 20 years in mining technology for non-coal mines

Following are a few thrust areas and strategic research programmes (SRP's) identified for undertaking R&D in mining technology for Indian metal mines during the next 20 years to become competitive with the rest of the world.

(a) Underground metal mines:

(i) Development of 'stoping' methods for very thin ore body in deep mines (>600m) for better, faster and safer extraction of minerals.

(ii) Development of "mass mining" method for e.g. block caving for massive and low grade ore bodies amenable to automation and centralized control.

(iii) Development of "new selective mining" system to deliver highly concentrated ore to the plant with minimum contamination by preventing dilution of ore with waste.

(Note: For preventing dilution of ore with waste by selective mining using fully automated cut-and-fill system and or using autonomous machines to follow individual veins and reject the waste into the fill preparation system or directly to the stope floor by installing instantaneous assay integrators with face machines. The ore can be automatically sorted at the face, crushed and delivered to the central haulage system by pipe line).

(iv) Development of a system based on ICT for introduction of real time automation and control of whole or part of the mine from centralized control rooms

(v) Development of "ventilation on demand" concept for energy saving in mines to allow air flow only to work places in real time.

(Note: Ventilation represents up to 40% of a mines energy cost and therefore there is enough scope to save energy. Presently, virtually the entire mine is ventilated all the time, although the actual extraction working areas may be very few. This may be done by using variable speed fans and variable louvers to direct the flow to desired places and sensor networks to monitor the resulting changes. An integrated tracking system will allow the quantity of air flow to match the demand from equipment and personnel. This technique can save +50% of energy presently required to ventilate a mine.)

(vi) Development of methods and techniques for control of "fugitive dust" and methods for identifying sources and control to help mines.

(vii) Development of methods to aim at "zero" water discharge from mines.

(viii) Development of methods/ techniques for 'energy reduction/reuse and recovery' from mines.

(ix) Development of techniques like GPR/ criteria to discriminate between un-mineralized and mineralized ore bodies at depth.

(x) Application of exploration geophysical methods as tool for searching ore bodies in footwall/ offset geological environment in mines to increase their life and reserves.

(xi) Development of methods for high speed development including high speed shaft sinking and tunneling.

(xii) Development of automatic hoisting system maintenance based on ICT.

(xiii) Development of an autonomous integrated environmental monitoring and control system.

(xiv) Development of 'In-situ-mining methods' including 'bio-mining' and 'acid leaching' for extraction of metals from in-situ low grade ore bodies.

(xvi) Development of methods for 'wireless condition monitoring' of underground mobile and remote mining machinery.

(xvii) Development of methods for converting an opencast/surface mine to a clean, energy efficient and safe underground mine.

(xviii) Preparation of disaster management plan based on ICT

(xix) Toxic and heavy water treatment technology

(b) Opencast/surface mines:

(i) Application of ICT to develop real time automation system in surface mines for optimum use of equipment, identify bottlenecks and increase in production and productivity resulting in lowering of cut-off grades and expansion of ore reserves.

(ii) Application of ICT for development of fully automated robotic surface mine system using labor saving technologies, operated from remote operation centre/control room.

(Note: The mine will use intelligent trains, drills and trucks fully autonomous without drivers to drive them. These mines can be operated from a remote operation system some several hundred/ thousands km away from the mine site.)

(iii) Development of criteria for introduction of surface miners for selectively mining rich ore pockets without dilution in iron ore, limestone, bauxite, copper, phosphate, gypsum, lignite, shale, sand stone and granite.

(Note: Presently +120 surface miners are in operation in coal and lime stone mines in India giving an average production of +4500 t/ day).

(iv) Development of environmental R&D that will enhance sustainability of mines and mining.

(v) Development of energy reducing/reuse/recycling methods for surface mines.

(vi) Development of measures for fugitive dust control on mine sites and identifying the fugitive dust sources.

(vii) Development of ICT enabled hardware and software platforms for information exchange from mobile equipment to company business systems via dedicated communication network.

(viii) Development of reliable maintenance system and on-board machine condition monitoring system for maintenance of mining equipment.

(ix) Development of bio-mining of waste tailing

(x) Criteria for introduction of 'high wall' mining (for non-coal sector).

(xi) Development and refinement of 'off-shore' mining technology of poly-metallic nodules

(xii) Development of methods for 'coastal mining' of mainly rare earth minerals.

(xiii) Development of a program for production control blast design, fragmentation and optimization in open pit mining using a drill monitoring system and image analysis system.

8.4.4 Futuristic mining technologies under development

For safe and efficient mining, increasing production and productivity combined with minimum impact on environment the following are a few promising technologies which are likely to be extensively used in near future.

(a) Introduction of fuel cell technology for operating mobile mine equipment like LHD, locomotives etc

(b) Tele/arm chair mining: In this technology distance is not a constraint. Tele operation is a semi-automated process in which an operator manipulates equipment from a distance. Guidance system are based on either optical laser or radio frequencies. It is used in LHD and drilling equipment.

(c) i. Mass blasting: Pillar recovery under high stress by mass blasting has been successfully demonstrated by HZL in India. It has been also successfully done in Canada by using advanced blasting technologies including Distance Motion Code (DMC), electronic detonators, i-con system of initiation

ii. Mass Mining: Technology resulting in better, faster and safer mining. The method is suitable for massive ore bodies of low grade. In this method no drilling and blasting is done. Instead the void created by a slice that has been extracted initiates a cave. The method is amenable to automation and control of whole mine from centralized control rooms. By and large it is man-less mine with no persons underground and no operators for loaders.

(d) Binding materials in back-fill: Use of cemented back-fill in place of hydraulic back filling by adding calcinated gypsum in place of cement can be successfully tried.

(e) High pressure direct injection (HPDI) technology for operating diesel engines has been successfully demonstrated and in use. These engines also work on natural gas which causes minimum pollution.

(f) Hydraulic pre-stressing unit supports: They are new generation of hydraulic mine supports pre-stressing device. They provide pre-stressing for wide variety of mine support including rock bolts to cable bolts and props. It can economically turn almost any passive standing support into an active support that can apply resistance immediately to mine roof/floor. Yield can be provided by incorporating a Yield value.

(g) Cavity monitoring system (CMS) : Developed in Canada it measures the extent of cavity development in accessible stopes

(h) In-situ leaching of minerals: has been successfully used in foreign countries for Uranium and low grade copper deposits. However, biotechnology can be used for extraction of metals from other low grade minerals. It is a future technology which can be successfully used along with mass blasting and block caving method of mining.

(i) In the coming years handling of waste produced by mineral industry will be a major challenge as the metal mines will be mining leaner and leaner ore bodies. This will need mounting of major R&D Projects to develop technologies for minimization of the volume of waste and their suitable disposal/ reuse/recycle.

(j) The development of ways to sense, visualize, interpolate, model and predict geologic anomalies in front of mining equipment will allow safer and more efficient mining. Specifically, the development of appropriate sensor technology and integration of sensors and other available data into three-dimensional models for deposits could be used to describe the overall prevailing geological details acquired during the mining process. These sensors would take measurements of parameters like ore grade, structure and discontinuity, in real time at the working face and could help mining companies to avoid high-reject, low-yield, mining situations. The device or devices could significantly reduce energy consumption and other operating costs, and could reduce miner exposure to difficult mining environments. The research could help to overcome barriers associated with the mining industry's inability to detect mining conditions and evaluate ore bodies in real time. Funding partnerships between equipment suppliers and government would be needed to support this long-term, high risk R&D.

The future R & D needs for efficient mining, the targets addressed and the obstacles faced are summarized in Table 8.4.3.

Table 8.4.3: R&D Priorities for safe and efficient mineral extraction

	R&D Priorities	Targets Addressed	Key obstacles
i.	Develop autonomous mining equipment	Productivity, worker health & safety and capital efficiency	work force skill
ii.	Develop geological sensing device to measure what is ahead of working face	Down time, productivity, capital efficiency, environment, worker, health & safety, down time and energy / material efficiency	Inability to detect difficult mining conditions, lack of visualization tools, inability to precisely characterise ore bodies
iii.	Develop more efficient technologies for removing fuel and non fuel minerals	Productivity, energy / material efficiency, capital efficiency, work health and safety	Lack of real-time portable data gathering and information for miners, unreliable positioning, robotics, communication
iv.	Develop advanced reserve system for mining to integrate geological data and models	Permitting time, environmental impact, worker health and safety, energy / material efficiency, productivity and capital efficiency	Lack of real-time data gathering and information for miners, unreliable positioning, robotics, communication
v.	Develop technologies for more efficient in-situ extraction and near face beneficiation	Energy / material efficiency, productivity, environmental emissions and impact, worker health and safety	Must move material to recover resources, no tool for visualization, inability to precisely characterise ore bodies.
vi.	Develop improved prognostic capabilities by machine to measure the on-line health of machine	Down time, capital efficiency, productivity, worker health and safety, environmental emission	Lack of realtime portable data gathering and information for personnel, lack of sensing devices
vii.	Develop improved ground control techniques to handle difficult mining environments for surface and underground	Worker health & safety, environmental emission and impact, energy / material efficiency	Ground control, inability to detect difficult mining conditions, lack of sensing devices
viii.	Develop more efficient alternative power supplies	Worker health and safety, environmental emissions energy / material efficiency, downtime, productivity	Lack of cost effective fuel source alternative, limitation in thermal efficiencies of equipment
ix.	Integrated safety equipment for respiration, ear and eye protection	Worker health and safety	Lack of safety gear for totally reducing harmful health effects

Enhancing the capability and capacity of the Existing National Laboratories

- Providing budgetary support to 2 premier National Laboratories to upgrade them to world class capabilities - Rs.50 crores annually

- Develop a National Coal Research Center at Central Mine Planning & Design Institute to bolster R&D initiatives of coal industry- funding support of Rs.50 crores for 5 years

Each thematic area will have several sub-components and the focus will be largely on demonstration of new technology which could leverage the performance of the industry. The portfolio of sub-components will be assessed using strategic and diversity criteria based on prospective leverage. Besides technical merit, the projects should have well defined goals as a function of time and effort. Likewise, the portfolio should include a diversified set of R&D projects with a balance across technologies, time frames, and degree of technical risk. Crucial to the success of the initiatives will be setting of goals which should be specific, quantified (with progress milestones and cost objectives), realistic and clearly related to the challenges the minerals sector is currently facing.

- Appendices 8.1-8.4 give thumb-nail pictures of the project proposals for each of the identified themes which could be the basis of substantial funding of such projects, including identification of players who could undertake the projects. If implemented, the projects can demonstrate how government/industry/ national laboratory/university partnerships in R&D can be an effective mechanism for development /transfer of technology with potentially large pay-offs to the nation. We firmly believe that the preferred approach to integration is co-funding and co-management of a sub-set of mission-oriented projects with clearly defined goals.

In Indian minerals sector, for national laboratories, for far too long consultancy has been construed as research. This mindset has to change. However, the outcomes from a number of consultancies in one specific area could, if synthesized, lead to effective research outcomes too. The mining faculties have to be supported substantially for basic research (such as bio-mining, mechanics of rock cutting) which needs to be prioritized. It is only within the context of an overall strategic framework that priorities can effectively be set and balanced. The funding for research in academic institutions should help in training and development of a band of mineral industry research scientists to fill in available positions in national laboratories and newly created Centres of Excellence. In University Departments, with multidisciplinary focus from electronics, computer science and IT faculty, projects related to advanced mining techniques, intelligent mining, new maintenance concepts can be attacked on a broad multidisciplinary basis.

- For efficiency of R&D, strategies of collaboration must be developed such as triple helix (industry, academia and society) to develop common vision, strategies and objectives and also find ways to co-finance the work
- The premier national laboratories need to be upgraded to world class institutions with substantial annual funding of the order of Rs.70-80 crores. The Central Mine Planning & Design Institute needs to be developed as a research arm of the coal industry with a funding support of the order of Rs.50 crores.
- For real-life trials of equipment and new safety systems, a National Experimental Mine needs to be developed in the model of Lake Lynn in the United States or the Canmet-MMSL experimental mine in Canada. Indian School of Mines had set up in 1993 an Experimental Mine with the support of BCCL. Such an Experimental Mine would be of value to National Research Laboratories and to academic institutions as well and will require a seed funding of the order of Rs.50 crores.
- The strategy shift in R&D programmes, with creation of National Centres and Mission-mode high priority research areas as above will necessitate the creation of an apex oversight body at the national level to oversee the implementation of the Road Map for R&D in the minerals sector.

It is necessary to reflect on the global scenario as of present on mineral sector R&D to provide a benchmark against which the above proposals could be compared and contrasted. Appendix 8.5 provides a synoptic overview of mineral industry R&D in Australia, the USA and Canada and the vector of R&D thrust areas.

9.0 SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

With an annual R&D investment of less than Rs.450 million and a total staff strength of some 162 scientists in two premier national laboratories, the R&D landscape for Indian minerals sector looks dreary, desolate, ill-equipped and unfocused. The technology status of the industry is that of a laggard where productivity levels and environmental performance leaves much to be desired. All of this contributes to relative stagnation of R&D in the minerals sector. In sharp contrast to the ICT sector in India, which has been hailed worldwide, the minerals sector continues to be anemic, low-tech and lacking a purposeful vision for the future. The R&D is exclusively funded by the State and the private sector is yet to be a part of any R&D consortia, shying away from high-risk research projects and those with long-term pay-offs. The minerals sector has faced in recent years major roadblocks to development arising from adverse environmental and ecological impacts; it has not launched any aggressive R&D to safeguard the industry's long term interests. Substantial research and development opportunities could be explored and identified for both surface and underground mining systems through improved techniques of rock fragmentation, ground support, equipment utilization and maintenance and these could significantly help upgrade the productivity and safety performance of the minerals sector. Not that these areas are not being pursued, but there is an apparent disconnect between the real and immediate needs of the industry and implementation of any industry- specific R&D. As already noted, consultancy assignments are being construed as R&D and the portfolio of projects show yawning gaps in areas which urgently call for re-focussing of R&D investment. This unfortunate state of affairs is exacerbated by the relative neglect of R&D in the minerals sector.

This report has two goals: (1) to evaluate the impact of R&D on the performance of Indian minerals sector, and (2) to prepare a roadmap for future R&D. A critical analysis has underscored the many lacuna that R&D initiatives suffer from, including adequacy of funding, skills shortage and infrastructure. The lack of a purposeful vision has led to the misalignment of industry's R&D efforts and we have noticed a large number of projects without definitive deliverables. Equally, the study has been constrained by lack of access to data on projects for meaningful evaluation.

The evaluation of impacts and relevance has been examined earlier on a broad base but programme details were not available for a detailed scrutiny. In general, most R&D projects have failed to deliver the end outcomes as originally conceived. In the absence of a well-conceived peer review system for each R&D programme, overall assessment of any particular programme has not been possible. But, broadly, the investments in explosive testing infrastructure, and fire gallery have had a high pay-off as permitted P-5 explosives could be formulated and tested for safety criteria. Likewise, the fire gallery has permitted the study and extinguishment of mine fires using a medley of combating systems.

Based on this study and analysis, the following generic recommendations can be advanced for a coherent and synergistic national R&D programme for Indian minerals sector:

- To be able to address effectively the many challenges that face the minerals sector in India, the investment in R&D in terms of funding and facilities need to be significantly enlarged. An annual budget of the order of Rs.660 crores would be necessary which could be disbursed as under:
  - Budgetary support to 2 National Laboratories and CMPDI and 5 Cooperative Research Centres- Rs.400 crores
  - Funding mission-mode projects –Rs.300 crores
  - Funding of extramural research in Universities – Rs10 crores
  - Demonstration of new technologies in industry – Rs.200 crores/year

- Scholarships/Fellowships at Universities for human resource development for R&D- Rs.2 crores/year

The funding for R&D could be generated through levy of a small cess of 1% on the value of mineral production. Capital investment for refurbishing and developing state-of-the-art facilities and creating new Institutes will be of the order of Rs.250 crores.

- Industry's disinclination to R&D needs to be overcome and a consortia approach, analogous to the PPP model of CEMI of Canada, espoused so that industry collaborates in joint research projects with academe.
- To help identify the national research needs and develop a purposeful R&D agenda, a national advisory committee (a Mineral Industry Technology Council) requires to be set up separately for coal and non-coal sectors with representation from industry, research institutes, academies and professional societies.
- To be abreast of developments in cutting edge technology and research around the world, twinning with research establishments abroad and participation in R&D projects would be desirable and needs to be actively pursued. India should strive to be a partner in the Global Mining Research Alliance(GMRA), created by Australian CSIRO, CANMET Mining and Mineral Science Laboratories in Canada, the NIOSH in the US and the Council for Scientific and Industrial Research in South Africa. The Alliance aims to become "the supplier of choice for mining research solutions and knowledge in the international mining and resources industry" by pooling some of the world's best research expertise and laboratory facilities.
- ICT could play a stellar role in mineral industry's R&D agenda and should be a major component of every R&D project.
- An oversight process should be established to provide periodic independent evaluation of project management, performance schedule, cost controls and risks.

There is an essential role for state support of fundamental research in engineering fields including mining. Basic research can become a dynamo with endless economic progress when applied research and development convert its discoveries into technological innovations. Development "component" to mining engineering has a substantial research component as well. This research tends to be "use-inspired" fundamental research which can be appropriately shown in Pasteur's Quadrant model in Stokes diagram shown below:

Research is inspired by:

		Considerations of user: No	Considerations of user: Yes
Quest for fundamental understanding?	Yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
	No		Pure applied research (Edison)

(adapted from Pasteur's Quadrant: Basic Science and Technological Innovation, Stokes, 1977)

The role of fundamental research, and the contribution of serendipity is often overlooked, and the opportunity for fundamental research spurring technological development is lost.

Indian minerals sector is entering a period of accelerating technological change and competitive advantage can only be gained through the leverage of technology based on aggressive and purposeful R&D. There is a compelling need to initiate research for advanced technologies to effect revolutionary changes in basic mining techniques and equipment to evolve the next generation of low-impact, high efficiency mines to maintain sustainable competitiveness for the nation.

APPENDICES

APPENDIX 8.1

R&D NETWORK FOR 'VENTILATION ON DEMAND" FOR LARGE UNDERGROUND MINES

MAIN GOALS

The concept of "Ventilation on Demand" for energy saving in large underground mines has been implemented in some Canadian mines which allows of airflow only to work places in real time. Presently, the entire mine is ventilated all the time although the actual working faces may be few. Using variable speed fans and variable louvers to direct the flow to desired places and an integrated tracking system will allow the quantity of air flow to match the demand from equipment and personnel. If the concept is implemented in Indian mines, it will result in huge amount of energy saving. In effect, therefore, ventilation on demand will help in providing the right amount of air, at the right place, in right time.

PARTICIPATING ORGANIZATIONS

Coal India and SCCL
HZL and HCL
Indian School of Mines
CIMFR

REQUIRED FUNDING

For implementing the project in at least 2 mines will call for funding of the order of Rs.80 million.

APPENDIX 8.2

R&D NETWORK FOR DEMONSTRATION OF INNOVATIVE TECHNIQUES OF THICK SEAM EXTRACTION AND EXTRACTION OF DEVELOPED PILLARS

MAIN GOALS

Extraction of thick seams continues to plague the coal industry with high losses and often beset with spontaneous heating. It is veritably a bete noir for underground mining globally and has been the subject of relentless search for appropriate techniques. Currently, LTCC (Longwall Top Coal Caving) is the preferred candidate system for exploitation of seams between 6m to 9 m thickness and has found successful application in China and in Australia (at Austar coal mine). It would be a major challenge for Indian coal industry to evaluate the site factors and demonstrate the feasibility of the method. Likewise, the coal industry is saddled with sizable reserves of coal in developed pillars which could be exploited using continuous miners on partial extraction layout which has been successfully tried out in Australia using the Duncan method. The demonstration of the method in Indian coal industry milieu will bolster the confidence of the industry and lead to improved recovery of coal which is currently sterilized.

EXPECTED IMPACTS

The project will impact on the recovery in underground coal extraction and lead to the wider application of the techniques. As a strategy for extraction of thick seams and improved extraction in mining of developed pillars, the productivity and recovery in underground mining could be significantly uprated.

LIST OF PARTICIPATING ORGANIZATIONS

Coal India, and its subsidiaries.
Singareni Collieries Co Ltd
CIMFR
NIRM
Equipment Manufacturers/Suppliers

FUNDING REQUIRED

A demonstration of LTCC, along with associated geotechnical studies and equipment complement, will call for a funding of the order of Rs.2000 million. A trial of Duncan method will require funding of Rs.600 million.

APPENDIX 8.3

R&D NETWORK FOR CONTROLLING FIRES IN SURFACE AND UNDERGROUND COAL MINES

MAIN GOALS

Mine fire, like pandemic diseases, is a scourge that afflicts the coal industry worldwide posing safety issues and loss of valuable coal resources. Indian coal industry has also inherited a legacy of fires due to unscientific exploitation of coal in the past and merits focused research on:

(1) Early detection of fires and their extent so that remedial measures could be mounted early

(2) Evolving innovative methods of fighting and controlling such fires on the surface and coal stacks

(3) Innovative techniques of using bulk flyash grout to stabilize and seal underground access arising from illegal mining/old workings and thus help prevent fires and their spread

The scientific objective will be to generate new knowledge and comprehension of mine fires and their control through demonstration/ trials of extant techniques of fire-fighting in Indian locales where fires continue to rage. The objectives will be achieved by the selection of at least one technology concept whose viability could be established through field trials. The research activities will be structured within 3/4 sub-projects to meet the overall project objectives.

Sub-project 1 will be aimed at fundamental studies on fire-ladder, namely the evolution of characteristic gases due to thermal decomposition of coal and assessment of the role of intrinsic parameters on susceptibility of coal using neural networking technique.

Sub-project 2: Design, development and trials with a crawler mounted high-pressure hydromonitor to fight surface fires from a remote location. The fire fighting tender will douse the fire by spraying nitrogen foaming agent.

Sub-project 3: Application of gaseous combustion products from GAG engines on surface and underground fires and evaluation of the efficacy and cost-effectiveness of the systems.

Sub-project 4: To demonstrate the application of bulk flyash grout for filling underground voids, prevent fires and undo the ravages of illegal mining. The technique, which is commercially available in Australia, has found successful application in control of heatings and remediation of old workings.

The first 3 sub-projects will cost around Rs.5-8 crores while sub-project 4 could cost up to Rs.20 crores, if tried out at 2/3 sites.

The participants/organizations would include: Coal India Ltd and its subsidiaries ECL, BCCL, MCL, SECL & CMPDIL, Indian School of Mines, Indian Institute of Technology, Kharagpur, and Coceeg Associates, Kolkata.

APPENDIX 8.4

R&D NETWORK OF EXCELLENCE IN SURFACE MINING

Main goals

In the context of growing importance of surface mining, the network project will focus primarily on demonstrations of the viability and utility of tools and techniques of surface mining using the best practice and global state-of-the-art processes. The focus of this approach will be on formation of a durable and complementary partnership comprising a critical mass of key research organizations, academics and industry leaders which should lead to:

- Improved efficiency through re-direction and alignment of industrial research programme preventing duplication of research efforts and sharing of existing and newly acquired infrastructure
- Identification of knowledge gap and formulation of new projects and tools to fill this gap. Formation of an authoritative body for identifying potentially promising projects.

Key issues and technology approach

The project will be divided into 3 areas – integrated activities on jointly executed research and demonstration and spreading of excellence. The first sub-project will evaluate ground probe, SSR and Rautech surveying radar system to improve design of a surface mine slope and upgrade record in safety. The project will also comprehend demonstration of new techniques of rock fragmentation such as use of high capacity rock breakers and health condition monitoring of the surface mine fleet.

Expected impacts

The project will impact on the developments and provision of "best available technique" and dissemination of output to the mining industry. List of participating organizations –

Coal India Limited and its subsidiaries companies
The Singareni Collieries Company Ltd
Central Mine Planning & Design Institute Ltd
NMDC Ltd
Indian School of Mines, Dhanbad
Indian Institute of Technology Kharagpur, and
Hindustan Zinc Ltd

Proposed Funding

The network project will call for a funding of the order of Rs. 50 crores for slope stability evaluation, improved rock fragmentation and remote access to maintenance data of surface mining equipment.

APPENDIX 8.5

AN OVERVIEW OF R&D IN MINING IN DEVELOPED COUNTRIES

Major developed countries engaged in R&D in mining on a regular basis include Australia, the USA, the erstwhile USSR, China and Canada.

8.1 Australian mineral industry and R&D efforts in non-coal mining

Australia is a technologically advanced mining nation. Its mineral and petroleum industries are strongly export driven, capital intensive and highly innovative. They are underpinned by a sophisticated, world competitive planning, design, development and servicing of mining software and equipment, scientific analysis, exploration assessment technology, mineral services and equipment. Australia has emerged as one of the world leaders in the development and provision of Mining Technology Services (MTS) due to Australia's position as one of the world's leading mining export oriented country. In addition, rapid globalization over the past decade has seen Australia emerge as one of a small number of key centers in the world's mineral industry.

According to the Australian Bureau of Statistics, mining was the top 3 business expenditure on R&D in 2005-2006 which was 33% more than the previous year (2004-05) expenditure. The expenditure in R&D in the mining and mineral sector during 2005-06 was Aus $225 million (Rs. 8500 million approx). Australia's export of minerals during 2005-06 was Aus $35.4 billion. In 2008-09, total value of export of minerals produced by Australia was Aus $162 billion.

Australia is a great innovator in mining technology services. Australian companies have developed about 60% of world's mining softwares. They are in the forefront of R&D related to exploration technology, mineral reserve estimation, development of mining methods and mining equipment, and mineral processing technology. They invested in 2006 about Aus $1 billion in mining services technology with a target of earning Aus $6 billion in 2010 by exporting mining technology to Indonesia, East and South-East Asian countries, India and China.

The Australian Bureau of Statistics' Business Expenditure on Research and Development (BERD) statistics showed that mining was one of the major contributors to the record levels of Australia's best performance. Mining showed the greatest increase for any sector, up 23%. In Australia, R&D in mining is done in close collaboration and cooperation between universities, research institutes, R&D departments of the industry and Government Agencies. The major R&D funding organizations for mineral industry in Australia include:

(a) Commonwealth Scientific and Industrial Research Organization (CSIRO) – it is the main funding body to the research institutes. In addition they are also involved in research activities.

(b) Australian Research Council – they fund the projects through competitive bidding, and

(c) Australia Mineral Industry Research Association (AMIRA) – they fund and conduct collaborative research.

During the last decade the most effective technologies developed in Australia for non-coal mining include:

(i) Digital revolution

(ii) Automated surface mines

(iii) Increased use of surface miners

(iv) Block Caving/Mass Mining, and

(v) Selective mining

In all the cases the focus was on lowering manpower and the cost per ton of ore produced. All the major mining companies have their own R&D departments which are conducting need based research and innovations. In 2006 Australia spent over Aus $ 6000 million (approx. Rs.210,000 million) for all research put together. The mining industry spent approx 10% of it (some Rs.21,000 million).

By far the biggest step change technology for the mining industry which reached into every area of minerals exploration, recovery and processing was the introduction of Computers and digital tools. For example the 'GLASS EARTH' software from CSIRO has opened up exciting possibilities of seeing through the upper 1 km of the earth to be able to target on the areas of high prospectivity. Another project under investigation by CSIRO is 'Modeling and Optimization of Metal Mining Systems'.

The application of Information and Communication Technology (ICT) led to real time automation in surface mines for optimum use of equipment helped identify bottlenecks and increase production and productivity resulting in lowering of 'cut-off' grades and expansion of ore reserves. Under 'Mine of the Future' project fully automated robotic surface mine using labor saving technologies was developed. M/s Rio Tinto's Iron ore mine at Pilbara, which is hundreds of kms away from Perth where the 'Remote Operation Centre' (ROC) is located, will manage and control the various operations including intelligent trains, drills and trucks fully autonomous without drivers to drive them. Operators will see the equipment from ROC.

Under 'Selective Mining' of ore, surface miners are being used for selectively mining the high grade ore including iron ore, bauxite, copper, limestone, coal, phosphate, gypsum, lignite, shale and sandstone.

For underground metal mines the Australian R&D efforts have experimented with and developed 'Block/ Mass Mining' technology resulting in better, faster and safer mining. The method is suitable for massive ore bodies of low grade. In this method no drilling and blasting is done. Instead the ore body is undercut allowing ore to cave progressively into the void created by a slice that has been extracted. The method is amenable to automation and control of whole mine from centralized control rooms. By and large it is a man- less mine with no persons underground and no drivers for loaders. The method has been used for extraction of diamond and copper in mines in Australia and South Africa. The 'New Selective Mining System' for underground non-coal mines was developed with an objective to deliver the highly concentrated ore to the plant with minimum of contaminants by preventing dilution of ore with waste by selective mining using fully automated 'cut and fill' system. In this system autonomous machines are used to follow individual veins and reject the waste into the fill preparation system or directly to the stope floor. The ore was automatically sorted at the face, crushed and delivered to the central haulage system by pipeline. Often, processing took place underground with only concentrate pumped to the surface. This was possible because of instantaneous assay integrators with face machine and the availability of network of quick setting 'foaming backfill'. The drives were only 2.5m square and the working area within the stope reduced to human dimension.

A few of the projects under execution by Western Australian School of Mines include :

(i) Backfill bench stoping operations
(ii) Application of InSAR Interferometry for slope deformation detection
(iii) Detection and monitoring of mining deformations using InSAR Technology
(iv) Modeling and optimization of mining systems
(v) Open pit load-haul operating practices
(vi) New underground haulage systems
(vii) Wall station surveying
(viii) Laser stope surveying system
(ix) Development of shaft and ore pass inspection system
(x) Utilization of remote, satellite based, techniques for monitoring of mining subsidence

8.2 US mineral industry

Achievement of the goals in 'The Future Begins with Mining' will make the US mining industry " the world's leader in producing and processing competitively priced mineral products and some of the world's lowest-cost coal, while minimizing land degradation, environmental disruptions, and hazards to workers".

Under the leadership of the 'National Mining Association (NMA)', the US mining industry is actively implementing Industries of the 'Future Strategy'. By coming to a consensus on common goals and priorities, the industry has created a powerful force for attracting and guiding public and private investment in new technology development. With several projects already under its belt, the partnership continues to pursue promising technologies and taken an active role in moving advances into commercial use.

Vision: 'The Future Begins with Mining' – A vision of mining industry of the Future. The landmark 1998 document established long-term goals and broad research priorities based on key market, business and environmental trends.

Roadmaps: Industry experts, working through the Technology committee of the National Mining Association, meet regularly to refine research priorities, issue proposal requests, rank recommended proposal for funding and review ongoing projects.

Implementation: To date, OIT has provided cost shared support for over 26 R&D projects proposed by collaborative partnerships to address industry – defined priorities and meet national goals for energy and environment

Technology Strategy: The Mining Team will focus on

(a) New projects in mineral processing, exploration, mine development and operation and other areas

(b) Partnership with federal agencies concerned with improving the safety, energy and environmental performance of mining industry

Based on industry defined priorities and recommendations, OIT awards cost-shared support to projects that will improve the industry's energy efficiency and global competitiveness. Each year OIT provides approx. $4 million (Rs.190 millions) to projects in OIT Mining portfolio. All awards are made on a cost-shared basis through a competitive solicitation process. Solicitations are open to collaborative teams with members from industry, academia, national laboratories and other sectors that have a stake in the future of the mining industry. For its share, the industry has provided $15 million (Rs.700 million) in project funding as well as support in specialized expertise, materials and facilities. Since beginning, the Industries of the Future process, OIT Mining Team has awarded a total of $13 millions (approx Rs.610 millions) in OIT funding to 26 projects. The projects funded by OIT in mineral sector which are under investigation include:

(a) Material transfer :
  i. Development and deployment of automated machine fluid analysis systems
  ii. Hybrid fuel cell mining vehicles
  iii. Advanced underground vehicle power and control

(b) Mine operations :
  i. High-temperature superconductors in underground communications
  ii. Robotics technology for improving mining productivity
  iii. Roof bolt system design
  iv. Remote sensing and imaging at the cutting edges of mining equipment
  v. Wireless mine-wide telecommunication technology

(c) Mineral preparation:
  i. 3-Dimensional simulation of charge
  ii. Motion in semi-autogenous grinding
  iii. SAG mills and ball mills
  iv. Advanced abrasion-resistant materials
  v. Comminution circuit optimization

(d) Physical separation:
  i. Selective flocculation of fine mineral particles
  ii. Dense-medium cyclone optimization
  iii. Novel dewatering aids for minerals

(e) Chemical separation:
  i. Mining by-product recovery
  ii. Treatment of cyanide solutions and slurries using air-spurge
  iii. Hydrocyclone technology

8.3 Canadian mineral industry:

Mining has for long been an important part of Canada's economic backbone. The mining industry directly employs around 0.4 million people or roughly one out of every 40 working Canadians.

In 1998, production from Canada's mining and mineral processing sector was $26.5 billion (appox. Rs. 927,500 millions) or 3.7% of nation's GDP. Despite significant growth in the Canadian economy, the Canadian mining sectors' GDP Contribution has remained within average of 3.5 to 4.5%, during the last decade. The reason has been the strong commitment of Canada towards innovation. Canadian mining companies continue to invest in R&D. In 1998, the minerals and metal sector invested approx. $363 million (approx.Rs.12,700 million) on R&D, with an additional $15 million (Rs. 525 million) expended on research into services related to the mining industry. These numbers have only grown with time.

8.3.1 Canada has several funding bodies/organizations for undertaking R&D in mineral sector.

These include:

i. Centre for Excellence in Mining Innovation (CEMI)
ii. Community Adjustment Fund Programme (CAF)
iii. Canadian Mining and exploration (CAMIRO)
iv. Canadian Mining Innovation Council (CMIC)
v. NSERC
vi. CANMET
vii. Mineral Exploration Research Centre (MERC) at Laurentian University
viii. Mining Innovation, Rehabilitation and Applied Research (MIRARCO)
ix. C-Care

In addition to above government assisted R&D funding bodies there are R&D Centres/Deptts. in the private sector organizations. These include:

i. ITASCA (Canada) Inc.
ii. Golder Associate
iii. Strates Inc.
iv. LCG Energy Management Group
v. SRK Consulting
vi. X-Strata Process Support (XPS)
vii. Mira Geo Science
viii. Rock Science

8.3.2 Centre for Excellence in Mining Innovation (CEMI):

It is a success story of Private Public Partnership (PPP) mode research which can be adopted by the mineral industry in India. They identify the need based R&D Projects and implement them directly in collaboration with universities and industry. The objective of incorporation was

(a) To establish and operate a networked institute for innovation and advanced studies with inter-disciplinary and inter-institutional arrangements.
(b) To promote and undertake research to enable utilization of mineral resources in a safe, sustainable and economic manner.

CEMI management has approved four strategic Research Programmes. These are:

i. FIND MINE: Application of geophysical and geological studies in mineral exploration to discover new footwall hosted ore bodies and mineral deposits. It involves discovery of new ore bodies by creating better geophysical tools by developing methodology leading to better understanding of rock mass physical properties.
ii. DEVELOP MINE AND MINE DEEP: The R&D activities under this programme include underground mine construction for rapid tunnelling. Many of the surface mines will be mass mining methods, particularly for low grade ore bodies, including block caving for which much of the mine infrastructure

is to be developed early. When a new mine is developed the biggest impact on its NAV is due to speed on development and, therefore, rapid shaft sinking and tunneling methods are being developed with mechanization. Similarly, the other parameters to be looked into for fast development rest on development of innovative support and ground control program for new large mines. The 'value proposition' i.e. NAV of a project is uprated by increasing the development speed and by preventing disruptions and reducing rehabilitation costs. Innovative ground control techniques are being developed for safe operation of high volume methods.

iii. GEO RISK: Under this the programme the focus is on mitigation for mining highly stressed are bodies at depth because in future deeper mines are to be exploited. The work includes development of mine design/planning and operational practices. For this work flow-based geo-hazard assessment tools are under development including modifications to the existing tools. To lower the project risk at an early stage leading to an increased likelihood of new mine project development decision, the 'fault-slip' control method is planned. The objective is to lower the annual mine operating costs and development of numerical modeling and mining method selection to control energy release.

iv. VALUE MINE: This program includes mine design to safely extract optional mining value from ore bodies. The main activities include: (a) Sustain mine: It is well known that sustaining mines and mining is of vital importance to all. New discoveries are needed to sustain mines and therefore, new and more efficient cost effective means of accessing deep ores and developing them economically are important factors and are ways to reduce the inherent risks of doing so. Equally vital is the need to develop environmental research that will enhance sustainability of mines and mining. With this in view the research projects undertaken and funded are related to:

   i. Energy reducing/reuse/recycling in mining
   ii. Climate change impact on mining infrastructure
   iii. Zero water discharge from mines
   iv. Control of fugitive dust on industrial sites and preparation of documents on fugitive dust sources and control to help mines.

(b) Mine Tech: There are several firms that service and support the mining industry by developing tailor-made hardware and software. SME and CEMI have supported these companies by bringing them to the mining customers and fund them partially; one such product 'PANDO' is a mine hardware computer that is building platform for information exchange from mobile equipment to company business systems communication via an IREDES streaming data standard. The other product successfully developed and in use 'Intelligent Monitoring' is an environmental hardened transmitter/receiver utilizing satellite communication with three weather stations. The other one 'E MAT Integration' is a software program that brings together EM Hoist Rope Testing Equipment with a digital on line assessment software for mine hoist ropes. 'M/s Rock Science' specializes in 2D and 3D analysis and design programs for civil and mining applications.

Another funded project under investigation is 'Ventilation on Demand-Energy Efficiency'. It is well known that in majority of underground mines the energy consumption by ventilation is up to 40% of the total energy cost. With mining progressing deeper, the energy costs rise and therefore, the impact on mines budget from ventilation also rise. Therefore, 'Ventilation on Demand' allows the air flow to a working place to be changed in real time by using variable speed fans and louvers and sensor network to monitor the resulting changes. The quantity allowed matches the demand from equipment and personnel. This resulted in reduction of total ventilation costs and improved the overall mining productivity.

CEMI membership programs: They allow and welcome the major mining companies and corporates to join hands with them for obtaining the benefit of the R&D work being undertaken by CEMI.

(a) Corporate membership programme: $ 50,000 per annum – enables them to access to one strategic research programme (SRP's)

(b) $ 1,00,000 p.a. membership programme: Members are allowed to have access and active participation to 2 SRP's in Technical Programme Development.

(c) Collaborative membership programme: $ 1,00,00 p.a. for at least 3 years which allows access and active participation to 3 SRP's in support of a specific research program.

8.3.3 University-led exploratory research programmes in Canada:

Canada ranks 1st amongst the G-7 countries for the percentage of private sector investments in university research. Universities in Canada are a $ 26 billion (about Rs. 1,000/- billion) enterprise and employ + 1,50,000 faculty and serve + 1.5 million students. There are 9 universities in Canada offering mining engineering courses. CEMD is one of the organizations supporting university-led research in niche areas.

8.3.4 Enabling technology development: The projects include:

(a) Exploratory projects include the following main projects

i. Sustainable energy recovery from mines

ii. Bio-mining of waste tailings

iii. Dynamic modeling and control of ventilation

iv. Hoisting system maintenance

v. Energy optimization of mine ventilation

vi. PERM – productivity enhancement and risk management

vii. Environmental monitoring

viii. Restoring metal contaminated soils

(b) Technology development projects: Funded and under implementation include:

i. Development of software package for selection of underground mining system.

ii. Wireless condition monitoring of underground mobile and remote mining machinery

iii. Ventilation on demand.

8.3.5 Canadian Mining and Innovation Council (CMIC): is one of the main government supported funding agencies with the objective of

(a) Increasing mining research, innovation and commercialization efforts in order to strengthen Canada's pre-eminent role as a global leader in mineral exploration, mining and knowledge based services and technologies.

(b) Increase the supply of highly qualified graduates from mining related faculties to meet the significant demand today and in the future of industry, government and academia.

8.3.6 Projects under investigation in Canada:

A few of the important projects in metal mines under investigation include:

i. A model for sustainable business transformation

ii. A novel approach to energy and GHG reduction in communication

iii. A preliminary investigation on non-cyanide lixiviates for gold leaching

iv. Aboriginal participation in mine design

v. Adaptation of the OECD protocol for metals to marine systems

vi. Alternative binder for backfill and tailing management

vii. Analysis of block cave induced seismicity
viii. Applications of molecular biology to mining
ix. Availability of mercury and cyanide in ecosystems affected by gold mining
x. Bioleaching of nickel
xi. Design of tunnel plugs in underground mining
xii. Development and implementation of cleaner technologies suitable for ASM
xiii. Development of metals in soils initiative
xiv. Dry disposal of mill tailing
xv. Effect of backfill on hydraulic radius in stope design
xvi. Energy efficient rock fragmentation
xvii. Exposure of mine workers to sources of vibration and noise
xviii. Extraction of molybdenum
xix. Impurity control in base metal processing
xx. Integrated underground mining and processing systems for massive sulphide ore bodies
xxi. Study of underground communication systems
xxii. Mine dust/gas analytical research
xxiii. Non-destructive rock bolt testing
xxiv. Open stoping design criteria for integrated pre-concentration systems
xxv. Options and flexibility in mining
xxvi. Explosive-free rock breakage (EFRB)
xxvii. Rapid excavation technologies
xxviii. Recovery of zinc from acid mine drainage sludge
xxix. Underground mine optimization

8.4 Future R&D areas in non-coal mining sector

8.4.1 Exploration

R&D in exploration is at present drawing maximum attention in developed countries interested in mineral sector. The goal of the mining industry's exploration and resource characterization activities for the next two decades and beyond is to develop ways to find and define reserves with minimal environmental disturbance. This goal includes the following technical activities:

(a) Reduce the environmental impact of exploration and resource characterization by developing non-invasive techniques, applying remote sensing technology to reduce the number of boreholes to define proven reserves

(b) Reduce the cost of exploration and resource characterization by reducing uncertainties of success and understanding the limitations/benefits of geophysical methods.

(c) Increase the value of run-of-mine products-the industry must increase knowledge of resources in order to mine and process them more effectively.

The mining industry feels strongly that the successful demonstration of several new technologies in the near term would provide a strong incentive to continue supporting co-operative R&D efforts. To this end, the mining industry has identified a number of potential near term winners from the priority R&D activities. These are tabulated in Table 8.4.1.

Table 8.4.1: Exploration and resource characterisation needs

i) Advanced Technology	(a) Develop advanced real time mineral content sensors
	(b) Improve ways to sense, visualize, interpolate, model and predict geological anomalies
	(c) Develop advanced imaging technology
	(d) Improve sensors for semi-autonomous machines for guidance and navigation
	(e) Develop better laser analytical technologies
ii) Information Management	(a) Develop an online database for environmental best practices
	(b) Evaluate existing satellite technology for potential use in mining exploration
	(c) Evaluate existing ground-based diagnostic techniques for their potential use in exploration
	(d) Develop modeling/visualization software to demonstrate the benefits of geophysical R&D in geophysics
	(e) Prepare a cost benefit study for exploration efforts across the mining industry

Remote sensing technology has been identified as the category of barriers considered by the industry as the most critical to achieve the targets as shown in Table 8.4.2, a key barrier is the lack of non-invasive technologies to quantify metal/mineral value in-situ.

8.4.2 Highest priority research needs for exploration

The R&D activities that have been given the highest priority, together with the targets they address and the key barriers that must be overcome for them to be successful, are discussed below. All of the proposed R&D activities address nearly all of the performance targets to one degree or another. The ultimate objective / target include

(a) Reduce environmental impact

(b) Reduce costs and

(c) Increase quantum of exploration

The R&D priorities for exploration and resource characterization include:

(a) Evaluate existing ground-based diagnostic techniques for their potential use in mining and exploration. The key barriers are lack of test sites and lack of good technology assessment.

(b) Develop sensors for semi-autonomous machine-guidance and navigation. The key barriers are current state of sensor technology, harsh environment and safety requirement

(c) Improve the accuracy of deep (>300m, beneath the surface) sensors of rocks, mineral, elements and structures. The key barriers include lack of demo site and current state of technology.

(d) Develop projectiles to be sent underground to transmit information. The key barriers include sensing technology at high speeds and sensor robustness

(e) Develop ways to sense, visualize, interpolate, model and predict geological anomalies in front of mining equipment. The key barriers are current state of technology, hostile environment and safety requirements

(f) Evaluate existing satellite technology for use in exploration

(g) Develop horizon sensing and interface detection on exposed material. The key barriers include current state of technology, hostile environment and safety requirements.

Barriers to evaluating existing ground based diagnostic techniques for their potential use in mining and exploration include lack of information on what is available and being used in other industries or by the Government in military or other applications to date. The successful adaptation of these technologies to

Table 8.4.2: R&D needed in exploration and resource characterization

	Remote Sensing Technology	Imaging Technology	Navigation and Control
i)	Develop real time mineral content sensor for all minerals	* Develop ways to sense, visualize, interpolate, model and predict geological anomalies in front of mining equipment	* Develop sensors for guidance and navigation of semi-autonomous machines
ii)	Conduct R&D to improve the accuracy of deep (>300m beneath the surface) sensing of rocks, minerals, elements and structures	* Develop super conducting quantum interference device (SQID's) for imaging	* Develop non geodetic referenced positioning technology
iii)	Develop horizon sensing and interface detection on exposed minerals	* Develop more analytical tools to facilitate accurate interpretation	* Develop remote control and autonomous exploration device for extreme environments
iv)	Develop projectiles that can be shot into the ground and can transmit geological information	* Develop cross-well instrumentation	
v)	Develop ways to sense and interpolate non-intrusive geological modeling of underground ore bodies	* Develop geophysical resolution modeling to enable enhanced mine modeling and mine planning software	
vi)	Develop a better understanding of the physics of remote technology	* Develop borehole radar for measurement while drilling	
vii)	Conduct research to predict the process response of ore via remote sensing characterization of that ore		
viii)	Develop better laser analytical technologies and use improved modeling to increase sensor accuracy		
ix)	Develop new sensors operating from space, high altitudes, low altitudes, above ground and below ground sensors		
x)	Develop rugged hand-held laser technologies for on-the-spot chemical analysis		
xi)	Develop sensors for effective under water exploration		
xii)	Develop sensors that can relate geological information		

exploration and mining process could, for example, reduce the need to drill bore holes, thus reducing energy and environmental costs as well as increasing the safety and health of those conducting exploration activities.

The development of sensors for semi-autonomous machines for guidance and navigation refers to both exploration as well as mining process. However, the main hurdles include lack of sufficient sophisticated and robust sensor technologies, time required to get trial permissions and lack of test sites where demonstration will not interfere with production. The positive environmental impact of these sensors is potentially very high because the exploration/ mining/cutting process will be more energy efficient. Safety is explicitly considered in the design of these machines. Energy efficiency could be greatly improved because the large amount of unwanted material that is mined to get the desired material would be reduced. At the same time the bonus will be reduction of impact on environment as well as on cost.

New and improved sensors could improve geochemical techniques to evaluate targets in covered areas. They could also be applied to develop techniques to combine penetration of radar with the discrimination of reflectance. Another possibility is the enhancement of deep penetration remote sensing 3-D seismic surveys.

Improving the accuracy of deep sensing of rocks, minerals, elements and structures is similar to both previous R&D needs, but more narrowly focused on the exploration process. The barriers to the development and successful adoption of remote sensing are the need to improve upon current technology or develop new technologies as well as education issues. By reducing the amount of drilling necessary to accurately characterize a reserve or an ore body and enabling more efficient mining, remote sensing could have significant environmental, energy and cost benefits.

Barriers to the successful development and adoption of another remote sensing R&D technology, a real time mineral content sensor, include the low detection level required of this type of sensor, the hostile environments in which they would be operated and the level of robustness required. The effects of the sensors on the environment, safety, energy, efficiency and cost could be extremely positive.

One proposed exploration technology that could be much less invasive than current methods of exploration is a projectile carrying sensors which, when shot into the ground, could relay information on the surrounding material. Because of the high speeds and the force of the impact with the ground, the sensor technology needed for this system would have to be more sophisticated and robust than available from current technology. The overall environmental impact could be less than that of drilling. There is some concern about safety, although the use of the technology could reduce injuries on drill rigs or from unstable ground. The technology could have sizeable energy and cost benefits because of reduced requirements for moving rock.

The evaluation of existing satellite technology for potential use in exploration is very similar to another high-priority R&D need, the evaluation of existing ground-based diagnostic techniques, although this one focuses on airborne technology. Both activities address the targets of reduced environmental impact associated with exploration, reduced costs, and increased exploration efforts. The lack of a thorough and accurate technology assessment performed by knowledgeable people is the only major barrier to this effort. Improvements to environmental performance, energy efficiency, and cost effectiveness could be substantial. Safety benefits could also be expected. The analogy of near-sighted versus far-sighted has been used to describe the difference between the development of horizon sensing and interference detection on exposed material and ways to sense and predict geologic anomalies in front of mining equipment. Horizon sensing involves very close sensing, which is a different objective than imaging geologic features in the un-mined volume ahead of the miner. These sensors will also allow mining equipment to maintain consistent operation while following a seam. Although used on exposed material, the technology itself is non-invasive. Key barriers that must be overcome include the lack of appropriate sensing technology capable of operating in the mine environment. Similar to the geologic anomaly prediction technology and the sensors for semi-autonomous machines, this improved characterization could enable a reduction in unnecessary mineral extraction.

APPENDIX 8.6

INAE workshop on impacts of R&D on Indian mineral industry performance – identifying new priorities and strategic initiatives 3rd July 2010, Kolkata

A 1-day Workshop on "Impacts of R&D on Indian mineral industry performance – identifying new priorities and strategic initiatives" and brainsteering session organized by the Indian National Academy of Engineering was conducted on 3rd July 2010 at the Acharya P.C. Roy Memorial Seminar Hall of Central Glass & Ceramic Research Institute, Jadavpur, Kolkata. The project, funded by the Office of the Principal Scientific Adviser to Government of India, seeks to define the trajectory of R&D projects of relevance to Indian minerals sector to help upgrade its performance.

Prof. A.K. Ghose, Principal Investigator of the Project, delivered the welcome address and introduced the objectives of the workshop which received the support of the Institution of Engineers (India) and the Mining, Geological & Metallurgical Institute of India. In the Inaugural Address, Dr. P.S. Goel, President of INAE dwelt on the new role of INAE in making a foray into different research areas including impacts of R&D in chemical industry, and also highlighted outcomes of the study on engineering education in India. He wished that the outcomes of the workshop and research project would materially help the mineral industry in redefining the focus of R&D. Prof. A.K. Singh, Chairman and Managing Director of Central Mine Planning & Design Institute Ltd

Dr. P.S. Goel, President, INAE and Chief Guest at the Workshop delivering keynote address

(CMPDIL) highlighted the status of coal R&D for which CMPDIL is the nodal agency. He also stressed the fact that despite adequacy in availability of R&D funds there were not many takers for conducting R&D studies in the mining industry. Dr. Amalendu Sinha, Director, Central Institute of Mining & Fuel Research (CIMFR) congratulated INAE for conducting the study and extended his support and felt such a study was necessary and would be meaningful if it could lead to identify priority research areas. Dr. Indranil Manna, Director, Central Glass & Ceramic Research Institute (CGCRI) also addressed the participants at the Inaugural Function.

The Inaugural Function was followed by 3 workshop presentations by the project team namely Prof. A.K. Ghose, Prof. Jayanta Bhattacharya and Prof. R.N. Gupta. Prof. Ghose presented the outcomes of the Delphi study and reviewed the status of R&D in Indian mineral industry. Prof. Bhattacharya discussed the challenges and status and weakness in R&D in coal mining while Prof. Gupta dwelt on the impacts of R&D in non-coal sector, namely, metal mines. The workshop concluded with a brainsteering session which was chaired by Shri R.P. Ritolia, Adviser (Coal) to Tata Steel. In this session, all the participants gave their considered views on new research areas for the mineral industry. Following are the conclusions and recommendations of the workshop:

(i) The level of investment in R&D in minerals sector is a miniscule, although there were substantial funds available from the Ministry of Coal and the Ministry of Mines.

(ii) While there is a spurt in R&D projects in the academic departments in the country, much of the research is being focused on areas which were not of key relevance for the industry.

(iii) The Delphi results call for increased volume of R&D on safety, health and environment (SHE) in view of its overarching importance.

(iv) There is need for defining the appropriate performance metrics of R&D outputs.

(v) In future, the R&D in mineral sector may be hamstrung by the looming skill shortage and lack of support for post-graduate studies for research.

(vi) The widespread perception on mining being conservative and resistant to charge needs to be dispelled and there has to be larger input of ICT for innovative developments in the minerals sector.

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Prof. Jayanta Bhattacharya

Dr. Jayanta Bhattacharya is a Professor in the Department of Mining Engineering, Indian Institute of Technology , Kharagpur. Dr. Bhattacharya introduced the aspects of reliability and quality engineering and management to the mining sector in India. He made pioneering contributions to the establishment of theoretical and scientific basis for reliability and maintainability assessment in the mineral industry, when there was little awareness on the subject. He and his team developed a chemo-bioreactor for wastewater bioremediation, a gravity filter – among few others. Recently he and his students made pioneering contribution in the development of CaO, Ca $(OH)_2$ and CaS nano-particles for rapid precipitation of in-soluble compounds from wastewater streams. These particles would find applications as catalyst, toxic waste remediation agent and absorbent – to name a few. He and his team developed and established a novel spectro-photometric method to measure sulfate concentrations in the mine water without interference of mainly, arsenate and phosphate ions. A continuous theme of research by his team is to develop natural carbon-hydrogen-nitrogen dosage supplements to support sustainable bacterial population in the wastewater remediation treatment.

A Fellow of the Indian National Academy of Engineering, Dr. Bhattacharya has been an advisor to the Ministry of Environment and Forest on technical matters. He is the first honorary advisor to Tata Steel for Environmental and Social Governance.

The Indian National Academy of Engineering (INAE), founded in 1987, comprises India's most distinguished engineers, engineer-scientists and technologists covering the entire spectrum of engineering disciplines. The aims and objects of the Academy are to promote and advance the practice of engineering and technology, related sciences and disciplines and their applications to problems of national importance. INAE also encourages inventions, investigations, and research in pursuit of excellence in the field of "Engineering".

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