Chapter One

INTRODUCTION

Over the past century, technological advances such as jackleg drills, longwall shearers, diesel power, and hydrometallurgy have had major impacts on mining and quarrying practices and the nature of the mine site in the United States.

The evolution of current technologies, as well as the introduction of new, breakthrough technologies, will continue and perhaps accelerate in the new century. Several industry objectives will drive future technology change, including

- Lowering production costs.
- Enhancing the productivity of workers and equipment.
- Opening up new reserves and extending the life of existing ore bodies.
- Meeting regulatory and stakeholder requirements in areas such as health and safety, environmental and aesthetic impacts, and land use.

Many technologies have been proposed for use in U.S. mines, including mechanical cutting of hard rock, remote-controlled and automated machinery, wireless communications and data networks, and in-situ processing. Which technologies will prove to be critical to the success of America's mining industry, and which technologies will have a less important role?

Mining and quarrying are capital-intensive activities, and many factors affect the pace of diffusion of new technologies: research and development (R&D) budgets, commodities markets and profit margins, regulatory and community requirements, the ability of firms to acquire and assimilate information, available technology options, the variability in cost structures among firms, and industry attitudes. In recent years, the organization of the mining industry has changed substantially as a result of enterprise restructuring, consolidation, and globalization. How will these factors drive or inhibit technology change in the coming years?

Drawing on the views of industry leaders, this study addresses these important issues shaping the technology profile of mining in the United States.

ABOUT THE STUDY

Task and Purpose

In 1999, the RAND Science and Technology Policy Institute was requested to conduct a series of in-depth, confidential discussions with key members of the mining community to elicit a wide range of views on technology trends in the U.S. mining industry. The goal of this research was to identify those technologies viewed by industry leaders as critical to the success of their operations currently, as well as technologies likely to be implemented between now and 2020.

This research was commissioned by the National Institute for Occupational Safety and Health (NIOSH) of the Centers for Disease Control and Prevention. In April 1996, NIOSH, along with its various partners, established the National Occupational Research Agenda, a framework to guide occupational safety and health research into the next decade—not only for NIOSH, but also for the entire occupational safety and health community.[1] This process resulted in a consensus about the top 21 research priorities, one of which was "emerging technologies" in the workplace.

In 1997, mining and quarrying firms in the United States employed about 240,000 people, three-quarters of whom were directly involved in production. Advances in technologies at mine and quarry sites provide important opportunities to minimize the drudgery of work and eliminate old hazards, but they also may create new, unforeseen risks to workers. Traditionally, hazards in the mining industry have been addressed retrospectively—that is, after they have occurred—but NIOSH policy also is to anticipate the potential health and safety consequences, both good and bad, of emerging technologies so that interventions can be engineered before accidents occur. This study is intended to define what are likely to be critical emerging technologies, in the opinion of leaders in the mining industry, so that NIOSH can then define the appropriate occupational research agenda to ensure the best possible safety and health outcomes for miners in the future.

Additional support for this study was provided by the Mining Industry of the Future program—a partnership of the U.S. Department of Energy (DOE) Office

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[1]Information about the National Occupational Research Agenda can be found at http://www.cdc.gov/niosh/norhmpg.html.

of Industrial Technologies and the National Mining Association.[2] An important activity of this partnership has been the industry's development of visions of its future in the United States and technology roadmaps to identify critical pathways for the R&D needed for mining to reach its productivity and other strategic goals. This report is intended to aid both industry and government in making decisions to support R&D that is critical to attaining the industry's vision.[3]

Several other agencies with significant interests in mining and mining-related activities—e.g., the U.S. Mine Safety and Health Administration, the U.S. Minerals Management Service, the U.S. Forest Service, the U.S. Office of Surface Mining, the U.S. Bureau of Reclamation, the U.S. Bureau of Land Management, and state mining departments—can draw insights from these industry discussions. Finally, the U.S. Department of Defense (DoD), with its interests in heavy construction and working in underground environments, may also benefit from the insights presented herein.

Just as important, this report also should help mining-industry executives, researchers, and stakeholders to obtain a broad view and understanding of technology trends pertinent to their operations. While mining and quarrying operations share many technologies and processes, the industry is highly competitive and fragmented, and, according to several industry executives with whom we spoke, information sharing among firms is very limited. Thus, industry decisionmakers can benefit from their colleagues' past experiences and forward-looking perspectives presented herein.

How the Study Was Conducted

This mining study was modeled after the RAND Science and Technology Policy Institute's 1998 National Critical Technologies Assessment and other critical technologies studies.[4]

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[2]For background on the Mining Industry of the Future program, see http://www.oit.doe.gov/mining/.

[3]We note that RAND was not tasked with identifying priorities for mining-technology research. While the RAND project was under way, a parallel analysis of mining and mineral processing-technology needs was commissioned by the Mining Industry of the Future partnership and was being conducted by the Committee on Technologies for the Mining Industries under the auspices of the National Research Council. It was anticipated that this committee would make recommendations for R&D funding priorities.

[4]Steven W. Popper et al., *New Forces at Work: Industry Views Critical Technologies*, MR-1008-OSTP, RAND, 1998; Susan Resetar, *Technology Forces at Work: Profiles of Environmental Research and Development at DuPont, Intel, Monsanto, and Xerox*, MR-1068-OSTP, RAND, 1999.

RAND researchers met with and led structured discussions with representatives from 58 organizations across a broad spectrum of the mining industry (Figure 1.1). The participating firms included 28 machinery, equipment, and service providers, ranging from heavy equipment manufacturers to suppliers of adhesives and engineering services; eight coal producers; 11 metals (including gold, silver, copper, nickel, iron) producers; and four aggregates and industrial minerals producers. Finally, we spoke with representatives from seven research and government institutions that have important roles in the technology development and demonstration process.

The majority of the participants were drawn from the executive ranks of the mining industry; they include chief executive officers, presidents, chief operating officers, and vice presidents. We also spoke with managers responsible for mining units, R&D, and technology acquisition, sales, and service.[5] Many organizations elected to commit more than one representative to this research effort, bringing the total number of individuals participating in the RAND study to more than 90 (see Appendix A).

The organizations and individuals that participated in this study were selected on the basis of their leading positions in the industry and for their ability to

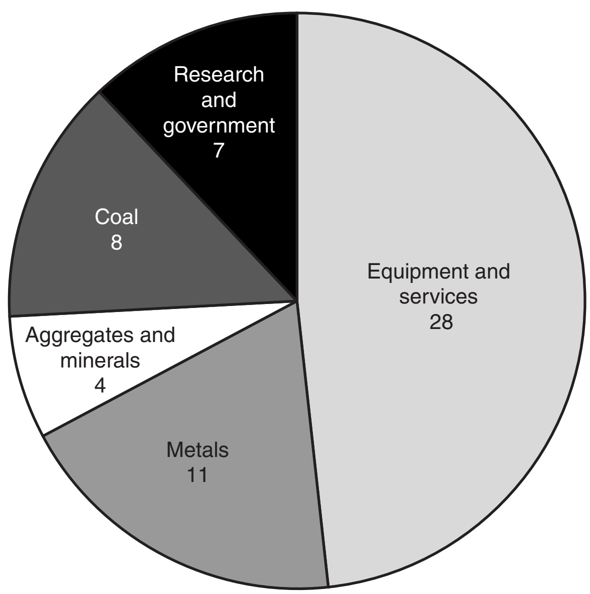

Figure 1.1—Mining Organizations Represented in the RAND Discussions

[5]On several occasions, we were also able to speak with mine foremen and rank-and-file workers.

think broadly and creatively about technology and management issues. RAND selected an initial pool of candidates in close collaboration with the National Mining Association, the National Stone Association, the DOE Office of Industrial Technologies, and industry consultants, as well as labor unions and government representatives. During the discussion phase, participants identified other organizations and individuals as being particularly innovative or having salient technologies and experiences, and in many cases these firms were added to the participant roster.

The industry discussions were conducted between March and July 2000 and consisted of structured, confidential conversations that typically were held on the participants' premises and lasted from 90 minutes to two hours.[6] The discussion protocol, also developed with the input of the aforementioned organizations, is presented in Appendix B.

While we sought to address the specific themes identified in the protocol, we let the discussants determine the issues that were valuable to highlight and those that could be disregarded within the brief meeting time. While keeping the meetings concise facilitated contacting a wide range of executives, it also limited the amount of time we could devote to any one technology prospect.[7] In almost every instance, though, we found the participants to be highly engaged, thoughtful, and willing to address even sensitive issues. On numerous occasions, the host firms generously provided technical literature and facility tours.

Definitions

Technology can be defined broadly as the application of knowledge toward practical ends.[8] Accordingly, technologies include not only physical hardware, but also operational procedures, organizational structures, and management practices. The inclusive nature of this definition is important: According to the industry leaders with whom we spoke, some of the most important innovations at U.S. mine sites concern organization and management.

Mining technology thus includes both the machinery and equipment commonly associated with mining (e.g., drilling, blasting, rock-cutting, loading, and hauling equipment) and technologies that support mining, such as monitoring, control, and communications systems; planning and design tools; and services.

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[6]Logistical constraints limited our ability to involve a few desired participant firms. To overcome this limitation, three of the 58 discussions were conducted by telephone.

[7]For example, the RAND protocol did not call for quantitative assessments of costs or benefits of critical technologies. Obtaining such information would have been of great value in assessing technology uses and needs but was beyond the scope of the study.

[8]*The Random House College Dictionary* (Rev. Ed.), New York: Random House, 1984.

For the purposes of this study, the definition of *critical technologies* was left to be determined by the participants.[9] That is, the primary attribute that made a technology critical was that it was valued by industry executives. In effect, the critical technologies identified in this study tend to include those that are generally important by virtue of either their widespread application (i.e., the success of mining operations depends upon them) or their distinction as a benchmark (i.e., having a desired feature such as reliability or speed). As a result of this approach, highly specialized technologies (such as those developed to meet a specific environmental objective) tended not to be discussed.

Scope

As noted above, the study participants were selected from the members of the mining community—operating companies, technology suppliers, mining consultants, and researchers. Mining sectors covered in this study include coal, metallic and nonmetallic minerals, and aggregates. The terms *mine, mine site,* and *mining* also refer to quarry operations, except where noted.[10]

The sample should not be considered representative of the entire mining and quarrying sector. In particular, the roster of operating companies is biased toward large and midsize companies.[11] These companies were chosen primarily because they are considered to have valuable experience with advanced technologies—their larger scale and income typically provide greater opportunities to explore technological solutions. The sample of technology suppliers, on the other hand, spans a range of small to large firms. The industrial minerals industry (e.g., phosphorus, potash, clays) is underrepresented in this study, largely due to logistical constraints. However, many of the arguments made regarding the aggregates industry also appear to apply to the industrial minerals industry.[12]

To obtain a broad, high-level view of mining technology trends, we sought out industry representatives in executive- and management-level positions. This approach assured that the discussions considered technology uses and trends within the greater context of the participants' firms, their sectors, and the mining industry as a whole. As a result, the discussions focused more on broad

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[9]For a discussion of the issue of defining critical technologies, see Steven W. Popper et al., op. cit.

[10]This corresponds with the U.S. Census's North American Industry Classification System Descriptions 212 (Mining—Except Oil and Gas) and 213 (Support Activities for Mining).

[11]The smallest firm in the sample was a gold producer with 125 employees.

[12]This assertion is based on discussions with DOE officials and industry specialists rather than with study participants.

technology trends and often did not entail detailed, "hands-on" knowledge of particular technologies or innovations.

This project focused on technologies applicable to operations conducted at the mine site: engineering development, ore extraction, quarrying, materials handling, and preliminary beneficiation (e.g., crushing, screening, flotation, washing, and concentrating). Prospecting and exploration and downstream processing (such as coal preparation, crystallization, drying, sintering, smelting, and refining) or other activities that typically occur away from the mine site were not addressed.

During the course of the discussions, the industry leaders typically focused on technologies that currently are available on a full-scale commercial or operational basis, as well as those that are poised to be available over the next five to 10 years (i.e., by 2010). This reflects executives' and managers' more immediate time horizons, especially in a very competitive business environment.[13] However, in a few instances, the discussants extended their horizon out to 2020. We asked the industry discussants to exclude ideal or "stretch" technologies and other innovations (even those that have been already developed) if they *are not likely* to be deployed on a production basis in the industry within this time frame.[14]

THE REPORT

To understand the technology development environment in mining, we asked participants to identify trends driving innovation in the industry. In Chapter Two, we discuss some of these drivers, including market forces, regulation, and globalization.

The study participants included a large number of companies working in many different environments and producing a diverse range of goods and services. Nevertheless, when asked to identify leading mine-productivity bottlenecks and the technologies critical to resolving them, participants identified a fairly consistent set of priority areas:

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[13]In general, participants from academic institutions offered longer-term technology views. In a prior visioning effort, the DOE/National Mining Association Mining Industry of the Future partnership asked industry leaders to identify an ideal development scenario and stretch technology goals out to 2020. The results of that visioning effort, *The Future Begins with Mining*, differed greatly in content and tenor from those of our discussions. See http://www.oit.doe.gov/mining/vision.shtml.

[14]For example, hard-rock fragmentation by means of high-pressure water or plasma jets was mentioned in a favorable light by some participants, although few believed that these technologies would reach commercial production within the next 20 years.

- Unit-operations (unit-ops) capabilities
- Process control and optimization
- Operations and maintenance (O&M)
- Issues relevant to broader organization and management

Within these priority areas, the discussions highlighted dozens of specific technologies that are being employed to enhance mine productivity and are shaping the character of mine and quarry sites in the United States.

The following four chapters address these priority areas and identify many technology solutions being pursued to resolve them. Chapter Three focuses on the basic hardware employed in mining: unit-ops equipment. Chapter Four discusses the application of information technologies (IT) for process control and optimization of mining operations. Chapter Five discusses innovative technologies associated with O&M. A cross-cutting theme present in the discussions was the importance of organization and management to the success of a mine; this issue is addressed in Chapter Six. In Chapter Seven, we close with some broad impressions and observations that we brought away from the discussions.

Each chapter presents the status of the technologies, trends in diffusion, and distinctions in application among mining-industry segments. Examples of applications are highlighted in boxes. In line with the project's goal of promoting frank discussion, we do not attribute comments or technologies to specific individuals or companies.

We emphasize that the slate of critical technologies identified in this report is not intended to be exhaustive. Rather, the report summarizes and synthesizes the perspectives of a sample of industry representatives, which are based on their understanding of their firms' mining-related activities and the industry at large. The absence of a particular technology in this analysis should not be interpreted as an intentional omission, but as an indication that the technology was not cited as critical during the discussions in this study.

We also note that this report does not present a consensus view. While we discovered many points of convergence during the 58 discussion sessions, we also heard many conflicting arguments. While some discussants spoke enthusiastically about the prospects for a new technology, others squarely disparaged it. We flag converging and conflicting views to illustrate the breadth of thought and experience across this very diverse industry.