In the preceding chapters, we have presented executives’ and managers’ views on critical-technology trends in the mining and quarrying industry. In this concluding chapter, we build on these perspectives and draw several implications for public- and private-sector mining-technology research, development, and diffusion in the future.

THE DIVERSITY OF THE MINING INDUSTRY

Many of the technology trends presented in this report apply to all segments of the mining industry. Yet the industry is diverse, and there are some important differences between the major players and the ways in which they affect critical-technology trends.

The metals segment differs from other sectors in its strong dependence upon exploration and acquisition of the best ore bodies and in its greater globalization of operations. Metals producers thus spoke the most about international technology trends and lessons to be gained from abroad. Despite present low metals prices, product demand remains high, and hence increasing productivity and lowering cash costs remain fundamental goals. Metals producers tend to be investing more heavily than other mining-industry firms in complex and advanced technologies such as dispatch systems, high-precision equipment positioning, and super-size equipment. In the future, metals producers are likely to spearhead the implementation of advanced remote-controlled and automated equipment.

“The primary concerns of the coal industry are regulatory reform, coal utilization, and energy policy.”

—Coal-company executive
Coal producers, on the other hand, presented themselves as less concerned about mine-productivity-enhancing technologies, primarily because of chronic oversupplies on coal markets and the resulting decline in coal prices (see Figures 2.2 and 2.3). As we note below, coal producers also are focused on major issues affecting coal utilization. Finally, historical precedent and tradition appear to be important influences in decisionmaking among coal companies, fostering a generally conservative outlook on technology prospects.

“We have a clear strategy: to build on our existing strong market positions through investment and acquisition.”

—Aggregates-company publication

The stone and aggregates segment stands out for enjoying high product demand and prices, and hence it has a strong incentive to achieve rapid productivity increases. In addition, given aggregates producers’ historical character as small-scale, relatively low-tech operations, product demands combined with a rapid wave of consolidation are resulting in significant investments to update excavating, crushing, and product-delivery technologies. Another important trend facing the segment is the increasing size and decreasing number of quarries, and their growing distance from urban centers. In sum, quarries in the United States are likely to see some of the greatest technology changes in the mining industry in the coming decades. As rising buyers of new machinery and equipment, stone and aggregates producers stand to become important drivers of mining-technology innovation.

The industrial minerals segment, while not widely represented in this study, generally enjoys the same favorable demand climate as aggregates producers. Interestingly, many industrial minerals producers appear to align themselves more closely with other industries, such as chemicals and agriculture. This may preclude important opportunities for collaborative R&D and problem-solving ventures with “mainstream” mining, as well as quarrying, firms and organizations.

RESPONSIBILITY FOR MINING R&D

Discussants from all corners of the mining community agreed that mining-technology R&D efforts in the United States have decreased substantially over the past few decades as a result of cutbacks in both public- and private-sector funding. As noted in Chapter Two, when we asked about their in-house efforts, nearly all of the operating companies stated that they had no formal R&D program. As a result, much of the recent innovation in mining has been in the form
of incremental improvements to existing technologies. Very few participants mentioned any R&D efforts on breakthrough technologies.

Approximately 60 longwall systems were in use in U.S. coal mines in 2000. The demand for such mining equipment is limited, even as the technology becomes increasingly complex and R&D requirements rise. Photo courtesy of Joy Mining Machinery.

Contributions from universities, in particular, have dropped significantly, and two causes were cited during the discussions: First, university mining research is being perceived as too theoretical and not product-oriented enough to satisfy the needs of the mining community. One university participant mentioned his institution’s efforts to counter this by forming a consortium that included industry and government partners, and by adopting corporate-style arrangements such as product milestones and deliverables. A second problem cited was the apparent mismatch between the duration of university research funding cycles and graduate-student tenures, on the one hand, and the increasing demand from commercial sponsors for short-term results, on the other. One university in our study had made a concerted and successful effort to adapt to this changing environment by taking on more smaller projects.

These circumstances appear to have resulted in a situation where, when a technology research interest is identified, it is unclear who within the community should champion R&D, demonstration, and commercialization. An example of this situation involves vehicle powerplants and the need for low-emission diesel engines and alternatives to diesel: Mining companies wait for truck manufac-
turers to address the need, and truck manufacturers wait for engine manufacturers; yet engine manufacturers may have enough business outside of the mining industry to keep them from responding with the same sense of urgency that the mining companies feel. Similar scenarios appear to exist for other technologies, including alternatives to hard-rock blasting, remote controls, and mineralogical sensors.

“Mining is a very small industry with small numbers of [items of] equipment, but it has large research and development needs. What do you do? Risks and investment should be shared.”
—Technology supplier

Discussion participants repeatedly raised the concern that there was not enough collaboration among technology suppliers and between technology suppliers and operating companies. Collaboration, it was said, was needed throughout the entire innovation process, from concept development to commercial demonstration. The need for collaboration is clear: The demand for mining equipment and services is limited, advanced technologies are increasingly complex, R&D costs often are too great for a single company to take on alone, and operating companies are wary of being early adopters. In addition, greater collaboration between suppliers and operators will improve knowledge flow and will facilitate both the relevance and the adoption of new technologies. In short, R&D roles as well as funding levels need to be reappraised in the industry.

Research and development partnership funding provided by the DOE Office of Industrial Technologies was mentioned as a positive step in this direction—suggesting that the federal government can play an important role in convening parties and catalyzing ventures. Several speakers also pointed to models of successful, long-term government/industry collaborative research on advanced technology development in Australia, Canada, and South Africa. As noted in Chapter Two, several operating companies appear to be recommitting themselves to mining R&D, so the industry may be seeing a paradigm shift.

UPSTREAM AND DOWNSTREAM INNOVATION

When asked to highlight critical technologies, operating-company participants often focused first on technologies in downstream activities (such as beneficiation and utilization) rather than those in upstream activities (such as ore extraction). Several study participants were able to discuss in detail the benefits of monitoring and control technologies for optimization of their processing plants, while the benefits of such technologies for optimizing ore production
were sometimes viewed as less critical or “too soon to tell.” Similarly, when discussing activities at the mine site, participants tended to focus more on haulage than on development, drilling, or blasting.

This disparity partially reflects the fact that minerals processing operations—downstream activities—have more in common with factories and refineries, where process optimization technology has been in use longer, than do upstream activities. The bias toward downstream technology also can be understood from an economic standpoint for those commodities in which processing represents the bulk of the cost: The value of productivity gains tends to increase with the value of the product, and value is added as the product moves downstream through the various operations of a mine. One manufacturer estimated that a 1 to 2 percent productivity gain in a metals-processing plant was equivalent in economic value to a 20 to 30 percent productivity gain in an underground mining operation.

In the case of coal, producers and technology developers emphasized the importance of preparation plants and transportation: The industry is not production-constrained, and transportation can account for as much as 50 to 80 percent of the cost of coal. Thus, gains in product quality and transportation costs are usually viewed as more valuable than gains in extraction productivity. Downstream technologies also receive particular attention because of regulatory and community concerns. For example, technology to reduce emissions during coal utilization was commonly cited by coal producers as an important avenue to sustain the market for high-sulfur Appalachian coal and, more fundamentally, coal in general. This downstream focus of the mining industry can help explain the incremental pace of technology innovation upstream at the mine site.

“The mining industry has ignored blasting, but improvements on the front end have a big impact on the back end.”

—Technology supplier

The incentive to innovate upstream operations may be increasing. As processing plants become more highly tuned—to meet higher productivity, emissions, or quality targets—the quality of feed materials becomes a more important determinant of plant performance. Similarly, the trend toward just-in-time delivery demands closer mine/plant integration to manage feed quantities. These two trends, in turn, are supported by the development of information technologies which are increasing the control over and the ability to link together unit-ops equipment. Drills and bulk explosives loaders, for instance, can be programmed to meet crusher demands. Finally, regulatory and community pressures (concerning aesthetics, noise, and land use, for example) increasingly
challenge the basic character of mining operations, especially for aggregates, industrial minerals, and metals producers. This suggests that R&D and innovations targeted at upstream mining processes are likely to have higher payoffs in the future.

COORDINATION OF TECHNOLOGY AND REGULATORY DEVELOPMENT

An issue raised in the discussions was the desire among the mining companies for more coordination of technology development and regulatory development. The regulatory framework in some areas, such as ground control, was cited as being outdated and hence of limited relevance to emerging technologies. In other areas, most notably ambient noise and respirable dust, several participants cited compliance with existing regulations as being technologically impossible, and proposed new regulations raised additional concerns. These discontinuities have prompted calls for early, proactive technology-development efforts when regulatory revisions are considered.

“Little forethought goes into co-developing technologies to successfully implement new regulations. The goal would be to have a technology available when a regulation is implemented, so as to provide for a smooth evolution for mining companies.”
—Coal-company executive

Further complicating the matter, claimed one participant, is the tendency for technology suppliers to focus on productivity-increasing and money-saving innovations, with technologies to address regulatory concerns apparently being viewed as unprofitable and thus unattractive for investment. More of the impetus for such development, he claimed, needs to come from the government.

“The diesel technology is there for over-the-road applications, but engine manufacturers don’t want to certify them for mines.”
—Coal-company executive

Finally, an opportunity for public-sector/private-sector cooperation to promote mining-technology development and diffusion is in certification. The mining industry can benefit from the application of many technologies, such as low-emissions diesel engines, that are presently or imminently available but whose technology developers do not see a strong business argument for going through the mining certification process.
WORKFORCE AGE

“The average age of a coal miner in the United States is 46 years. This miner is not getting any younger and, with age, is more susceptible to fatigue and injury. . . . It also takes longer to recover from any injury the miner does suffer. This reality provides an added incentive to reexamine both the work that we do and the way that we do that work.”

—Coal-company document

In 1999, the average age of a coal miner in the United States was 47 years, and it is expected to increase in the future. The aging of the mining workforce was mentioned in several discussions, and the issue raises several important technology-related concerns: physical limitations of mine workers, ergonomics, know-how retention, and training and retraining.

An aging workforce in a strenuous industry raises questions about increases in injury rates, longer injury-recovery times, and more time lost due to non-mining-related medical concerns. Factors such as reduced stamina, flexibility, and strength need to be considered when designing equipment, planning maintenance, or setting protocols for mine safety and rescue procedures. Increases in chronic ailments such as back pain and deteriorating vision may also be important limitations. It therefore will become increasingly important to consider the needs of an aging workforce when developing mining technologies and operator interfaces—both to minimize injuries in the future and to enable mining and quarrying companies to retain their most skilled workers in a very competitive hiring environment. However, a coal-company executive noted that although he has tried to work with manufacturers, “not a lot of thought” has been put into designing new pieces of equipment with an older workforce in mind.

Mining skills are acquired largely through hands-on learning from experienced workers—especially in the area of safe practices. As experienced workers retire and as workforces are reduced in size due to productivity enhancements and consolidation, valuable knowledge may be lost. In addition, know-how retention becomes more important as mining technologies grow in complexity. Consolidation and globalization may alleviate this situation by shifting workers and sharing information among sites and companies. On the other hand, new technologies such as operator assists and remote controls that rely on the use of video images and joystick controls are readily adopted by younger workers, said several discussion participants. Research may be needed to sort out the implications for both productivity and safety of the aging workforce and technological change.
TECHNOLOGY CROSSOVER OPPORTUNITIES

Mining in the United States has a tradition of self-reliance: Mines typically are in remote locations, and the ore bodies they work often have unique characteristics. Yet, as discussed above, our discussions revealed a desire for increased information sharing and R&D collaboration in the industry. Executives from several of the larger mining companies noted that they hold periodic “summit meetings” among representatives from different sites to share information on operations and technology. As noted in Chapter Two, a few study participants had initiated efforts to identify potentially relevant technologies from outside industries. The National Mining Association also has a committee dedicated to technology issues. Nevertheless, existing information-transfer and technology-search mechanisms in the industry do not appear to be fully exploiting opportunities for technology crossover within companies, across the mining industry, or, importantly, with nonmining sectors.

Outside the mining sector, several technology areas may have valuable crossover applications. Previous RAND research has indicated that maintenance is a critical-technology concern for many industries. Diagnostics such as vibration, lubricants, and ultrasonic analysis are not yet used extensively in mining, even though these monitoring and analysis techniques are common in industries with much smaller capital investments in their fleets. Over-the-road trucking, construction, and manufacturing—like mining—have high downtime costs, and the mining companies may gain tremendous benefit from learning about new maintenance concepts and best practices in these sectors. Several other broad issue areas also offer technology crossover potential:

- As mines strive to reduce the cyclical or batch character of their operations, they can draw on technologies and know-how from refining and other processing industries. More generally, the mining industry can draw on concepts such as Total Quality Management (TQM) and “Six Sigma” enterprise process redesign (approaches developed and championed by General Electric and other manufacturers).

- Mining is not unique in having an aging workforce (although that workforce’s extent and its implications may be more significant than in other industries), and the sector can learn from and share its experiences with other industries, such as those represented in the DOE Industries of the Future programs.

- Industries such as petroleum production and chemical manufacturing may have important lessons to share, for example, lessons on resource conservation and pollution prevention.
Of particular note are opportunities for technology and know-how crossover arising from the similarities between mining and the military in technology needs and applications and the working environment. Both sectors share a highly specialized and limited market for technology development; a reliance upon robust mechanical and electronic hardware that can withstand harsh operating conditions; and operational and logistical challenges imposed by remote, variable, and unpredictable working environments. Each sector offers complementary expertise that could benefit the other in areas such as position monitoring and wireless communications. The military can provide critical know-how to the mining industry in managing complex maintenance and repair operations; advanced use of modular designs, subsystem replacement, and centralized repair depots; and assuring rapid resupply of low-demand spare parts.

One potential solution is the creation of a communitywide “mining center of excellence” dedicated to generating and disseminating reliable and actionable information about technological needs and developments. The goals of a mining center of excellence might include:

- Initiating innovative research projects aimed at attaining long-term strategic development goals in the mining industry.
- Acting as an information clearinghouse for technology availability, costs, case studies, and other relevant information.
- Stimulating strategic partnerships between researchers, suppliers, mining companies, and government agencies to bring together the complementary expertise necessary to address complex technological challenges.
- Providing individuals with the skills mix to become informed leaders in the mining industry.

**MEASURING THE IMPACT OF NEW TECHNOLOGIES**

One of the challenges of summarizing industry leaders’ discussions is that of reconciling the widely differing views they expressed on the prospects for many new technologies, including the expected costs and benefits of expected innovations. These differences of opinion were rooted in varying assessments of the expected performance, costs, and benefits (the productivity value) of those new technologies. We believe that the variation in assessments is a result of a dearth of reliable information about costs, productivity benefits, and other consequences of technology investments, and the lack of information may be skewing priorities in favor of conventional technologies and practices and slowing new-technology development and diffusion.
One explanation repeatedly cited was that operating companies—especially smaller ones—have limited knowledge of costs across their operation, often a result of the fact that mining and quarrying enterprises typically do not have sufficient financial and technical know-how to analyze such questions.

This makes technology assessment difficult. One manufacturer noted that even though the operating costs of his machinery were demonstrably lower (by more than an order of magnitude) than those of competing products, it was difficult for him to convince operating companies of his machinery’s merit. Another executive, frustrated with the difficulty of convincing operating companies of the merits of his company’s advanced analytic and problem-solving capabilities, inquired about lessons to be learned from other industries for better communicating technology benefits.

In addition to investment and operating costs, numerous other factors come into play in assessing a technological investment in mining. Among these are training and staffing requirements, mining productivity, energy consumption, environmental impacts, worker health and safety impacts, spin-up time, transportability to additional sites, and time to return on investment. Moreover, given the widely varying needs and capabilities of different mining operations, all of the above factors need to be assessed in terms of commodity type, mine size, mining method, geology, climate, local skill availability, community acceptance, and regulatory constraints.

Although suppliers provide new-product performance data to prospective buyers, several operating companies cast doubts on the reliability of such information, implying that it is especially inadequate for guiding decisions involving major investments and facility reengineering. Several reasons for this were offered in the discussions, including

- The limited number of technology demonstrations, such that there are often no installations in comparable operations.
- Insufficient resources to collect rigorous performance data.
- Insufficient communications, resulting in firms being unaware of applicable information regarding new-technology performance.
- A tendency in mining to assess effectiveness by experience and “feel” rather than quantification.
Finally, measuring productivity benefits of new technologies on parameters such as equipment availability and durability, reduced maintenance requirements, fit with existing systems and practices, and contributions to process integration and optimization are notoriously difficult tasks—for any industry.

Objective, third-party measurement and assessment of emerging technologies could better support critical-technology acquisition as well as R&D investment decisions. Such an effort would have the added benefit of providing a source of quality control for mining technology: Successful technologies could be highlighted, and unfruitful approaches could be identified and modified or eliminated. In addition, research in this area could help identify the key factors, e.g., company size or industry sector, that are important in making investment decisions. Finally, the federal government has a long-term interest in tracking productivity trends across the economy; better quantification of the productivity benefits of new technologies being adopted in the mining and quarrying sector would inform economic forecasting and monitoring efforts.

Over the past decade, the mining industry in the United States has shown greater productivity increases than other sectors such as manufacturing and construction. Yet many in the industry are concerned about mining’s health and its long-term viability. Take the example of coal: Thanks to the introduction of new technologies, the number of labor-hours required to produce a unit of coal has dropped by a factor of eight since 1950, yet the industry suffers from overproduction, low market prices, and unfavorable profit margins. This suggests that conventional measures of success, which are geared toward perfecting methods of mass production, are no longer serving mining-industry decisionmakers well.

As we heard throughout the technology discussions, mining and quarrying operations today also compete on a range of other parameters: their ability to attract skilled and motivated workers; health and safety, environmental, and aesthetic impacts; supply-chain integration and getting products to the market at the right time; and, ultimately, customer and community satisfaction. These are critical measures that must increasingly be considered as new mining technologies are envisioned, developed, and assessed.