Chapter Two

DRIVERS OF AND IMPEDIMENTS TO TECHNOLOGY CHANGE

To establish the context of technology development and diffusion at U.S. mine and quarry sites, RAND asked participants to address the process of technology innovation in the industry. In other words, what factors determine the development and diffusion of new technologies at U.S. mine sites? And how will technology flows evolve in the coming years? Several drivers of and impediments to innovation were discussed, including

- Industry demand for new services and equipment
- Commodities markets
- R&D funding and alliances
- Regulatory and community constraints
- Industry consolidation
- Globalization

In view of these trends, industry representatives suggested that technology innovation in the mining industry for the foreseeable future was likely to be characterized by slow but steady incremental improvements. Innovations that require significant private sector R&D expenditures, capital investment outlays, and facility reengineering are likely to be viewed as too speculative and costly in the current industry climate.

INDUSTRY DEMAND FOR NEW SERVICES AND EQUIPMENT

The United States has the largest mining industry in the world, with a raw material production value of over $52 billion in 1997 (see Table 2.1). Yet many industry representatives noted that as a buyer of goods and services, mining is relatively small in comparison with other industries, and its ability to finance R&D specific to mining is limited. As a result, many technology innovations in mining are adopted from other sectors such as construction, automobiles, and

Table 2.1

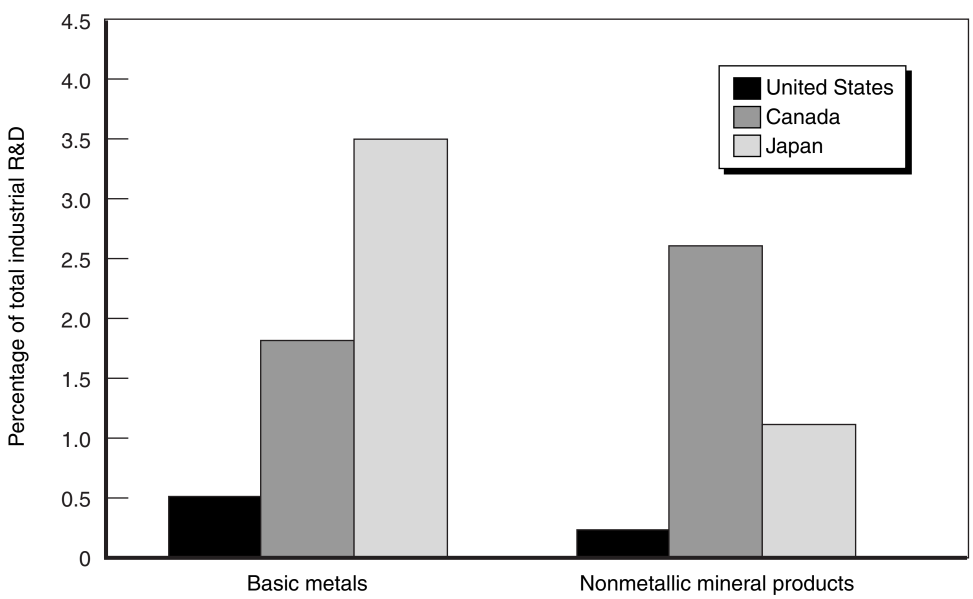
The U.S. Mining and Quarrying Industry, 1997

Item	Total	Coal	Metals	Nonmetallic Minerals
Value of shipments ($ billions)	52.3	24.0	11.5	16.8
Employment	239,400	93,000	48,500	97,900
Number of establishments	7,350	1,511	493	5,344

Source: U.S. Census Bureau.

aerospace. An example of technology crossover is the Global Positioning System (GPS).

Although the mining sectors in Australia and Canada are smaller than those in the United States, their local economic impacts are greater, and mining in these countries has received significantly more public- and private-sector R&D support (see Figure 2.1). Not surprisingly, many discussants pointed to innovative mining technologies coming out of these countries that may have an impact in the United States.



Source: National Science Board, *Science and Engineering Indicators 2000*, NSB-00-1, National Science Foundation, 2000.

Figure 2.1—Mining-Related R&D as a Percentage of Total Industrial R&D, 1996–1997

According to many discussion participants, the mining industry as a whole tends to be risk-averse in its application of technology. Several speakers repeated an industry saying: "Miners like to be first to be second." "The inertia to change is large," said a service provider. Many causes for this were cited, including the basic nature of the raw-materials production process, volatile commodities markets, and, interestingly, industry culture. Operating-company representatives frequently pointed to other enterprises or units as being technology leaders in one aspect or another, but they typically painted their own organization as more conventional.

Economic factors tend to favor risk-averse technology decisions in mining. The volatility and uncertainty inherent in commodities markets raise the perceived cost of long-term planning and investment. Because of the large scale and complexity of many pieces of earthmoving equipment and the need to coordinate technology acquisitions with mine-development plans, investing in new technologies often entails massive capital investments. Yet the period required to recover the cost of investments in mining tends to be much longer than in other industries, because of the highly competitive nature of the business and resulting thin margins.

> Firms in the construction industry typically expect to obtain a return on their technology investments within three to six months. In the mining industry, investments are often not recouped for two to three years.
>
> *—Industry representative*

The mining industry purchases relatively few pieces of equipment. Moreover, because of its scale and ruggedness, mining equipment often has no application in other sectors. Thus, R&D, demonstration, and start-up production costs per number of units sold are high. As an example of one extreme, the most recent sale of a new dragline for surface mining in the United States was made in 1993. The time required to develop and recover the development costs for large-truck tires is currently 10 years, reported one industry representative, and this has constrained the scale-up of haul trucks. With low turnover, the capability to prototype or make design improvements based on field experience is limited. As equipment increases in size, power, versatility, and durability, mining companies are reducing the number of units they need to purchase, thereby extending the development-cost recovery cycle.

REGULATORY AND STAKEHOLDER PRESSURES

During the course of the RAND discussions, federal health, safety, and environmental regulations were rarely cited as a major driver or inhibitor of technology innovation in mining. However, when specific regulatory issues were raised that have been under discussion at the federal level (concerning, for example, diesel emissions, air quality, ergonomics, and noise), industry representatives tended to argue along two lines: On the one hand, speakers often implied that potential regulations could be met as part of the normal technology development and diffusion process. New standards to reduce diesel emissions, for example, were not seen as a technology concern by any mining company or equipment supplier. Rather, it was argued, the diesel regulations somehow would be addressed by engine manufacturers. "We tell them what we need, they do all the work," said one mining-equipment representative.

On the other hand, discussants argued that application of existing regulations and prospective regulatory changes that are seen as impractical (proposed coal-dust and noise regulations were cast in this light on several occasions) simply would result in a halt to mining operations. Speaking of the lengthening environmental permit process for new mines, a coal-industry executive described the situation as "an effort to discontinue what we are doing entirely." In other words, industry representatives believe that such regulations have passed beyond the realm of technology solutions.

Complying with state and local regulatory efforts—concerning land-use permitting, for example—also was seen as impractical from a technology perspective. While stone and gravel producers currently enjoy strong demand for their products, they also face increasing demands to regulate hours of operation, noise, visual impacts, road use, and groundwater impacts, especially at interior (in-town) quarries. Yet there are few economically feasible technology solutions for complying with such regulations in real time. Reducing the footprint of a quarry by, for example, reducing on-hand product inventories and outsourcing support services was cited as a potential solution for some sites. In Montana and Colorado, ballot initiatives to ban the use of cyanide in gold production have been mounted (the Montana initiative was successful, the Colorado initiative was not). Several industry discussants pointed out that no economically feasible alternatives to cyanide are currently available, but three executives from technology supply firms did suggest that in the event of a ban, economic imperatives would drive a shift to alternative leaching agents.

The development of new mines and quarries in the United States has been constrained in recent years by a combination of factors: economic pressures, environmental and land-use regulations, and political constraints. As a result, technology innovation in U.S. mining is devoted largely to reengineering processes and facilities to boost productivity, increase recoverable reserves, and extend the life of existing facilities. One outcome is that some operations are mining much deeper than originally envisioned, resulting in greater technological demands being placed on logistics, utilities, and safety systems. Deeper operations combined with environmental and aesthetic concerns may motivate more open-pit mines and quarries to shift to underground operations in the future—what two representatives described as "pulling a cover over our head."[1]

> In the coming years, land-use restrictions are likely to result in a drop in the number of quarries in America. Operations that remain open will be located farther away from populated areas and will have a larger average size.
>
> *—Aggregates-industry representative*

The prevalence of mature mining operations in the United States tends to constrain innovation because of a hesitance to abandon legacy systems (e.g., existing machinery and mine layouts) and engage in costly reengineering exercises. In contrast, discussants often pointed to newer mines in South America, Africa, and Australia as being technology leaders in areas such as planning and automation.

Regulation rarely was cited as an inhibitor of innovation. However, on one occasion, a speaker observed that roof-support technologies were advancing quickly, but that the existing regulatory framework (i.e., the lack of guidelines for application of new technologies) has slowed their diffusion. And another executive noted regulators' reluctance to abandon stench gas in favor of newer hazard-warning technologies perceived to be more effective.

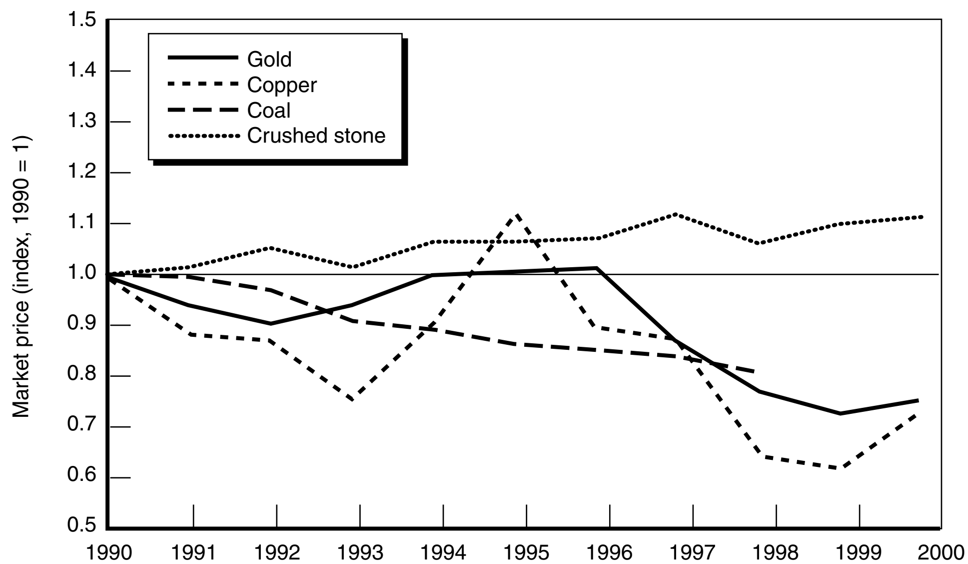
Rather than speaking about government mandates, discussants pointed to their voluntary initiatives. Corporate policies that place a primacy on health, safety, and environment have become widespread in the industry. Improvements in worker safety and health frequently were presented as a function of good management and the need to hire, retain, protect, and motivate both management and staff employees in a competitive and selective labor market. Similarly, innovations in environmental protection were portrayed as a function of proactive risk management, good public citizenship, and maintaining employee morale.

COMMODITIES MARKETS

Over the past several years, prices for many mineral commodities, including gold, copper, and coal, have been at or near long-term market lows, thereby

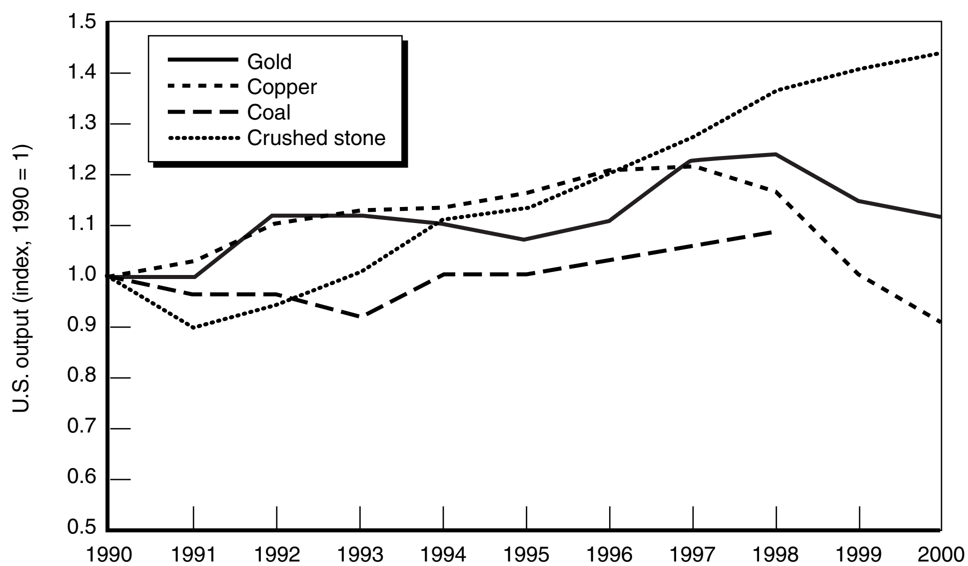
[1]There are about 5,300 stone and aggregates quarries in the United States. According to one source, the United States has about 100 underground quarries in operation, with another 25 in planning and development. A stone and aggregates producer with whom we spoke estimated that his company's underground operations may double, increasing from six to 12 by 2020.

shrinking margins across much of the industry (see Figure 2.2). This has caused mining activity for metals in particular to decline (see Figure 2.3).



SOURCE: U.S. Geological Survey, U.S. Bureau of Mines.

Figure 2.2—Market Prices for Copper, Gold, Coal, and Crushed Stone



SOURCE: U.S. Geological Survey, U.S. Bureau of Mines.

Figure 2.3—U.S. Output of Copper, Gold, Coal, and Crushed Stone

Interestingly, industry executives presented two strikingly different views of the technology implications of a difficult business environment. One set of executives argued that low market prices for their products and the resulting thin operating margins impair their ability to raise the capital (from both operating revenues and capital markets) needed to invest in new machinery and equipment and thus constrain innovation. Indeed, many coal and metals companies have been forced in the last few years to defer spending, idle and mothball operations, and restructure their enterprises—"in conservation mode," as described by a gold-company executive. A historically large number of distressed operations have been put up for sale. In this environment, executives are particularly wary of new and unproven technologies and technologies that may require major reengineering of mine operations.

> "The year of 1999 was a difficult year for [the company] due to the lowest gold prices of the last 20 years. . . . The focus of [the company's] activities during the year continued to be to reduce debt and operating and corporate costs, improve liquidity, and enhance and preserve the company's important gold assets."
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> *—Gold-company annual report*

> "Anticipating reduced near-term market demand, [the company] curtailed its capital investment plans in 1999 and expects to further reduce its capital spending in 2000. Current efforts are directed at optimizing production from existing mines with the lowest production costs."
>
> *—Coal-company annual report*

Another set of executives explicitly refuted this perspective, arguing that the prevailing harsh financial climate in metals and coal is motivating managers to make major changes in their operations in efforts to achieve significant productivity breakthroughs. A metals-company executive reported that his firm had "significantly changed the way we work" at its U.S. facilities by reengineering the facilities and bringing in new equipment such as jumbos[2] and remote-controlled vehicles. He added that these technology investments represented "a huge change" in the company's approach to mining. Several discussants argued that their decision to invest in new technologies in the current period was based on a strategic calculation that commodity prices might not rebound in the foreseeable future.

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[2]A jumbo is a drilling apparatus used for drift development in underground metal mines.

> "[The] ability to generate cash throughout the year, coupled with our strong balance sheet, enabled us to actively acquire aggregates companies and fund an aggressive capital investment and expansion program within our heritage businesses."
>
> —*Aggregates-company publication*

An important exception in the sector is the stone and gravel industry, which has been enjoying historically strong demand and growing revenue streams as a result of the record-long U.S. economic expansion and generous public-sector spending on infrastructure (see Figures 2.2 and 2.3). Many stone and gravel producers are using their cash to acquire weaker firms and invest in new technologies to quickly ramp up production and capitalize on a favorable market environment.[3]

RESEARCH AND DEVELOPMENT FUNDING AND ALLIANCES

According to industry executives, cuts in R&D by government and industry are likely to result in fewer fundamental or breakthrough technology innovations in the future.

Over the past three decades, many participants noted, mining concerns in the United States have scaled down or eliminated entirely their R&D operations—a function of trimmed profit margins and a broader business trend of focusing on "core competencies." This decrease is reflected in the low rankings of mining-related industries in a comparison of R&D expenditures across industry sectors (Figure 2.4). In addition, dramatic cutbacks in federal funding for industry since 1988 have reduced budgets for advanced R&D in both academia and the private sector.[4] As a result, almost all mining companies said that their mining-related R&D activities (if they reported having any) were largely confined to short-term and site-specific problem-solving. This has shifted the locus of technology research, development, and demonstration to technology providers.

As mining technologies become more complex and mining processes become more tightly integrated, the need for sustained, strategic alliances between equipment developers and mine operators is becoming more critical. Few organizations have the capability to combine metallurgy with machine design to

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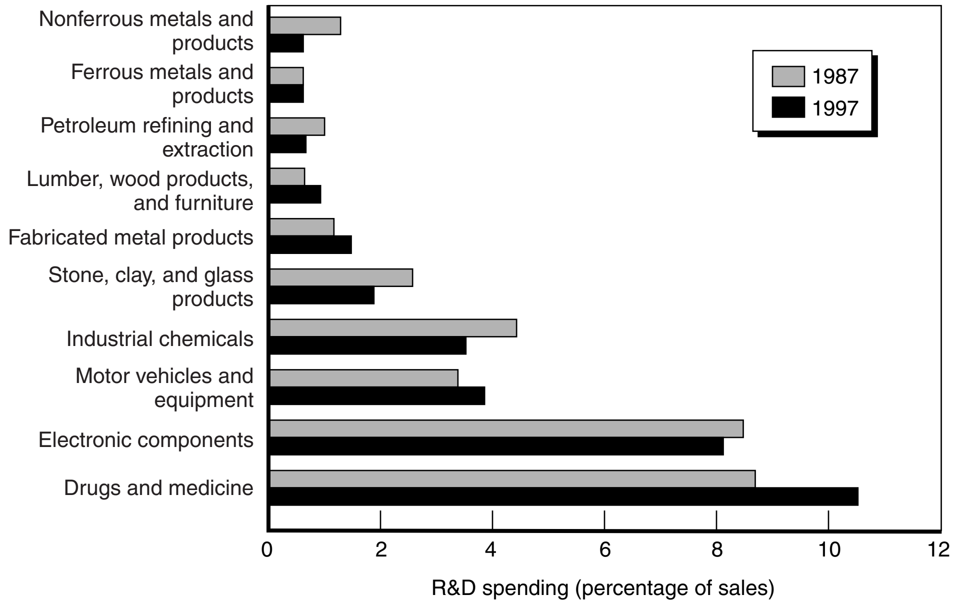
[3]Industry discussants suggested that the strong and steady market for most industrial minerals, such as aggregates, is likely to support continued technology investment in that industry as well.

[4]National Science Board, *Science and Engineering Indicators 2000*, NSB-00-1, National Science Foundation, 2000. The principal source of federal funding for mining technology R&D was the U.S. Bureau of Mines, which was abolished in the mid-1990s. The discussants, however, were divided on the practical technology implications of this act.



SOURCE: National Science Board, *Science and Engineering Indicators 2000*, Arlington, VA: National Science Foundation, 2000 (NSB-00-1).

Figure 2.4—U.S. Nonfederal Industrial R&D Spending as a Percentage of Sales

develop advanced rock-cutting technologies, one industry executive noted. Similarly, the development of automated equipment requires coordination and collaboration among producers of machinery, communications and GPS, sensors and imaging technologies, and control algorithms. But funding from both the private and public sectors to catalyze and sustain such partnerships has been very limited in recent years.

Some operating firms have begun to reconsider the trend away from investment in R&D by searching more widely for new technologies to apply and by expanding their in-house R&D activities. For some, the driver was the desire to achieve productivity breakthroughs in a difficult business climate.

- A stone and aggregates producer has convened an in-house “technologies task force” to conduct a systematic survey of other industries, as well as government laboratories, for technologies to apply to its quarry operations.
- Reconsidering its strategy dating back to the 1970s, a metals producer has rebuilt its R&D center over the past three years. The staff of 40 has undertaken more than 200 research initiatives—including more “far-out” speculative ventures in remote sensing and materials science.

Innovation often springs from insights gained through the technology buyer/supplier relationship. "You need everyone at the table to work things out," said one manager about the ideal innovation environment. Yet one technology developer characterized the current situation as a "stalemate." According to several discussants, many operating companies are not particularly interested in alliances, risk-sharing, and pilot-testing new technologies. Several mining company representatives stated that they wanted to use only those technologies that already were proven on a commercial basis. Said one supplier, "Not too many of them want to be first at anything." As if in response, another technology provider quipped, "We never send a new product out the door with 'Serial Number One' on it."

INDUSTRY CONSOLIDATION

In response to commodity-price pressures and the desire to achieve economies of scale, the mining industry is undergoing consolidation, among both operating firms and technology suppliers. Most participants expressed the expectation that this consolidation would continue or even accelerate over the next decade. Consolidation presently is having an especially strong impact on the profile of the stone and aggregates industry in the United States, which counts an estimated 5,000 operations and traditionally has been dominated by small-capitalization "mom-and-pop" organizations. Meanwhile, the coal and metals segments are continuing a trend of consolidation that has been under way for several decades.

Consolidation is likely to have an impact on facility size and age. As operating firms consolidate, the number of mines is likely to fall, and the average size of the remaining operations will increase. With fewer small and medium-size firms, the merits of developing smaller ore deposits and shorter-lived facilities (i.e., niche operations) will diminish.

Consolidation could, in theory, have a positive impact on the flow of new technologies in mining. Consolidation among technology suppliers should result in economies of scale in R&D (especially as mining equipment becomes more complex and costly) and should encourage greater technology integration, for example, of IT and unit-ops. Larger firms also tend to have greater financial resources and know-how to identify, evaluate, and acquire new technologies, and mergers and acquisitions offer important opportunities for units to share their best practices and technologies and bring operations up to an even level of technical proficiency.

> "A key benefit of unification is the opportunity it gives us to share, determine, and benchmark best management practice in every area of our business—from customer service to employee development and operating standards."
>
> —*Aggregates-company publication*

However, several technology developers expressed concern that consolidation could retard technology innovation, arguing that as mining companies grow in market share, they also gain in their ability to drive down equipment prices and to push more R&D costs back onto suppliers. In February 2000, 14 mining companies announced the creation of an internet-based mining exchange to centralize and streamline acquisitions. Several technology providers openly wondered if the move to an on-line machinery and equipment market would further erode suppliers' margins, preclude value-adding opportunities, and rend buyer-supplier relationships that have led to past technology innovation.

GLOBALIZATION

As the industry consolidates, mining companies and technology providers are becoming increasingly global. Economic liberalization and falling barriers to international trade also are encouraging firms to invest in East Asia, Africa, South America, Eastern Europe, and the former Soviet Union, and mines in these countries are now important customers for U.S.-based technology developers. Meanwhile, many foreign mining companies and equipment and service providers have invested heavily and acquired operations in the United States.

Executives with whom we talked had diverging opinions about how globalization will affect the mix and pace of technology innovation at mine and quarry units in America: Some implied that it had a neutral or restraining effect, but most argued that globalization tended to favor technology innovation and diffusion in the United States.

One major underground-mining-technology provider reported that the equipment his company provides to operations abroad often is one or two generations behind the latest technology. Representatives at a U.S.-based multinational mining company pointed out that logistical constraints often limit the ability to implement cutting-edge practices in remote and poorly serviced locations abroad. An aggregates-industry representative pointed out that while lessons learned from Western European practices have prompted higher standards for road-building materials in the United States (and hence the demand for improved crushing and screening technologies), U.S. quarry operations are, on average, more innovative, due to the higher demand for construction materials and greater competition within the local industry.

Most mining-company representatives argued that their operations abroad were at a level of technology application comparable to that of their units in the United States. They noted that key staff members are rotated throughout a global company, and they pointed to the cost advantages of standardization and groupwide purchasing across a firm's operations. However, three technology suppliers argued that groupwide sourcing can have a negative impact on technology innovation: By seeking a single supplier and common technologies for all of their operations, regardless of local conditions, operating companies can overlook technologies that may be more innovative.

Several argued that with limited R&D and few new mining developments in the United States, innovations from operations in countries such as Australia, Indonesia, Peru, and South Africa will play an increasingly important role in influencing the character and management of mine sites in the United States. For example, advanced mine modeling and design software developed and widely deployed in Australia is now being adopted in the United States. The first U.S. application of an automated ore-stacking technology developed by a U.S. company came only after several successful installations abroad.