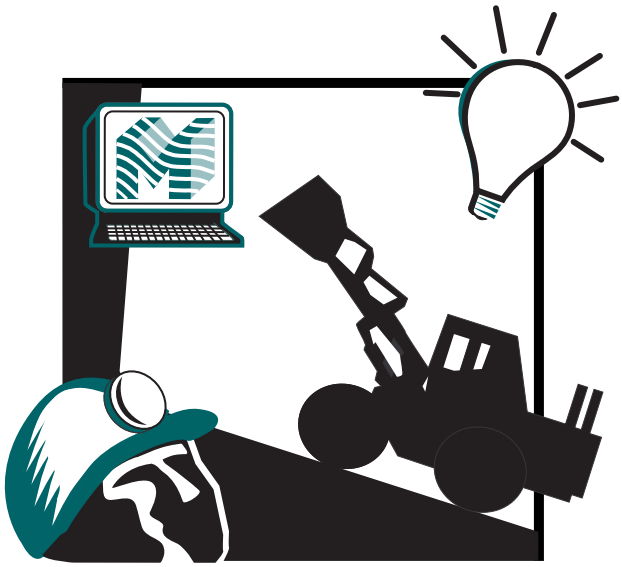
Mining Industry Roadmap for Crosscutting Technologies



Mining Industry of the Future

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Executive Summary

Defining the Vision

In September of 1998, the mining industry completed a document entitled, *"The Future Begins with Mining: A Vision of the Mining Industry of the Future"*. That document describes a positive and productive vision of the US mining industry in the year 2020 which rests on the achievement of the following goals.

- **Responsible Emission and By-product Management**: Minimize the impact from mining activities on the environment and the community by fully integrating environmental goals into production plans. Support the development of technologies to reduce carbon dioxide emissions to near zero and sequester additional emissions.
- **Safe and Efficient Extraction and Processing**: Use advanced technologies and training to improve the worker environment and reduce worker exposure to hazards that reduces lost time accidents and occupational diseases to near zero.
- **Superior Exploration and Resource Characterization**: Develop ways to find and define larger high grade reserves with minimal environmental disturbance.
- **Low Cost and Efficient Production**: Use advanced technologies to improve process efficiencies from exploration to final product.
- **Advanced Products**: Maintain and create new markets for mining products by producing clean, recyclable and efficiently transportable products and form cooperative alliances with the processing and manufacturing industries to jointly develop higher quality and more environmentally friendly products.
- **Positive Partnership with Government**: Work with government to reduce the time for resource development cycle by two-thirds. Achieve equitable treatment for mining compared to other industries that produce materials and energy relative to international competition by making the legal and regulatory framework rational and consistent.
- **Improved Communication and Education**: Attract the best and the brightest by making careers in the mining industry attractive and promising. Educate the public about the successes in the mining industry of the 21st century and remind them that everything begins with mining.

A consensus was reached that achieving these goals 'will inspire a committed investment community to fuel the cycle of increased capital investment vital to the success of the industry and to the future economic growth of the United States'. This document is a roadmap highlighting technology developments along the path from today toward this bright future.

Crosscutting Roadmap Development

Members of the National Mining Association Technology Committee, and other mining experts met during 1-2 October 1998 in Denver, Colorado, at a crosscutting technology roadmapping workshop. The attendees of this session are listed in the appendix. Knowledgeable representatives from mining companies, suppliers, academia, and government came together to craft a roadmap document. These individuals worked together to identify barriers and technology options, specify technical requirements, set priorities, and establish research pathways in three distinctive areas:

- **Exploration and resource characterization** is defined as those activities that included finding and defining a reserve.
- **Mining** includes all activities, techniques, and methods to extract a non-fuel mineral or coal.
- **Mineral processing** is defined as those activities, techniques, and methods of providing a raw material or by-product, up to and including beneficiation.

The roadmap is called crosscutting because the topics, barriers, targets, and priorities apply to all minerals and to all aspects of exploration, mining, and processing technologies. A list of the highest priority research needs identified in each of the three major areas of this document – exploration, mining, and processing – are provided in the next three sections of the roadmap. The research priorities outlined here will be used as the basis for making new research investments by government and industry. However, the roadmap is a dynamic document, and will be re-evaluated at regular intervals to incorporate new market and technical information and to ensure the research priorities remain relevant to the industry.

1. INTRODUCTION

Directions in the Mining Industry

Modern mining is a highly sophisticated industry. The use of advanced technologies, including automation, satellite communications, smart sensors, and robotics is widespread. Computers and microprocessors are responsible for making big machines efficient and reliable, and for assisting exploration, mine operations, and mineral processing adapt to new competitive environments in a safe and environmentally sound manner. For example, remote control of hauling equipment and the use of autonomous mobile transportation equipment is increasing worker safety as well as reducing industry costs.

Advances in mine exploration, extraction and processing technology is creating new markets for metals and industrial minerals. The consumption of zinc is now increasing, after years of decline, because its use as an anti-corrosive coating for metals has grown. Copper, with its high degree of conductivity and relatively low cost, has an opportunity to expand its markets. High efficiency motors, for example, contain larger volumes of copper. Copper is also becoming the metal of choice for high performance integrated circuits. Gold's corrosion resistance and high conductivity make it an essential component in the growing market for sensitive electronics and other advanced products. There will be an increase in the demand for lead as battery driven vehicles penetrate the transportation market.

As demand for such commodities increase, so will the need to mine and process them at competitive costs. This means continually finding better methods, technologies, and processes to maintain and improve safety and environmentally sound conditions while permitting the production of lower cost mineral commodities.

The vitality of our nation depends on cost effective access to, and development of, key mineral resources. In the course of a lifetime, each American will use 3.5 million pounds of minerals, metals, and fuels. Every year, 46,000 pounds of new minerals including 7,500 pounds of coal energy must be provided for every person in the US to maintain our standard of living. Low cost coal and uranium are used to generate over three-quarters of the nation's electricity supply, helping to keep US electricity costs among the lowest in the world and thereby enhancing the competitiveness of US industry. The contribution the mining industry has made to the economic health, well-being, and security of our nation, throughout our history, is unquestioned.

The United States leads the world in developing and employing highly efficient and advanced environmental technologies to supply the world with non-fuel minerals and coal. Of the 2,500 known minerals, coal and 74 non-fuel minerals and materials are explored, mined and processed in the US. All of our 50 states produce non-fuel minerals and/or coal. Our abundance of mineral resources has served the US well.

The US mining industry continues to serve the needs of all other domestic industries. As stated by the National Mining Association, "Everything begins with mining." Today, the minerals industry alone is a $39.5 billion industry. Total mine production for coal is estimated to be valued at about a $19.9 billion, for metals about $12.4 billion, and for industrial minerals about $27.1 billion. Also, there is an estimated $2.1 billion of processing equipment developed and shipped annually to support mining operations.

The mining industry is a major employer in the US. Many times a company is the main employer in a locality. It is estimated over 355,000 people work directly in the mining industry and about 5 million people are employed in other industries that support the mining industry. Wages on average are about $45,000 per year, among the highest paid for any US industry.

However, the strength and contribution mining will make to the US over time is dependent on its ability to be lower cost and efficient. The value of mined products is highly competitive with other sources of mined materials. The minerals commodity market not only competes with other domestic suppliers but also with suppliers from the international market. Competition in mining is keen in terms of cost-effective exploration, mining and processing of mineral products. For example, exploration investments in Canada, Australia, the US, and Africa were about 78% of the world's total investment in mining in 1991. Investment in exploration in these countries dropped to 53% of total, while investment in Latin America increased to 29% and that in the Pacific countries grew to 11% of total by 1996. In addition, the United States imports more than half of its needs of 22 vital minerals, such as chromium, tantalum, cobalt, tin, tungsten, bauxite and manganese.

Keystones

The industry's ability to be the lower cost and most efficient producers of mined products in the future will depend on its continued responsiveness to its three keystones – environment, health and safety, and energy efficiency.

Environment. The environment is a keystone of the technological progress the mining industry has enjoyed. For example, coal mining operations have reclaimed in excess of 2 million acres over the past 20 years, and this number continues to improve for mining in the US. The handling and disposal of waste and products containing metals, long range transport of air pollutants, and agreements addressing other environmental concerns presage an increasing global approach to environmental concerns and issues. The mining industry is responding to climate change strategies through advanced research and testing, including: improvements in energy efficiency, methane emission control, reduction of carbon use, and carbon dioxide sequestration. The aggressive program set forth by the industry calls for greater energy efficiency in mining operation and in the processing and use of mined products, thereby reducing the impacts of acid mine drainage and metal tailings affecting land, air, and water. Industry initiatives have made the US mining industry the leader in environmental performance throughout the world.

Safety and Health. An equally important keystone to the success of the mining industry is its constant vigilance to improve safety and health in the mining workplace. Mining has one of the best industry records in protecting its employees. The mining environment can be harsh; exposure to radon, uranium, coal dust, and other types of rays, dust, and chemicals can be harmful to humans in those environments. Also, the equipment used to explore, mine, and process minerals is powerful and can be dangerous when used improperly. Training and education are constantly emphasized across the industry, and new types of equipment for ventilation and protection are being developed to keep miners healthy and safe. Improved personal equipment and safety technology used by miners, new sensors and controls, and new miner training programs are essential to the well being of the miner of today and tomorrow.

Energy. The US mining industry consumes about 1 to 2 quadrillions BTUs annually. The Energy Information Agency indicates the mining industry consumes 3.2% of the total energy used by all industries. Energy costs are an important component to the mining industry; it has been estimated to be about 5% of the value of all commodities produced. Significant efficiency gains could be obtained by improving exploration techniques, drilling, ventilation, excavation, and extraction technologies and in beneficiation, grinding, crushing, milling, rolling, and smelting processes. The goal to consume less energy per ton of ore mined and processed remains a key objective of the mining industry.

This roadmap addresses each of the keystones identified above and should serve as a reference for the research needs and opportunities available to the mining industry. By addressing these research priorities, the industry intends to achieve the vision put forth in the document *The Future Begins with Mining*.

Roadmap to the Future

Leaders in the United States mining industry recognize both the opportunities and challenges they face as they head into the 21st century. They also recognize that to achieve success in competitive global markets will require new business strategies that align technology investments across industry and government. To ensure continued competitiveness in future markets, the industry has developed a research plan encompassing metallic minerals, nonmetallic minerals, and coal mining.

This research plan, known as a 'Crosscutting Technology Roadmap', is part of the "Industries of the Future" program developed by the US Department of Energy's Office of Industrial Technologies and carried out in partnership with the National Mining Association. The first step in this program was completed in September 1998 with the publication of *The Future Begins With Mining*, a unified vision of a prosperous mining industry in the year 2020. The industry defined performance targets in the areas of exploration and characterization, extraction, processing, utilization, and environmental, safety, and health performance based on the major challenges identified by industry leaders in the vision. This crosscutting technology roadmap will specify the research accomplishments necessary to meet the targets and achieve that vision. It is anticipated that additional roadmaps will be developed to address issues specific to mining, processing, and other elements vital to the industry's future.

The ultimate value of this crosscutting technology roadmap is its ability to align research across industry, academia, the states, and the federal sectors. By articulating and charting its own technology strategy, the US mining industry hopes to motivate companies, the academic community, state governments, and the federal laboratories to focus their research efforts to meet the mining industry's goals from the vision and achieve the future, as foreseen by the industry, in 2020.

2. EXPLORATION AND RESOURCE CHARACTERIZATION

The goal of the mining industry's exploration and resource characterization activities for the next twenty years and beyond is to develop ways to find and define reserves with minimal environmental disturbance. This goal includes the following technical activities:

- **Reduce the environmental impact of exploration and resource characterization** — Methods for achieving this include developing non-invasive techniques, reducing the impact of invasive techniques, and expanding the amount of knowledge obtained from an ore body with less environmental impact. Remote sensing technology to find and define resources is also needed. At a minimum, a reduction in the number of boreholes to define proven reserves is desired.
- **Reduce the costs of exploration and resource characterization** — The industry would like to reduce uncertainty of success of exploration ventures. *In situ* and real-time resource defining technologies are needed as are new techniques to define, mine, and blend at the mining and extraction point.
- **Increase the value of run-of-mine products** — The industry must increase knowledge of resources in order to mine and process them more effectively.
- **Increase exploration efforts** — Desired outcomes include finding more economic deposits and doubling the current rate of successful exploration. Techniques are also needed to explore previously unexplored regions, to ultimately include non-conventional resources such as those found in oceans and space.

The major barriers to achieving these performance targets are shown in Exhibit 2-1. These activities have been organized into the following categories:

- Remote sensing technology
- Imaging technology
- Environment and safety

Remote Sensing Technology was identified as the category of barriers considered by the industry as the most critical to achieving the targets. As shown in the chart, a key barrier is the lack of non-invasive technologies to quantify metal/mineral value *in situ*. Exhibit 2-2 presents the research and development activities the industry feels are needed to overcome the barriers.

The mining industry feels strongly that the successful demonstration of several new technologies in the near term would provide a strong incentive for companies to continue supporting cooperative 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 listed in Exhibit 2-3.

Highest Priority Research Needs

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 and are presented in Exhibit 2-4. All of the proposed R&D activities address nearly all of the performance targets to one degree or another.

Exhibit 2-1. Barriers to Improved Exploration and Resource Characterization[1]

Remote Sensing Technology	Imaging Technology	Environment & Safety
Lack of non-invasive technologies to quantify metal/mineral value *in situ* Current remote sensing techniques don't work well underneath forest canopy Lack of navigation and guidance sensors for underground machines Unable to analyze special elements at ppm levels by remote techniques Unable to make prediction of cost without physical samples Lack of deep-penetration remote sensing Lack of understanding of limitations (and benefits) of geophysical methods No verified models of remote sensing data	Lack of high-resolution imaging while drilling Lack of real-time sensing technology for mineral content Lack of high-resolution, 3-dimensional tomography imaging between well bores Lack of methods to measure metal/mineral values between drill holes Lack of modeling techniques for dispersed ore bodies Lack of understanding of the time resolution barrier in geophysics Lack of methods to interpolate metal values between drill holes	Expensive environmental regulations and standards Size, weight, and cost of machinery used on exploration Lack of knowledge regarding safety issues for exploration and mining of extreme environments

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

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. There is a lack of demonstration of these technologies for mining or miner-related applications to date. The successful adaptation of these technologies to exploration and mining processes 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 processes. Key barriers include the lack of sufficiently sophisticated and robust sensor technology, the time associated with receiving federal certification and the lack of demonstration sites where technology testing will not interfere with actual 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. The environmental impact could be reduced, as well as costs.

New and improved sensors could improve geochemical techniques to evaluate targets in covered areas. They could also be applied to develop techniques to combine the penetration of

radar with the discrimination of reflectance. Another possibility is the enhancement of deep penetration remote sensing- 3-D seismic surveys.

Exhibit 2-2. R&D Needed in Exploration and Resource Characterization[1]

Remote Sensing Technology	Imaging Technology	Navigation and Controls
Develop real-time mineral content sensor for all minerals Conduct research and development to improve the accuracy of deep (>1000' beneath the surface) sensing of rocks, minerals, elements and structures Develop horizon sensing and interface detection on exposed material Develop projectiles that can be shot into the ground and can transmit geologic information Develop ways to sense and interpolate non-intrusive geological modeling of underground ore bodies Develop a better understanding of the physics of remote technology Conduct research to predict the process response of ore via remote sensing characterization of that ore Develop better laser analytical technologies, and use improved modeling to increase sensor accuracy Develop new sensors operating from space, high altitudes, low altitudes, above ground, and below ground sensors Develop rugged hand-held laser technologies for on-the-spot chemical analysis Develop sensors for effective underwater exploration Develop sensors that can relate geological information	Develop ways to sense, visualize, interpolate, model, and predict geological anomalies in front of mining equipment Develop superconducting quantum interference devices (SQUIDs) for imaging Combine methane draining and imaging Develop more analytical tools to facilitate accurate interpretation Develop cross-well instrumentation Develop geophysical resolution modeling to enable enhanced mine modeling and mine planning software Develop borehole radar for measurement while drilling	Develop sensors for guidance and navigation of semi-autonomous machines Develop non-geodetic referenced positioning technology Develop remote control and autonomous exploration device for extreme environments

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

Exhibit 2-3. Exploration and Resource Characterization Technology Needs

Advanced Technologies

- Develop advanced real-time mineral content sensors
- Improve ways to sense, visualize, interpolate, model, and predict geologic anomalies
- Develop advanced imaging technology
- Improve sensors for semi-autonomous machines for guidance and navigation
- Develop better laser analytical technologies

Information Management

- Develop an on-line database for environmental best practices
- Evaluate existing satellite technology for potential use in mining exploration
- Evaluate existing ground-based diagnostic techniques for their potential use in exploration
- Develop modeling / visualization software to demonstrate the benefits of geophysical R&D
- Prepare a cost/benefit study for exploration efforts across the mining industry

Improving the accuracy of deep sensing of rocks, minerals, elements, and structures is similar to both the 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 levels 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 this 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 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.

Exhibit 2-4. Exploration and Resource Characterization R&D Priorities

R&D Priorities	Targets Addressed	Key Barriers
Evaluate existing ground-based diagnostic techniques for their potential use in mining and exploration	- Reduce environmental impact - Reduce costs - Increase exploration	- Lack of test/demo site - Lack of a good technology assessment
Develop sensors for semi-autonomous machines - guidance and navigation	- Reduce environmental impact - Reduce costs - Increase exploration	- Current state of sensor technology & harsh environ. - Safety requirements
Improve the accuracy of deep (1000' beneath the surface) sensing of rocks, minerals, elements, and structures	- Reduce environmental impact - Reduce costs - Increase exploration	- Lack of demo site - Current state of technology - Education
Develop real time mineral content sensors for application on remote semi-autonomous machines	- Reduce environmental impact - Reduce costs - Increase value of run-of-mine products	- Lack of robust technology - Low detection levels needed - Hostile environs
Develop projectiles to send underground to transmit information	- Reduce environmental impact - Reduce costs - Increase exploration	- Sensing technology at high speeds - Sensor robustness
Develop ways to sense, visualize, interpolate, model, and predict geologic anomalies in front of mining equipment	- Reduce environmental impact - Reduce costs - Increase exploration	- Current state of technology - Hostile environs - Safety requirements
Evaluate existing satellite technology for use in exploration	- Reduce environmental impact - Reduce costs - Increase exploration	- Lack of a good technology assessment
Develop horizon sensing and interface detection on exposed material	- Reduce environmental impact - Reduce costs - Increase exploration	- Current state of technology - Hostile environs - Safety requirements

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 interface detection on exposed material and ways to sense and predict geologic anomalies in front of mining equipment. Horizon sensing involves very close-by sensing, which is a different objective than imaging geologic features in the unmined 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.

3. SAFE AND EFFICIENT MINING

Efficient and safe mining refers to the processes and technologies involved in the primary extraction of mineral materials from the earth. The performance targets for efficient and safe mining identified are shown in Exhibit 3-1.

Exhibit 3-1. Performance Targets for Safe & Efficient Mining

Target	Unit of Measure	Revised Target/Comments
Use of technology to increase output expressed as tons per employee hour by 100%	Productivity, e.g., tons or ounces per employee hour	100% by 2010 Should be able to improve further by 2020
Increase the output efficiency of capital by one-third	Return on assets (ROA)	33% improvement over today's ROA of about 5% to 7%
Increase energy and other consumable efficiencies per unit of output by 50%	Energy consumed per ton of ore	50% acceptable, but ambitious
Reduce operational downtime to near zero	Scheduled downtime Unscheduled downtime	Reduce by 50% Near zero
Reduce discharge of solid, liquid or gaseous emissions and waste to near zero	Volume/ton	Near zero acceptable, but ambitious
Use advanced technologies and training to improve the worker environment and reduce worker exposure to hazards and reduce recordable accidents and occupational diseases by 50%	Number of accidents Work-related illnesses	Zero Zero
Reduce permitting times and re-source development to one-half of today's average in the next 10 years	Number of years/months to receive permits	2 years by 2010 1 year maximum
Fully integrate environmental goals into development and production plans to minimize impact from mining activities on the environment	N/A	N/A

As shown in Exhibit 3-2, a number of barriers stand in the way of achieving these performance targets. As a category, shortcomings in geological assessment and mine planning capabilities present the biggest barriers to more efficient mining operations. The most critical individual barriers to achieving the performance include:

- The presence of more difficult mining conditions in the future, including deeper mines, thinner seams, smaller veins, or lower grade ores
- Lack of ability to detect and assess more difficult mining conditions and incorporate this information into mine planning and operations in order to avoid problems
- Lack of reliable, robust sensors for characterizing minerals and geological structures as well as detecting gas, dust, and noise; for assessing minerals; for determining positioning and rock structure; for determining machinery position and orientation; and for evaluating rock structure and other geologic conditions

Exhibit 3-2. Barriers to Safe & Efficient Mining[1]

Mining Process/ Equipment	Geology/Mine Planning	Environmental & Health	Sensors/ Information Management
Lack of ability to handle difficult mining conditions (i.e., deeper mines, thinner seams, smaller veins) Limits to cutting technology Size and complexity of machinery Limited durability of system components Lack of good predictive tools and diagnostics Lack of reliability in continuous miner continuous haulage systems Inefficient roof and slope stabilization Lack of cost-effective fuel source options (i.e., fuel cells) Lack of improved materials for liners Lack of technology to recover resource without moving material Low thermal efficiencies of equipment	Lack of ability to detect difficult mining conditions Lack of visualization tools to minimize waste Lack of ability to precisely characterize ore bodies	Lack of economic methods for handling some solid waste Lack of data on health effects of mining Lack of good ways to control water infiltration Need to capture fugitive emissions	Lack of sensing devices for gas detection, dust detection, noise detection, minerals positioning, rocks Insufficient reliability in positioning / robotics / communications Lack of real-time portable data gathering instruments Lack of real-time information and communications for personnel

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

Exhibit 3-3 shows the research needs identified by industry as critical to overcoming the barriers to safe and efficient mining, organized into five categories:

- Mining Equipment
- Mining Process
- Sensors
- Mine Planning
- Health and Safety

The research needs for mining have been identified and prioritized as shown in Exhibit 3-3, where they are further divided by the time frames estimated for commercial use (i.e., the time from the beginning of a successful research program to the first commercial application of the research results). Near (0-3 years), mid (3-10 years), and long-term (more than 10 years) research activities are identified, along with several ongoing research needs that will yield commercially applicable results in all three time periods. The next section discusses the top-priority research needs in more detail.

Exhibit 3-3. R&D Needed in Safe & Efficient Mining[1]

Time Frame	Mining Equipment	Mining Process	Sensors	Mining Planning	Health & Safety
NEAR (0-3 Years)	Develop method for high-pressure water extraction Improve prognostic capability of equipment Research and catalog material wear properties Develop equipment to traverse steeper slopes	Develop communications system for surface-underground and surface-surface communication	Develop ways to monitor entire mining, environ-ment (workers, equipment, communi-cation, systems)	Develop method for using bore drilling information to predict what lies ahead Adapt what has been developed for other industries to mining	Develop comfortable, integrated, cost-effective safety equipment to protect respiration, ears, and eyes Develop advanced simulation / virtual reality systems
MID (3-10 Years)	Develop autonomous mining equipment Develop more efficient alternative power supplies for equipment	Improve roof control to handle difficult mining conditions Understand and control solution migration underground Develop blasting techniques that mini-mize noise, dust, and flying rock Reprocess mine waste to recover saleable by-products Better understand processes that lead to emissions Transfer oil recovery techniques to *in situ* mining	Develop rugged sensors that can work in small, hot environ-ments	Develop system to integrate geologic data into models	Develop ergonomic robotics Develop warning systems for catastrophic failures

Time Frame	Mining Equipment	Mining Process	Sensors	Mining Planning	Health & Safety
LONG (>10 Years)	Develop "miniature" technologies for mining thin seams or small veins	Reliably model and predict impacts of emissions Develop more efficient *in situ* extraction and near-face beneficiation Develop alternatives for material transportation	Develop geological sensing devices to monitor and evaluate material ahead of the working face		
ONGOING	Develop new mobile equipment fuels and fuel strategies			Develop a better under-standing of rock mechanics	Develop lighter weight materials and supplies for worker safety

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

Highest Priority Research Needs

The top research needs in efficient and safe mining are listed in Exhibit 3-4 in order of priority. The targets and barriers they each address are also listed. Highlights from the discussion of each research need are presented below.

The top-ranked research need is to develop autonomous mining equipment that out-performs existing technology so that portions of the mining process can be fully automated. This research could yield research results in the 3 to 10-year time frame, and would primarily support the mining industry's performance targets for worker health and safety and for productivity. The biggest impacts would be on safety because fully automated equipment could obviate the need for placing workers in difficult mining conditions. While the equipment may cost more to buy, lower operating costs, reduced downtime, and improved productivity/capabilities could yield a better overall return on assets. This research would chiefly address workforce barriers. Cost sharing for this research could be provided by equipment suppliers with support from individual mining companies.

More efficient technologies for removing rock and coal involves developing 'exotic' mining techniques that utilize very different ways of cutting, drilling, or moving rock in mining, as opposed to incremental improvements to existing technologies. This research would produce 'next generation' rock removal technologies that could help achieve the performance targets related to mine output/productivity and energy and materials efficiency. It would help to overcome barriers associated with handling the difficult mining conditions anticipated in the future, and could also reduce barriers related to operating large, complex, and capital-intensive equipment.

Depending on the actual technology developed, the benefits of this research activity could be substantial and wide-ranging. New rock removal technologies have the potential to greatly improve ore removal in thin seams with corresponding reductions in operating costs. These technologies with improved designs could have positive impacts on worker health and safety and environmental performance. This research is envisioned as an ongoing effort with incremental improvements occurring in the near-term and the development of new technologies occurring over the longer term.

An 'Advanced Reserve System' for mining would be a network-based system integrating geologic and real-time data into mine planning along with three-dimensional models for simulation and control of mining operations. This research could build on similar programs, such as those developed in part by national laboratories for active modeling and control of petroleum reserves. With improved mine planning and modeling capabilities, mining companies could develop more detailed data for use in permits, greatly reducing permitting times. The ability to integrate environmental goals into mine planning could also be improved, with corresponding positive impacts on environmental performance.

More efficient *in situ* extraction and near-face beneficiation refers to mining techniques that enable the material of value to be brought to the surface without the usual burden of large amounts of unusable material. For example, selective mining could be used to beneficiate near the face, so that only the final product is brought to the surface. This research may involve re-opening investigations of potentially promising techniques as *in situ* coal gasification, solution mining and other types of chemical mining. This research could have very positive impacts on all aspects of mine operations. Partnerships among government, the mining industry, and suppliers would be needed to fund this long-term, high risk research area.

Integrated safety equipment for respiration, ear and eye protection is needed to improve worker health and safety and reduce costs. The improved safety equipment might be a single unit that is comfortable to wear, cost-effective, and provides the worker with complete respiratory, noise, and eye protection. Ideally, the unit would also incorporate communications equipment for underground and underground-to-surface communications. There may be opportunities to adapt technology developed for other applications, such as military or space operations.

The development of improved prognostic capability by machine to measure the on-line 'health' of machines could enable mining equipment to diagnose a problem before it occurs. This capability could help reduce unscheduled downtime, improve capital efficiency, lower production costs, and improve productivity. Better machine prognostication could also result in fewer machine-related accidents and reduced exposure to hazardous situations, with positive impacts on worker health and safety. This research could produce results in the near-term with funding support from equipment suppliers, industry, and government partners.

Improved ground control techniques to handle difficult surface and underground mining environments may include underground roof support systems, ground control systems, slope stabilization methods, and other techniques to enable the mine of the future to deal with difficult mining conditions in inferior, less desirable mine sites. Research on rock mechanics and means to assess changing geologic conditions or determine ground stability would feed into this mid-term research effort. The primary performance targets addressed by this research are worker health and safety and reduced downtime, with secondary impacts on energy and materials efficiency and the environment.

Exhibit 3-4. Safe and Efficient Mining R&D Priorities[1]

R & D Priorities	Targets Addressed	Key Barriers Addressed
Develop autonomous mining equipment	- Productivity - Worker Health & Safety - Capital Efficiency	- Workforce skills
Develop geological sensing device to measure what is ahead of the working face	- Downtime - Productivity - Capital Efficiency - Environmental - Worker Health & Safety - Downtime - Energy/Material Efficiency	- Inability to detect difficult mining conditions - Lack of visualization tools - Inability to precisely characterize ore bodies
Develop more efficient technologies for removing fuel and non-fuel minerals	- Productivity - Energy/ Material Efficiency - Capital Efficiency - Worker Health & Safety	- Inability to handle difficult mining conditions - Large, complex machinery - Lack of capital
Develop "Advanced Reserve System" for mining to integrate geological data into models	- Permitting Time - Environmental Impact - Worker Health & Safety - Energy/ Material Efficiency - Productivity - Capital Efficiency	- Lack of real-time portable data-gathering and information for miners - Unreliable positioning, robotics, communication
Develop technology for more efficient *in situ* extraction and near-face beneficiation	- Energy/ Material Efficiency - Productivity - Environmental Emissions & Impact - Worker Health & Safety	- Must move material to recover resource - No tools for visualization - Inability to precisely characterize ore bodies
Develop improved prognostic capability by machine to measure the on-line "health" of machines	- Downtime - Capital Efficiency - Productivity - Worker Health & Safety - Environmental Emissions	- Lack of real-time portable data gathering and information for personnel - Lack of sensing devices
Develop improved ground control techniques to handle difficult mining environments for surface and underground	- Worker Health & Safety - Environmental Emissions - Environmental Impact - Energy/ Materials Efficiency	- Ground control - Inability to detect difficult mining conditions - Lack of sensing devices
Develop more efficient alternative power supplies	- Worker Health & Safety - Environmental Emissions - Energy/ Materials Efficiency - Downtime - Productivity	- Lack of cost-effective fuel source alternatives - Limitation in thermal efficiencies of equipment
Integrate safety equipment for respiration, ear and eye protection	- Worker Health & Safety	- Lack of safety gear for to fully reduce harmful health effects.

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

The development of an integrated information system for mine-wide information transfer and communication would better enable a machine and/or person underground to receive all the information needed to make real-time adjustments to mining operations as well as transmit

information about mine conditions to others. Improved technology can achieve complete communication capabilities between man and machines in above- and below-ground locations.

Such a system would better incorporate monitors, sensors, communication, information management, and feedback control devices. The potential benefits in terms of worker health and safety and reduction of unscheduled downtime could be significant. It could also improve mining efficiency, by allowing sequenced equipment start-ups and shut downs, enhance real-time communication and improve overall management and planning. In the near-term, it is anticipated that a funding partnership between suppliers and government could produce an improved wireless communications system for real-time communications among mine workers. Development of a more sophisticated information management system would likely require a longer-term research effort.

More efficient alternative power supplies for use in equipment refers to the development of lower-emission and more energy-efficient alternative power supplies for mining equipment. Alternatives to diesel technologies that produce fewer air emissions and less noise, while consuming less energy and posing no other environmental hazards, would contribute greatly to industry targets for worker health and for safety and environmental emissions. There is some question, however, about whether alternative power supply technologies will be able to satisfy all these goals at the same time. For example, current fuel cell technology is not especially energy efficient. A key focus of this research initiative would be to develop technologies that are cost-effective, while also meeting goals for reduced emissions, reduced noise, and improved energy efficiency. A funding partnership between equipment suppliers and government could potentially produce a commercially applicable technology in the 3 to 10-year time frame.

4. SAFE AND EFFICIENT PROCESSING

The performance targets for safe and efficient processing include: increasing the efficiency of using energy, consumables, and capital resources; reducing discharges of effluents and wastes; increasing product value; reducing downtime; and improving safety, health and environmental performance.

The barriers facing the mining industry as it strives to achieve these targets are listed in Exhibit 4-1. The industry considers the most critical category of technological barriers to be Processing Equipment and Practices. In addition to the barriers specific to processing, there are issues that cross over into other areas of the mining system. Processing can only be truly optimized when exploration/characterization and mining are also optimized for integrated system performance.

The research and development that will be needed to achieve the performance targets (shown in Exhibit 4-2) has been categorized as follows:

- Materials
- Comminution
- Modeling
- New processing techniques
- Transportation and handling
- Measurement, sensing, and analysis
- Mining
- By-product utilization

Highest Priority R&D Needs

The highest-priority processing research needs are shown in Exhibit 4-3, together with the performance targets they address and the key barriers that must be overcome for them to successful.

New materials for wear, construction, and process application are needed to minimize operational downtime and to improve energy utilization as well as the use of other consumables. It is possible that the need for these materials may be met using advanced materials developed by other industries. The energy, safety, and cost benefits resulting from the use of new materials for wear and construction could be moderate to high.

Two of the highest priority R&D needs — new materials for phase separation and improved separation and cleaning technologies, including dewatering, water treatment, and by-product management and utilization — address the performance target of improved separation efficiency. Advances in mineral processing technology have leveled-off, making radical technological breakthroughs necessary for significant advances. These two proposed R&D activities also contribute to the goal of improved by-product management and utilization, specifically through the reduction of effluents and waste. A positive environmental impact is expected because separation and cleaning processes are normally used for environmental remediation, and could result in more usable materials from waste. Although the development of breakthrough separation and cleaning technologies could lead to major cost savings, continuous incremental improvements may have only moderate cost-savings potential.

Exhibit 4-1 Barriers to Safe and Efficient Processing[1]

By-product Utilization	Feedstock	Processing Equipment and Practices	Information Gathering, Exchange, and Use	Safety	Environment
Need more and better ways to utilize "waste" Not enough by-product processing locations Lack of effective dewatering techniques	Cannot detect or respond to variable feedstock Poor under-standing of mine face fragmen-tation Need improved knowledge to examine *in situ* mining Poor selectivity in raw mineral extraction	Low energy efficiency of size-reduction technologies Lack of adequate use of information technology to allow integration of unit processes Need to process significantly lower-grade and smaller amounts of material Can't make significant reduction in size of equipment Ineffective models to integrate mining, processing, and usage Inefficient equipment for some separations Inadequate models for pyro- and hydro-metallurgical separations Need to reduce existing bottlenecks within the process Poor process variable detection available Lack of online monitoring technologies Current equipment and materials are not as well-developed as in other indus-tries Need better understanding of hydrodynamics of mineral/ water suspension Inability to make final products at the mine site	Inadequate sharing of ideas and information among mining companies, equipment suppliers, and research community Availability of data-bases and data mining capability is limited	Must consider safety explicitly for process and equipment design	Need better models for environmental improvement Detecting parameters for environmental protection is difficult Lack of detection technologies

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

Exhibit 4-2. R&D Needed in Safe & Efficient Processing[1]

	Comminution	Modeling	New Processing Technologies	Transportation and Handling	Measurement and Sensing Analysis	By-product Utilization
Research new materials for wear resistance Develop ways to use cost-effective light weight materials Develop repairable hard facings Research and develop a compre-hensibly accepted biodegradable hydraulic fluid Develop new nondestructive testing techniques	Develop comminution schemes that take advantage of natural weakness in rock Develop new ways to deliver impact energy to ores Correlate materials response to drilling and blasting with its response to comminution Develop technology to break rock in tension rather than in compression Improve grinding technology	Develop intelligent self-building process models Develop models of fracture and wear surfaces of minerals	Conduct research on mineral and solution properties, and behavior of fine particles in solution Develop new techniques for cleaning minerals, particularly with regard to hazardous materials Develop improved technology for separations, dewatering Further develop air-sparged hydrocyclones Characterize and minimize cost of environmental requirements in mineral processing Improve cooling methods Develop bioextraction technologies Investigate the performance of electric charge in static screen separators	Develop better forms of transportation Conduct research into reducing transportation cost, including transporting less unusable products, drying and packaging of products after processing Develop efficient power management methods	Improve sensors for process stream characterization and control Improve use of spectroscopes to quantify species in a stream Improve real-time analytical techniques for material analysis Need improved fault detection mechanism for pipe and sheet liners Develop a device to detect carbonatious activity Implement NDT initiatives Develop inexpensive tracers to identify mined product	Develop alternative technologies for processing by-products Develop alternative uses for products and hydro-products Conduct research on waste characterization for by-product use

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

The development of improved comminution technologies, including modeling of fracture and wear surfaces, also addresses the goals of improved separation efficiency and reduction of effluents and waste. In some instances, the mineral processor may want to perform crushing and grinding operations as soon after the process as possible. Alternatively, excessive mineral breakage can lead to dust and handling problems with current comminution processes. These include poor energy efficiency and a lack of understanding of the physics of rock fracture. Improved comminution technologies have a high potential for improving energy efficiency, which could also lead to significant cost benefits as well as reduced environmental impacts.

The goal of improving the capital productivity of mining operations is addressed by the development of improved sensors for process stream characterization and control and the development of self-building, intelligent process models. Moreover, the use of these sensors and models could lead to wide-ranging improvements in mining operations, with potential contributions to many other industry performance targets. Conventional sensors suffer from poor process variable detection, and available modeling methodologies are relatively ineffective for mining processing needs. The development of improved sensors and process models involves the use of advanced information technology to improve processing and productivity. A number of information transfer barriers, particularly concerning real-time data transfer, must be overcome before these technologies can be successfully developed. The adoption of new sensor and modeling technologies by the mining industry could yield substantial energy, environmental, and cost benefits. Mining techniques guided by advanced models have the potential to minimize the amount of unwanted material that is removed from the face, thus also minimizing the environmental impacts of disposing of that material.

As the higher-grade, more plentiful, and relatively accessible ore deposits are depleted, the industry will increasingly have to rely on thinner seams, lower-grade ores, and remote or environmentally sensitive locations in which mining operations must occur. A high degree of priority has been given to the development of improved technology for exploiting small, low-grade, remote ore bodies that today cannot be mined energy efficiently or economically. Technologies must not only be able to provide sufficient returns on investment to justify using these less desirable ore bodies, but must do so with the highest regard for environmental and safety concerns. Barriers to doing this include a lack of technological sophistication and the inability to make the final product at the face. The energy and environmental benefits of successfully developing this technology are expected to be very high.

Basic research on materials properties, solution properties, and the behavior of fine particles in solution represents a broad category of research needs focused on improving the understanding of basic, fundamental chemical and physical phenomena that occur during processing. Major advances in understanding exactly what is occurring to the material in bulk and on a molecular level will contribute towards the goals of improved separation efficiency, improved combined chemical/physical methods, and minimized impact from processing on the environment and community. As with separation and cleaning technologies, breakthroughs in these fundamental areas leading to innovative new processes could have significant cost implications. Moreover, the research would also be expected to lead to new technologies that could reduce energy consumption and environmental impacts.

Exhibit 4-3. Safe and Efficient Processing R&D Priorities[1]

R&D Priorities	Targets Addressed	Key Barriers Addressed
Develop new materials for wear and construction	- Reduce downtime - Increase energy efficiency	- Not benefiting from newly developed wear materials
Separations including: new materials for ion exchange, phase separation, including membrane	- Improve separations - Improve chemical/physical methods	- Inefficient separations equipment - Dewatering problems - Separating ore from material at face
Improved sensors for process stream characterization and control	- Increase capital productivity - Increase product value at mine - Improve chemical/physical methods - Reduce wastes	- Lack of real-time information - Cannot move large amounts of information - No on-line monitoring - Process variable detection is poor
Intelligent, self-building process models	- Increase capital productivity - All targets	- Lack of adequate use of information technology - Ineffective models for integration
Improved techniques for small, low-grade, remote ore bodies	- Increase product value at mine - Increase capital productivity - Minimize environmental impact	- Lack of technological sophistication - Cannot make final product at face - Ore and waste not segregated at face
Basic research: mineral properties, solution properties, and behavior of fine particles in solution	- Improve separations - Improve chemical/physical methods - Minimize environmental impact	- Cannot detect or respond to variable feedstock - Dewatering - Hydrodynamics of mineral-water separations
Improve separation/cleaning technologies - dewatering - water treatment - by-product management and utilization	- Reduce wastes - Increase product value at mine - Reduce permitting times	- Dewatering - Ways to utilize waste - Water treatment - Focus on cost vs. value
Develop comminution modeling and technology	- Improve separations - Increase energy efficiency	- Crushing and grinding as soon after mining as possible - Energy efficiency of size reduction techniques is poor - Physics of rock fracture not understood

[1]Information is listed in relative ranked order by the individuals attending the roadmapping session.

5. ADDITIONAL CHALLENGES

A number of additional challenges have been identified by the mining industry which impact the areas of exploration, mining, and processing. These issues indirectly affect technology development, and will be integral to any technologies the mining industry develops to address energy, economic, and environmental challenges. It is crucial that technology developers and users address these additional factors:

- Environment
- Safety
- Education
- Technology Transfer
- Operating Environment
- Funding

Environmental Issues. The environmental impact of mining is a dominant driver for most technology development in the industry today. Although much of this effort is focused on waste treatment and disposal, a significant amount of waste prevention has also occurred.

To increase production, the focus of the mining industry has shifted in recent years from merely increasing the tons of mined materials to dramatically increasing the amount of product generated per ton of material removed. This strategy produces less waste and thereby reduces waste treatment and disposal costs. Advances in technologies to extract useful products from today's waste materials will further this trend. Development of technologies to displace less material during mining will also result in reduced environmental impact. A long term vision for the industry would find constructive use for all material removed in the mining process.

Safety Issues. Safety is the most important additional challenge identified, impacting every aspect of exploration, mining, and processing. The mining industry has identified a number of ways to overcome barriers to continue to reduce recordable accidents and exposure to hazards for workers.

Improved ergonomics and safety is a broad need that is not only adjunct to all elements of research, but also an important R&D need in its own right, and one that could be addressed by the development of new technologies. Safety is improved by continually taking into account the ergonomic dynamics of bringing together mining, technology, and human beings.

It is also important to develop improved mine rescue techniques, and the tools to implement them. These improvements will yield immediate benefits in saved lives and reduced injury for those in need as well as for the rescuers.

Educational Issues. Key target areas identified by industry include both traditional and nontraditional educational opportunities. Three thrusts have been identified:

- Reevaluating the education system
- Training to match new technology development
- Conveying positive local impacts to mining communities

Mining efficiencies have significantly decreased the labor needed for production. Although the benefits of this shift in terms of cost reduction and safety enhancement are inarguable, the lack of a growing workforce has also had disadvantages. Among the disadvantages of this trend is the lack of new knowledge from fresh mining school graduates.

Reevaluation of the educational system is necessary to ensure future mining productivity and alignment of academic research with industry needs. Employees joining a mining company must be able to make productive contributions immediately without extensive training. Academic mining research institutions need to focus on projects that address industry's needs in order to optimize the use of available research funds. While the roadmap may help align academic and industrial interests, continuing communication between industry and academia will also be necessary. Successful evaluation and, if necessary, adjustment of the educational system could eventually contribute to all of the performance targets listed in this document.

Ensuring that educational institutions fully educate students on the importance of the safety and environmental responsibility of the mining industry may lead to improved environmental performance for companies hiring these students. Reevaluating mining curricula may also have significant impacts on the safety and health of workers in the mining industry. The industry stresses the role of safety and environmental performance as components of doing good business, and expects educational institutions to incorporate these concepts in their mining curricula.

Training must match new technology development. The mining industry is continually adopting new automated methods to cost-effectively improve their operations. The industry needs new training methods to keep mining industry workers up-to-date, whether it be new tools for management or automated equipment in the mine. In addition, it is important to develop websites for technical information integration. Finally, it is important to provide training to cause a shift to new technologies that do not focus on refinement of existing methods but are truly new methods to improve mining operations.

The mining industry also recognizes that the cultural and public relations aspects of safe and efficient mining plays an important role in achieving the technical objectives set forth in this roadmap. The mining industry can investigate ways of demonstrating to communities that mining has positive local impacts. There is a need to identify methods of involving the localities to develop a positive image and a trust that mining industry activities will benefit a community or a region. Overcoming negative perceptions helps to reduce the cost and effort it takes to establish any mining activity. Education in the local school curriculum, for K-12, is another method to show the benefits to a community from mining.

Technology Transfer. Technology transfer is necessary within a broad-based and diverse industry such as mining. Of the most value to the industry is the dissemination of information to improve the safety and to reduce the environmental impacts of mining, two things which are necessary to its continued health and to any future growth. In addition, because safety and environmental impact are an integral part of any new technology, this need for industrial dissemination extends to almost all research and development activities.

For various reasons, cooperative efforts between the mining industry, government and others, have been minimal and thus there has been little technology transfer between industry and

national laboratories. The industry has a largely undeserved reputation for a lack of technological sophistication to adopt new techniques. More widespread use of new technologies currently in use on a small scale can quickly change this perception.

There has traditionally been a lack of information on new crosscutting R&D developments that could positively impact upon the mining industry. To achieve maximum impact, R&D initiatives must result in the transfer of technology into the marketplace. This process begins with technology development, continues with technology deployment, and ends with the dissemination of the technology to those who will purchase and use it. The application of a particular technology through pilot projects and technology demonstration is critical to the ultimate transfer of any technology.

A second important transfer is of enabling technologies from outside the mining industry to mining applications. A common theme advanced by industry is that there is a lack of knowledge on existing technologies from other industries. There are promising advances in the national laboratory system that could be exploited by the mining industry. Examples of potentially useful technologies from other industries and the federal laboratories include:

- Satellite technology for use in exploration,
- Ground-based diagnostic techniques for use in exploration,
- Remote sensing for precision imaging during extraction,
- Improved materials for wear and construction, and
- Lightweight materials for equipment.

Federal, industry, and academia databases may contain information on other available technologies that could be readily adopted to solve technological problems in the mining industry. Better communications are needed between industry and research laboratories to facilitate the transfer of knowledge about advances as well as to facilitate the adoption of advanced technologies.

The mining industry relies heavily on educational institutions to undertake both basic and applied research described in this roadmap, particularly longer-term activities. These research institutions must be kept abreast of the pressing technological needs that the mining industry is facing and will face in the future to ensure that any research done is relevant to industry. Clear communications between the industry and academia are lacking, making it difficult for researchers to understand and address mining's technological needs.

The development of new enabling technologies that benefit the entire mining industry is a Mining Industry of the Future priority. Sensors and controls, advanced industrial materials, innovative power and propulsion systems, and engineered ceramics are examples of new technology areas that can enhance industrial productivity across the board.

Finally, while the majority of the Mining Industry of the Future efforts will involve technology development and deployment, companies are also encouraged to evaluate those energy efficient technologies that are available in the market but are not being used. The adoption of these commercial technologies can be part of a comprehensive strategy to achieve the Mining Industry of the Future emission reduction goals. Technical assistance from the US Department of Energy is available to companies who wish to adopt highly efficient industrial equipment such as motor, steam, and compressed air systems. In addition, user-friendly computer tools and

websites could provide introductions or simulate how new technology or methods could be used within mining.

Operating Environment Issues. Key barriers to success in achieving the Mining Vision are focused on the legal and regulatory environment the mining industry. The industry recognizes that poor environmental and safety practices are detrimental to the industry, both in the short and long term, and that proper regulation is necessary to a thriving industry. However, it is also clear that a cooperative environment is more conducive to success than an antagonistic one. Therefore, the mining industry is striving for a more positive partnership with government and other oversight organizations to work toward a cleaner and healthier industry that will continue to produce needed commodities at no cost to the environment.

Many technologies listed in this Crosscutting Technology Roadmap can contribute to the goal of a positive partnership. For example, permitting can be a long and expensive process for the mine developer. Many times federal intervention complicates the permitting process particularly in those states that have clear permitting functions established. With improved mine planning and modeling capabilities, mining companies could develop more detailed data for use in permits, greatly reducing permitting times. An advanced reserve system for mining could be a network-based system to integrate dimensional models for simulation and control of mining operations. This research could build on similar programs, such as that developed in part by national laboratories for active modeling and control of petroleum reserves.

It is hoped that this and subsequent Roadmap documents will help to coordinate and unify the constituent groups that impact permitting. Better communication and improved understanding of the technologies and processes involved will only contribute to reduced permitting times and higher productivity.

Funding Issues. Key barriers to meeting industry's goals include shrinking government research budgets and a lack of industry-driven research. Approaches to overcoming these barriers include leveraging research and development dollars and by coordinated application of limited funds.

A valuable leveraging tool is the use of research tax credits. Although these tax credits have existed for some time, many companies do not take advantage of them for various reasons. For example, identifying or defining an activity as 'research' is difficult if the project is performed in the field. Also, because funding may come from mining companies who don't do research, there is a question over what constitutes 'research funding'. In addition, some question whether the definition of research will cover industry-academic interactions. Increased communication among the mining industry will increase the knowledge of how to apply and share the benefits of these credits. The industry foresees the creation of investment opportunities where mining companies can work together and share in R&D profits.

Other barriers are concerned with creating new investment opportunities through increased funding; encouraging industry to forge new partnerships with a variety of institutions conducting related research; and examining and changing the educational and institutional mechanisms available to encourage an increased awareness of the benefits to be obtained from greater exploration and improved characterization. All of these could greatly enhance the industry's ability to meet the aforementioned goals.

6. ACHIEVING OUR GOALS

Several technical and institutional issues are common among the three areas of focus in this Roadmap — Exploration and Resource Characterization, Safe and Efficient Extraction and Safe and Efficient Processing. Some examples are provided below:

- **Environment.** Any technology which combines aspects of exploration, mining, and processing has the potential to reduce the environmental impact versus processes with a singular focus. For example, sensing technologies which allow a mining machine to follow a seam of ore may result in less overburden being removed. An in situ separation process in the mine may result in less waste material handled by a processing plant. Although these advances result in increased productivity, they may also reduce waste generation significantly.

- **Safety.** Safety is a constant and explicit consideration in every technology or business practice incorporated into an operation. It is specifically addressed as part of both the extraction and processing research needs.

- **Education/Training.** Mining efficiencies have significantly decreased the labor needed for production, resulting in an aging workforce and gradual loss of expertise. This problem may be somewhat curbed by enhancing education about mining on the primary level (K-12), encouraging more people to enter the mining field, but it will also require a concerted effort by companies to hire and train new employees.

- **Mining Lower Grade and Thinner Seam Conditions**. It will become necessary to exploit less desirable ore bodies as many of the highest-quality, most accessible ore deposits in the US are depleted. Mining these more difficult deposits has implications for all areas of the mining process, including exploration in harsh or sensitive environments; mining deeper, thinner seams; and processing lower-grade material.

- **Sensing.** Sensing devices are critical in all aspect of the mining process. Advances in real-time sensing, data collection, and data analysis and interpretation will help avoid unproductive mining situations, reduce the environmental disturbance associated with finding reserves and mining the material, and will increase the value of the product at the mine, as well as yield secondary health and safety benefits. The development of autonomous mining equipment, and the sensors needed for navigation and control of this equipment, have been identified as top-priority research needs for the industry.

In summary, optimization of the overall mining process, not just the individual elements of mining, is a high-level industry goal. Overall systems integration, from exploration through processing, is one method of optimizing the entire mining process. Fully characterizing the resource to be collected before extraction begins represents a first step. Opportunities to combine mining and processing whenever possible, thereby eliminating the need to transport unwanted material from the face, would reduce costs and improve productivity. Refinements in mining can make processing more efficient and cost-effective by minimizing by-product material. The development of a model of the entire integrated mining process is a specific research need aimed at enabling the industry to consider the implications of system integration and opportunities that it may present.

Finally, we consider shrinking R&D budgets that affect all aspects of technological development in mining and in other industries. Increased cooperation between mining companies, equipment vendors, government, and academia are critical to the successful realization of the mining industry's vision. Today, many federal R&D programs are seeking cost-shared partnerships with groups of companies and with entire industries. This technology roadmap will help such programs identify matches between their research objectives and those of the mining industry. Through this effort to lay out its own technology strategy, the industry has provided the means for the entire research community to refocus its R&D efforts in mining technology in keeping with the industry's top-priority needs.

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