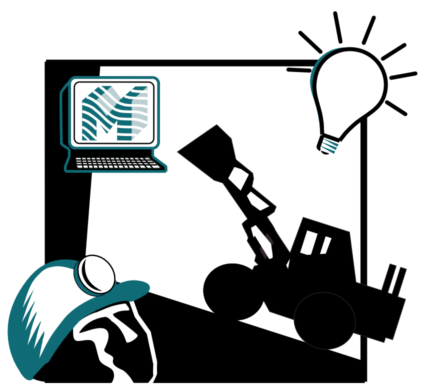
Mining
Industry of the Future

Mineral Processing Technology Roadmap



September 2000

Foreword

In June 1998, the Chairman of the National Mining Association and the Secretary of Energy entered into a Compact to pursue a collaborative technology research partnership, the Mining Industry of the Future. Following the Compact signing, the mining industry developed “The Future Begins with Mining: A Vision of the Mining Industry of the Future.” That document, completed in September 1998, describes a positive and productive vision of the US mining industry in the year 2020. It also establishes long-term goals for the industry.

Using the Vision as guidance, the Mining Industry of the Future is developing roadmaps to guide us in achieving industry’s goals. This document represents the roadmap for Processing Technology Research in the US Mining Industry. It was developed based on the results of a Processing Technology Roadmap Workshop sponsored by the National Mining Association in conjunction with the US Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of Industrial Technologies. The Workshop was held January 24 - 25, 2000.

Participants at the Workshop represented a wide range of technologies and activities in the industry and crossed various mined commodities including copper, uranium, iron ore, coal and others. The workshop participants included individuals from mining companies, equipment suppliers, technology developers and implementers, government agencies, research laboratories, and universities.

Arlene Anderson
US Department of Energy

Michael Barron
TJ Gundlach Machine Company

Jim Bartis
Rand

Ken Bennett
Caterpillar Inc

George Bockosh
National Institute of Occupational Safety and Health

Kenneth W. Boras
BCS Incorporated

Mike Canty
US Department of Energy

Charles A. Carroll
ASARCO Incorporated

Lisa Corathers
National Mining Association

Gerald DeCuollo
Hydrocarbon Technologies, Inc

Edward Dowling
Cleveland-Cliffs Inc

Kenneth M. Green
BCS Incorporated

James Hackwood
Modular Mining Systems, Inc

John Hamric
American Electric Power Service Corporation

Rick Honaker
University of Kentucky

David Hyman
National Energy Technology Laboratory

Greg Kawalkin
National Energy Technology Laboratory

Komar Kawatra
Michigan Technological University

Randy Kosky
CONSOL Inc

Paul Lever
University of Arizona

Toni Maréchaux
US Department of Energy

John Marsden
Phelps Dodge Mining Company

Jerry May
Idaho National Engineering and Environmental Laboratory

James McWilliams
American Electric Power Service Corporation

Richard Noceti
National Energy Technology Laboratory

BK Parekh
University of Kentucky

Felicia F. Peng
West Virginia University

Jon Price
Nevada Bureau of Mines & Geology
University of Nevada-Reno

Bill Riley
Albany Research Laboratory

Dennis Stover
Rio Algom Mining Corporation

Roy G. Tiley
BCS Incorporated

Bruce Tippin
North Carolina State University

Bob Washnock
ASARCO Incorporated

John L. Watson
University of Missouri-Rolla

Dave Wildman
National Energy Technology Laboratory

Richard D. Witham
Molycorp, Inc

Richard Woodward
Metrika Systems/Gamma-Metrics

Roe-Hoan Yoon
Virginia Polytechnic Institute and State University

Introduction

'Everything in the 21st century begins with mining.' Taken from the Future Begins with Mining*: A Vision of the Mining Industry of the Future*, developed by the mining industry in September 1998, these words communicate the critical but often unseen role that mining plays in the economy and the lives of each individual. For example, 46,000 pounds of new minerals including 7,500 pounds of coal energy must be provided annually for every person in the US to maintain their standard of living. In the course of a lifetime, each American will use 3.5 million pounds of minerals, metals, and fuels[1]. In addition to individual impacts, mining also has a strong impact on US economic competitiveness:

- US electricity costs are among the lowest in the world due to the availability of low cost coal.
- Demand for minerals and mineral products in 1998 was US$415 billion or nearly 5% of the US gross domestic product[2].
- The total value of non-fuel raw mineral production was US$40.5 billion[2].
- The value of metal mine production was $10.6 billion. The value for non-metals was US$29.5 billion[2].
- More than 320,000 people work directly in the US mining industry, who support an additional five million jobs in manufacturing, engineering, and environmental and geological consulting[1].

The use of advanced technologies, including satellite communications, computer modeling, and smart sensing is widespread in the mining industry. Information-based technologies are responsible for making mining and processing more efficient and reliable and help the industry to adapt to new competitive environments in a safe and environmentally sound manner. As demand for mineral commodities increases, so will the need to mine and process them at competitive costs. This means continually finding better methods, technologies, and processes.

The mining industry has a positive and productive vision of the US mining industry in the year 2020. This Vision rests on achieving 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.

[1] The National Mining Association, *The Future Begins with Mining, A Visions of the Mining Industry of the Future*, September 1998, <http://www.oit.doe.gov/mining/vision.shtml>. Estimates developed by National Mining Association based on data from US Department of the Interior, US Geological Survey, Mineral Commodity Summary (mineral consumption); US Department of Energy, Energy Information Administration, Monthly Energy Review (coal energy consumption); US Department of Commerce, Bureau of Census (population). <http://www.nma.org/fastfacts.html#anchor208017>.

[2] Mining Journal Ltd., *Mining Annual Review 1999*

- ***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.

The Mining Industry of the Future is concerned with achieving all of these visionary goals. The first technology roadmap supporting this vision, the *Mining Industry Roadmap for Crosscutting Technologies* <http://oitdev.nrel.gov/mining/ccroadmap.shtml>, was published in February 1999. That roadmap focused on technologies which could impact the processes for all products of the mining industry. This document, the Mineral Processing Technology Roadmap, addresses those technologies leading to mineral processing improvements which may apply to one or to multiple mining product areas.

Many other steps in the mining process are identified in the vision but are not addressed in this document. These include exploration, ore extraction from the earth, and product development. Each of these topics may be explored in future technology roadmaps.

In addition, it is clear that many processing improvements can be made through the application of best practices for plant operations. These include optimized motor systems, pump systems, steam systems, compressed air systems, ventilation systems, and other system improvements which are less concerned with research and development, but more oriented toward use of the best existing equipment and technology. Many processing plants, due to age or to historical construction, are not optimized for energy efficiency and offer a large opportunity for savings in this area. Although best practices are clearly part of a more energy efficient minerals processing industry, this roadmap does not intend to encompass those technologies.

Processing Improvements

Improvements to existing mineral processes as well as brand new processes will be needed to achieve the vision goals. As used here, the term 'processing' refers to those methods employed in the mining industry to clean, separate, and prepare coal, metals, and non-metallic minerals from mined material into final marketable products. It also includes the secondary processing of waste streams to produce useable or saleable products with the objective to totally eliminate air emissions, dust emissions, water emissions, slurried tailings, or other solid wastes. Many opportunities to improve energy and environmental performance are associated with these mineral processing activities.

For example, rock crushing and grinding for mineral preparation is one of the most energy intensive processes in mining. Some by-products that occur with the desired metals, such as mercury and arsenic, can be harmful to the environment if improperly managed. Fuels and chemicals the industry uses in processing are also potential pollutants. Today's processes create and employ hazardous substances that must be handled with care. The industry is also striving to reduce other pollutants from processing operations such as dust and noise.

It is projected that improvements in mineral processing technology will lead to the following benefits:

- Energy Efficiency - Improved energy efficiency per unit of output
- Environment - Reduced emissions per unit of output
- Health and Safety - Improved worker safety in processing activities
- Productivity - Reduced cost and higher value per unit of output
- Reserve Base - Increased reserves through technological advances and improved economics

This roadmap identifies three areas of processing technology where the most impact and the greatest progress toward the mining vision goals can be expected.

1. Mineral Preparation
2. Physical Separations
3. Chemical Separations

Each of these are described more fully in roadmap pathway charts outlining process improvements and staged technology targets.

Several particular process improvements cut across each of these three areas:

Modeling - The application of integrated plant information systems with accurate process models would provide plant personnel with the operating history necessary to develop process optimization schemes and identify abnormal operating conditions. Development of modeling tools for separate processes like material handling and process piping systems could help achieve the goal of developing full scale simulators. Interim targets contributing to this goal are to model many individual processes, then to find ways to interface these models. Of course, any full scale process modeling effort must be flexible to handle individual plant design and maintenance differences. A shared target for the three sections of this roadmap is to implement ten new individual process models within 4 years, and to implement overall system models within 20 years.

Characterization - To measure performance or to model processes, characterization of processes and process streams is necessary. In-line characterization of key chemical and physical properties, such as composition, density, surface characteristics, particle size, hardness, impurity level, pH, etc, are all needed to utilize sophisticated process modeling. Shared targets for the three sections of this roadmap include reduction in cost and improvement in facility for in-process sampling and timely characterization.

Structural Materials - All processes include material handling and containment of the process flows. For many of these, improved wear, fatigue, corrosion, and creep resistance is needed to implement more efficient processes. Smart materials utilizing condition-based maintenance technologies can contribute to the efficiency of numerous processes. A shared target for the three sections of this roadmap is to implement ten new structural materials in various applications within 6 years.

Health and Safety - At a minimum, no new process or process improvement should result in occupational exposure exceeding recognized limits. In fact, it is expected that new technologies will result in reduced employee exposure to health and safety risks. Specific targets include reducing the rate of processing-related fatalities to zero, reducing the number of health and safety-related reportable incidents to zero, and effecting advances which will enable zero notices of violation of safety and health regulations.

1. Mineral Preparation

After extraction from the ground, minerals must be made ready for direct use or further processing. Mineral processing includes the following:

- **Comminution -** the gradual reduction of a hard mineral to a fine powder or dust by crushing, grinding, or attrition for direct use or further processing. This includes liberation of a product, such as coal from non-coal material. It also includes primary crushing, where run-of-mine ore is reduced to a size small enough to feed a secondary crusher and rock is broken down to an adequate size for grinding. During grinding, rock may be mixed, with or without liquid or grinding media, in a rotating cylinder or conical mill where it is reduced to fine particles.
- **Makedown -** the conversion of extracted soft rock minerals into a slurry. This may include the application of mechanical work, such as blunging, and chemicals to achieve particle dispersion.
- **Classification -** the process of separating particles of various sizes, densities, composition, and shapes as part of the preparation circuit to control the final product.
- **Blasting and drilling -** processes not typically considered part of traditional mineral crushing include those activities associated with identifying optimum locations within mineral deposits for the placement of explosive charges and the detonation of those charges. The shape, size, and morphology of the material coming into the mill can dramatically affect the efficiency of further processing. Blasting and drilling are included under the definition of mineral preparation because of forward thinking by industry on opportunities to improve the efficiency of mineral processing through advanced blasting and drilling techniques.

Mineral comminution requires large capital, labor, and energy costs and may account for more than half of hard rock processing energy costs. The mining industry uses approximately 29 billion kWh of electrical energy annually for size reduction, which is approximately 99 trillion Btus. Energy and capital costs could be reduced through improved blasting and extraction techniques, more efficient motors and equipment, optimized operation, and reduced wear and tear on equipment. A number of research needs involve the development and implementation of new simulation and modeling technologies as well as new methods to reduce the cost of in-process sampling and characterization.

There is a wide range of mineral preparation research and development activities that, if implemented, can improve energy efficiency, environmental performance, health and safety, and productivity. These research activities are grouped into four categories:

Dust Emissions - Process improvements and research can address aesthetic and environmental issues related to dust emissions. Dust emissions are a high profile issue for the industry and a high priority. Improvements of both active and passive methods for dust control are needed to further reduce dust emissions. The industry hopes to reduce dust emissions by 90 percent over the long term.

Blasting and Drilling - Significant opportunities exist to improve productivity and energy efficiency in the early stages of mineral preparation operations, specifically by changes in blasting and drilling techniques. This includes research to improve tools for analyzing mineral deposits and to better understand the characteristics of mineral deposits. Improved models, sensors, and instrumentation will help to better understand the nature of the minerals to be mined and thereby enable industry to improve the effectiveness of blasting and drilling activities. Improved blasting design could lead to smaller size inputs to crushers thereby helping to improve energy efficiency in crushing as well as reduced maintenance and wear. In addition, revolutionary technologies in this area could create an opportunity for process integration, where mined minerals could go directly to other downstream activities eliminating energy and waste impacts from crushing and grinding. An associated benefit of more efficient blasting and drilling could be reduced dust emissions.

Classification - The ability to improve the efficiency of machinery currently used in altering or reducing the particle size will help to improve overall processing energy efficiency and productivity. Process improvements to achieve optimal grain size will help to reduce the amount of unusable particles, improve liberation, increase throughput, and reduce dust emissions. Advanced grinding and comminution schemes that take advantage of natural weakness in the rock can improve the efficiency of crushing operations. Models which characterize the fracture and wear surfaces of ores can help to attain optimal grain size as well as reduce dust emissions. The delivery of smaller-sized materials to processes and improved liberation through the use of on-line sensors can also improve efficiency. Improvements in the efficiency of existing machinery and better and more efficient classification schemes can save time and energy as well as making sizing more efficient.

Instrumentation and Sensors - Advanced sensors and instrumentation can result in crosscutting efficiency and productivity improvements across blasting and drilling, sizing, and classification operations. Research is needed to gather, analyze, and understand information about the mineral feedstock. Application of this knowledge may allow greater control over comminution and classification processes. Sensors and instrumentation to improve the characterization of the ore to determine if more or less crushing is needed would greatly enhance the process. On-line systems to characterize the mineral going into a mill or coal preparation plant will enable a better understanding of the feed in terms of ore type and oxide content. Imaging sensors for use in classification devices, especially cyclones, can assist in optimizing feed to comminution processes.

Materials - In addition to the above, the mining industry is looking to future advances in existing structural and containment materials and the development of new materials to improve wear resistance in crushing and grinding. Heat-resistant materials, such as advanced ceramics for use in feeders, liners, and balls would help to reduce wear and therefore maintenance and replacement costs. In addition, by reducing the wear of grinding media and containment materials, their presence in further processing can be reduced, and can result in less contamination and more usability for tailings. It is expected that application of many of these advanced processes, technologies, or materials may require higher up-front costs; however, they could significantly reduce life-cycle costs.

2. Physical Separations

Physical Separations are those processes where valued substances are separated from undesired substances based on the physical properties of the materials. They include solid-solid and solid-liquid separations. Efficiency in physical separations can be viewed as an overall system efficiency, from the prepared mineral and resulting in a separated product. Typical physical separation processes and their definitions include:

- **Flotation -** Mineral separation, in which a variety of reagents are added to an agitated and aerated mixture of liquids and solids. This causes certain finely crushed minerals to adhere to air bubbles and to rise to the surface where they enter a froth, leaving the remaining minerals behind.
- **Dewatering -** Separates solid materials from water in which it is dispersed, performed by equipment such as thickeners, classifiers, hydrocyclones, filters, and centrifuges.
- **Thickening or Settling -** Reduces the proportion of water in a material by means of sedimentation or elutriation.
- **Filtering -** Separates suspended solid particles from liquids, or fine dust from air.
- **Drying -** Removes water using air or heat.
- **Flocculation -** Selective agglomeration, or adhesion of material components to water or other immicible liquids. In this process, loosely bonded associations of particles and bubbles are formed that are lighter than water.
- **Screening -** The uses of one or more screens or sieves to separate particles into defined sizes.
- **Magnetic Separation -** The uses of permanent or electromagnets to separate magnetic particles from other process streams.
- **Classification -** The separation of particles of various sizes, densities, and shapes through their movement in a fluid. Includes centrifugal separation.
- **Washing -** Removes ash, shale, sulfur, and other unwanted products from crushed material using water.

There is a wide range of physical separations research and development activities that, if implemented, can improve energy efficiency, environmental performance, health and safety, and productivity. These research activities are grouped under three categories and associated subcategories:

Fine Particles - In contrast to coarser fragments, these are powdered or finely crushed material such as crushed clay, coal, or rock. Fine and very fine particles are a desired final product for many industrial minerals. In metal ore processing, fine particles are an interim product, but they can be made too fine to be smelted by ordinary methods. Some fine coal particles may be smaller than the minimum specified size for shipping or processing. Significant opportunities in separation, utilization, and dewatering can improve the production and use of valuable fine particles.

In dry separations, better definition of the characteristics of fine particles and their surface properties can lead to an improved understanding of fundamental separation forces. Enhancements of magnetic separation processes can also play a role in improving dry separations. The development of air injected hydrocyclone technology may be able to improve separation of contaminant or other undesirable species from mineral ores by combining flotation and dewatering in one step. If unwanted carbonaceous, clay, or other minerals could be selectively removed, the amount of reagents and energy-intensive processing needed to extract desired minerals from host ores could be decreased.

In wet separations, improvements are needed to reduce moisture content during processing, and also in waste pond recovery to reduce losses in valuable fine particles. Dewatering tends to be a very energy-intensive process, and many minerals would benefit from process improvements in this area, or even the elimination of the need for processes such as thermal drying. Several new chemical and mechanical approaches are under investigation in various industries, including the use of liquids other than water. Efforts could initially focus on technology transfer among these efforts.

Many minerals are losing large amounts of valuable material to undersized fine particles. For example, it is estimated the phosphate industry loses 30 percent of potential product to fines. Presently, saleable mineral fine particles have unique properties that can be beneficial in some applications. For example, the best coking coal is often found in coal fines. Research to enable size enlargement and agglomeration can help to improve fine material utilization and will help to minimize problems with storage and transportation, may help reduce the large dust problem in dry applications and flow problem in slurries.

Process Design and Controls - Improvements in process design and control offer opportunities for large energy and cost savings in the mining industry. Improved sensors, systems, and empirical models can allow the industry to exert more control over processes and increase the unit capacity and extend the operating range of existing equipment. Sensors are needed in monitoring equipment and processes, as well as for monitoring feedstock characteristics. Interim targets include identifying sensor needs in the near-term. In the mid-term there is a need to develop economical online sensors and to automate critical decisions related to throughput and product quality.

Industry hopes that improvements in sensor analysis systems and automation of critical decisions will reduce the cost of system design by 90 percent over the long term. This will not only allow industry to better utilize existing systems, it will help them to integrate and prove advanced design systems in physical separation activities.

Automating physical separation processes will increase efficiency as well as benefitting employee health and safety in the industry. Systems that increase automation will limit exposure of workers to hazards such as noise, toxic chemicals, and dust and improve the feedstock consistency. This will require smart systems that adjust to material properties. In the near-term, research is needed to emphasize utilizing existing systems and integrating management. Once this is achieved, research could then progress to advanced systems integration and verification.

Developing inexpensive full-scale simulators of processing plants, which will include aspects of plant economics, will increase plant efficiency and health and safety in the industry. Identifying critical unit operational modeling needs is the near term goal. For example, efforts are needed to eliminate the current discontinuity between crushing, screening, and flotation. To achieve the mid-term goal, research is needed to complete modeling of all unit operations. The unit operations models will be used to achieve the long-term goal of a full-scale model for processing plants. In the long term, models need to incorporate plant economics, as well as integration with full-scale simulators that will lead to intelligent plant design to increase efficiency, improve feedstock consistency, and help keep workers away from hazards. A “long-term” goal is to automate much of the critical “decision making” process related to throughput and product quality.

3. Chemical Separations

Chemical Separations involve isolating metals and minerals from their ore by chemical processes. Typical chemical separation processes and their definitions include:

- **Solvent extraction -** The separation of one or more substances from a mixture by treating an aqueous solution of the mixture with a solvent that will extract the required substances, leaving the other undesirable materials behind.
- **Leaching -** The extraction of soluble metals or salts from an ore by means of slowly percolating solutions. This may include above ground heap leaching or in-situ mining processes.
- **Bioleaching -** The catalytic action of bacteria, such as Thiobacillus ferroxidans and Thiobacillus thiooxidans, to accelerate chemical oxidation reactions by as much as one million times those of chemical reactions alone; especially useful in leaching copper and uranium systems.
- **Smelting -** The chemical reduction of a metal from its ore by a process usually involving fusion, so that earthly and other impurities separate as lighter and more fusible slags and can readily be removed from the reduced metal. The two most important types of smelting are reduction smelting, which produces molten metal and molten slag, and matte smelting, which produces molten matte and molten slag. Smelting can be conducted in a blast furnace, a reverberatory furnace, or an electric furnace.
- **Refining -** An electrolytic or chemical process that produces a pure metal.
- **Electrowinning -** An electrochemical process in which a metal dissolved within an electrolyte is plated onto an electrode resulting in a pure metal.
- **Pelletizing** or **Briquetting -** A process by which coke breeze, coal dust, iron ore, or any other pulverized mineral is bound together under pressure, with or without a binding agent such as asphalt, and thus made conveniently available for further processing or for commercial markets.

There is a wide range of chemical and metallurgical separations research and development activities that, if implemented, can improve energy efficiency, environmental performance, health and safety, and productivity. These research activities are grouped under the following:

Increasing Reaction Kinetics - Improving our basic understanding of reaction kinetics for many processes can lead to increased conversion efficiency. Bio-enhanced processes, improved membranes, and advanced modeling can all contribute to this goal.

Improving Heat Efficiency - Many minerals processing steps require heating and cooling of process streams. Optimizing the use of process heat, maximizing combustion efficiency, utilizing waste heat, and streamlining processes to minimize heating and cooling can all lead to increased conversion efficiency.

Increasing Direct Conversion and *in-situ* Recovery - The most effective way to increase conversion efficiency is through the reduction or elimination of processing steps. Finding safe and effective ways to eliminate physical removal of the ore from the site is one obvious goal, and beneficiating it as much as possible at the mine face can dramatically reduce material transfer costs. Another possibility is to devise dry processes or processes that don't need external heating, both of which would have large positive impacts on energy efficiency.

By reducing the amount and type of chemicals that are added to the process, we can also reduce what must later be removed from the product and from by-products. This can increase the possibilities for by-product utilization. By changing the input chemicals, we can also reduce any possible human exposures to toxic elements or trace metals.

Decreasing Time to Close Processing Operations - The energy, time, and effort in preparing for and in closing of processing operations has been targeted for improvement. Decreasing the amount of waste produced throughout the life of the mine is one way to address this. Another is to design the plant operation to utilize all mine products in some way, either as a saleable product or in a benign manner on the mine site. Ultimately, the use of life cycle analysis by all mineral processing operations during the initial planning phase will lead to decreased closing times, but this process must be updated throughout the life of the operation in order to dynamically adjust to the quality of the ore body and to utilize new technologies.

Other process improvements are identified in the areas of modeling and simulation, sampling and characterization, equipment ergonomics, structural materials technology, and control system effectiveness.

Additional Challenges

A number of challenges must be overcome to realize the research benefits identified in this roadmap. These challenges directly and indirectly affect process improvements and will be integral to any advances the mining industry makes in achieving energy, economic, and environmental goals.

- **Public and Government Perception of Mining -** Public and government perception is a large challenge. The critical role of the mining industry to our economy and quality of life is often overlooked. Publicizing the development and use of the process improvements in this roadmap is needed to show that the mining industry is not only a cleaner, safer, and more technologically advanced industry than is commonly perceived, but that it is vital to meet the needs of the population.
- **Government-Industry Partnerships -** The Mining Industry of the Future embodies the possibility of making mining activities in the US more progressive and more economical than outside the country. This trend would reduce our dependence on mined imports from other nations. Several other countries provide a far more beneficial environment to conduct research and develop new technologies. For example, many US regulatory statutes discourage companies from trying unproven and innovative processes. The mining industry is striving for a more positive partnership with government and other oversight organizations to work together toward a cleaner and safer industry.
- **Human Resources –** 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) and encouraging more people to enter the mining field, but it will also require a concerted effort by companies to hire and train new employees. Students and qualified engineers are not pursuing careers in mining at the rate that is needed by the industry. The mining industry must get the word out that their industry is highly technical with many opportunities for scientists and engineers. Achieving this goal will mean improved education to students not only in the universities but also at the secondary and primary level.
- **Basic Sciences -** US industry generally can not afford to conduct basic scientific research that could help them better understand processing technology, and the minerals industries are no different. The government agencies which traditionally carry out basic sciences, such as the National Science Foundation, the DOE Office of Science, and the National Institutes of Standards and Technology, are currently unaware of many of the needs in the mining industry and are not addressing them. For example, a better theoretical understanding of reaction kinetics, rock mechanics, or the physics of fine particles can help to find better ways to break and crush ore using less energy or find unique characteristics of minerals that can increase efficiency in separating minerals from wastes. Basic science can also lead to mining hard-to-exploit ore bodies such as thin seams, low-grade resources, complex minerologies, and resources with large sulfur contents, all of which are currently challenging the mining industry.
- **Unpredictable Commodity Prices and Thin Profit Margins -** Mineral commodity prices are very uncertain and have thin profit margins. One cause is a lack of advanced products with a higher value-added than current basic minerals. These challenges prohibit the commitment of capital and resources to new technologies and processes.

Other non-technical challenges are the continued industry consolidation and the need for strong industry leadership that is willing to take risks and get involved in research and development. Strategies to maximize our technology investment include transferring technology from other industries and focusing our resources on those technologies with the widest applications cross the industry. A few of those opportunities for direct application of existing technologies are identified here:

- **Energy Efficiency -** Improvements and the use of best industry practices in the energy efficiency of machinery and equipment can lead to near-term energy savings for the industry. This includes optimized pumps and motors used for dewatering, for crushing and grinding, and for conveying and transferring material.
- **Sensor Technologies -** 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 to understand the characteristics of materials prior to processing and improve the efficiency and processing activities.
- **Improved Materials -** Advances in structural material technologies and the application of those materials in mining processing environments can reduce machinery wear, reduce repair and replacement costs, and extend machinery life.
- **Environment -** Many of the advances in processing identified herein have the potential to reduce environmental impacts. For example, improvements in methods for dust control will address a high profile environmental issue for the industry. In addition, greater use of modeling and sensor technologies which reduce blasting and processing requirements will result in reduced waste and energy expenditure for the industry.
- **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 all areas of processing research and development.

Achieving Our Goals

Through the successful implementation of research activities charted in the Processing Roadmap, and the attainment of the performance targets outlined herein, the Mining Industry of the Future seeks to achieve important objectives in five major goal areas by 2020. These include:

Energy

- A 30% increase in energy efficiency (processing energy consumption per unit of product output)

Environment

- A 20% reduction in emissions per unit of product produced
- Advances which will enable zero notices of violation of environmental regulations
- A 20% increase in utilization of removed material per unit of product output

Health and Safety

- Zero processing-related fatalities
- Zero processing-related health and safety reportable incidents
- Advances which will enable zero notices of violation of safety and health regulations

Productivity

- A 20% increase in unit of product per labor hour
- A 20% increase in return on capital employed
- A 20% increase in value added at the processing facility

Reserve Base, or Mineral Supply

- A 50% increase in US fuel and non-fuel mineral reserves through improved economics and technology advances

These goals will be achieved only through a continued research partnership between industry, government, and academia. For this partnership to remain strong, it is critical that each member of the partnership understands the others' priorities and values. A major purpose of this roadmap document is to demonstrate the dependencies among the various processes and technologies and to highlight the interrelationships among them.

Mining is a highly complex and multidimensional industry made up of literally thousands of different processes. Many of the research needs identified in this roadmap are highly specific to the various processes and technologies in Mineral Preparation, in Physical Separations, and in Chemical Separations. Because of the wide variety of processes and products across the mining industry, it is not always easy or possible to link each process improvement with a specific technology target.

It is even more difficult to consistently associate process improvements with the ultimate benefit in energy, environment, health and safety, productivity, and reserves. However, this is critical to the success of our government-industry partnership, and even more so to the ultimate success of the US mining industry itself.

It is also important to recognize that the greatest improvements in mineral processing will potentially arise from the optimization of combined processes and the synergies which arise. A key example of this is to consider blasting and drilling as an integral part of the crushing and grinding process. Similarly, combining grinding and beneficiation into a single process would result in the removal of the valuable mineral from further grinding once it has been liberated from the ore, and could save substantial time and energy.

Another example is to combine beneficiation, dewatering, and agglomeration into a single process, thereby reducing flowsheet complexity and material handling. Ultimately, in-situ mining may be able to combine several mining processes and eliminate many of the more inefficient ones. 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.

Finding the links among processes, the ties between process improvements and technology targets, and the ultimate connection of technology achievements to societal benefits is the ultimate challenge to the mining and mineral processing industries.

In an effective partnership with integrated goals, no process improvement would have a negative impact on any one of the five benefits. We will find that efficient processes can also be safer processes. That safer and more efficient processes can - and most probably will - have less environmental impact. That safer, more efficient, and less impacting processes all lead to higher productivity and to an increased reserve base. The integration and interdependence of each step in the overall process can be as important as the whole.

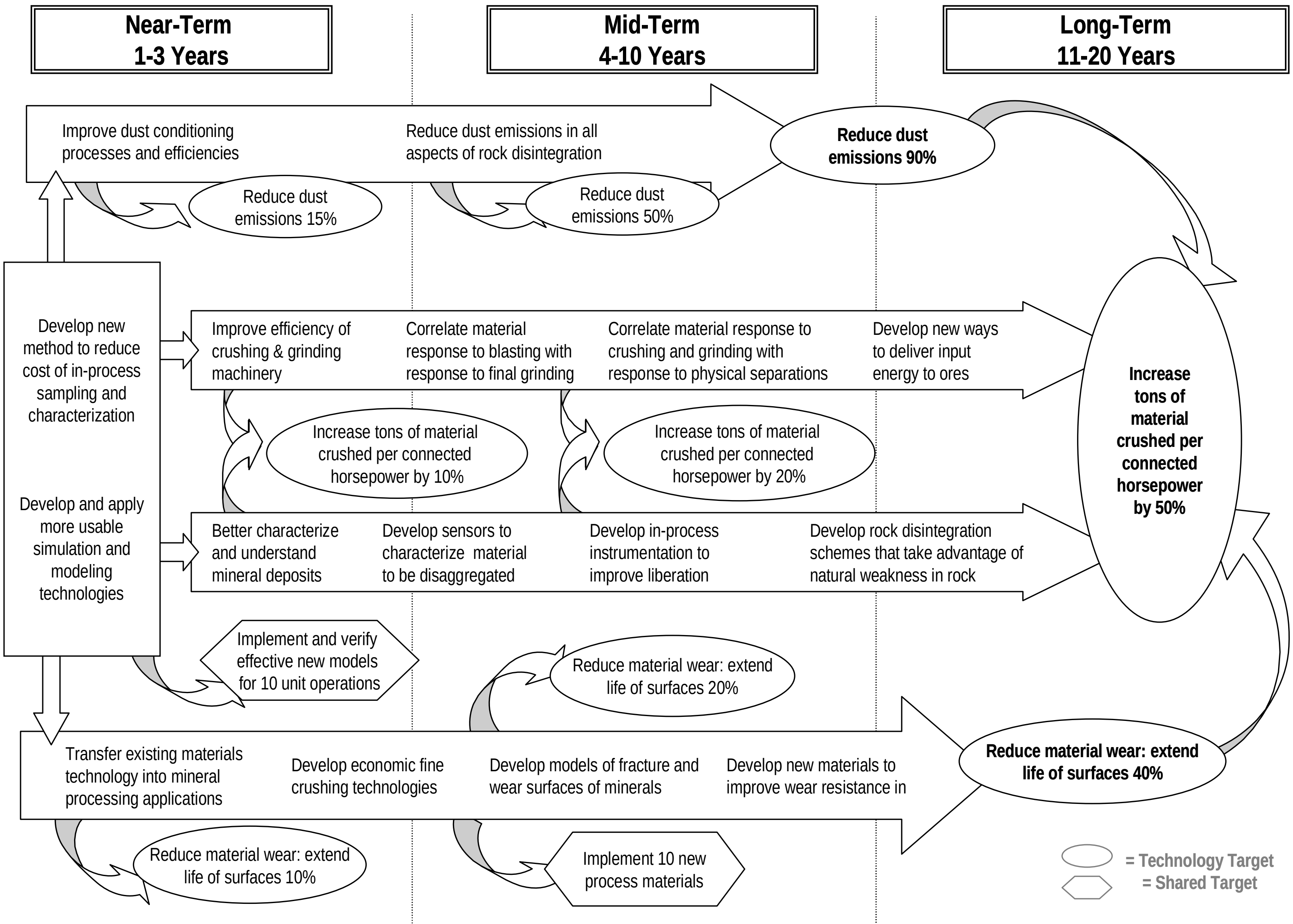
The optimization of the overall mining process, not just the individual elements of mineral processing, is a high-level industry goal. Shrinking research and development budgets affect all aspects of technological development in mining and in other industries. Pre-competitive cooperation among mining companies, equipment vendors, government laboratories, and academia is critical to the successful realization of the mining industry's vision.

Another key partner to success are the government agencies who collect, analyze, and disseminate data describing mining industry products and processes. Numerous federal, state, and regional entities currently collect a staggering array of information about mining in the US. Using this data to determine new technology directions, to discover effective implementation strategies, and to justify technology decisions will be necessary for overall program success.

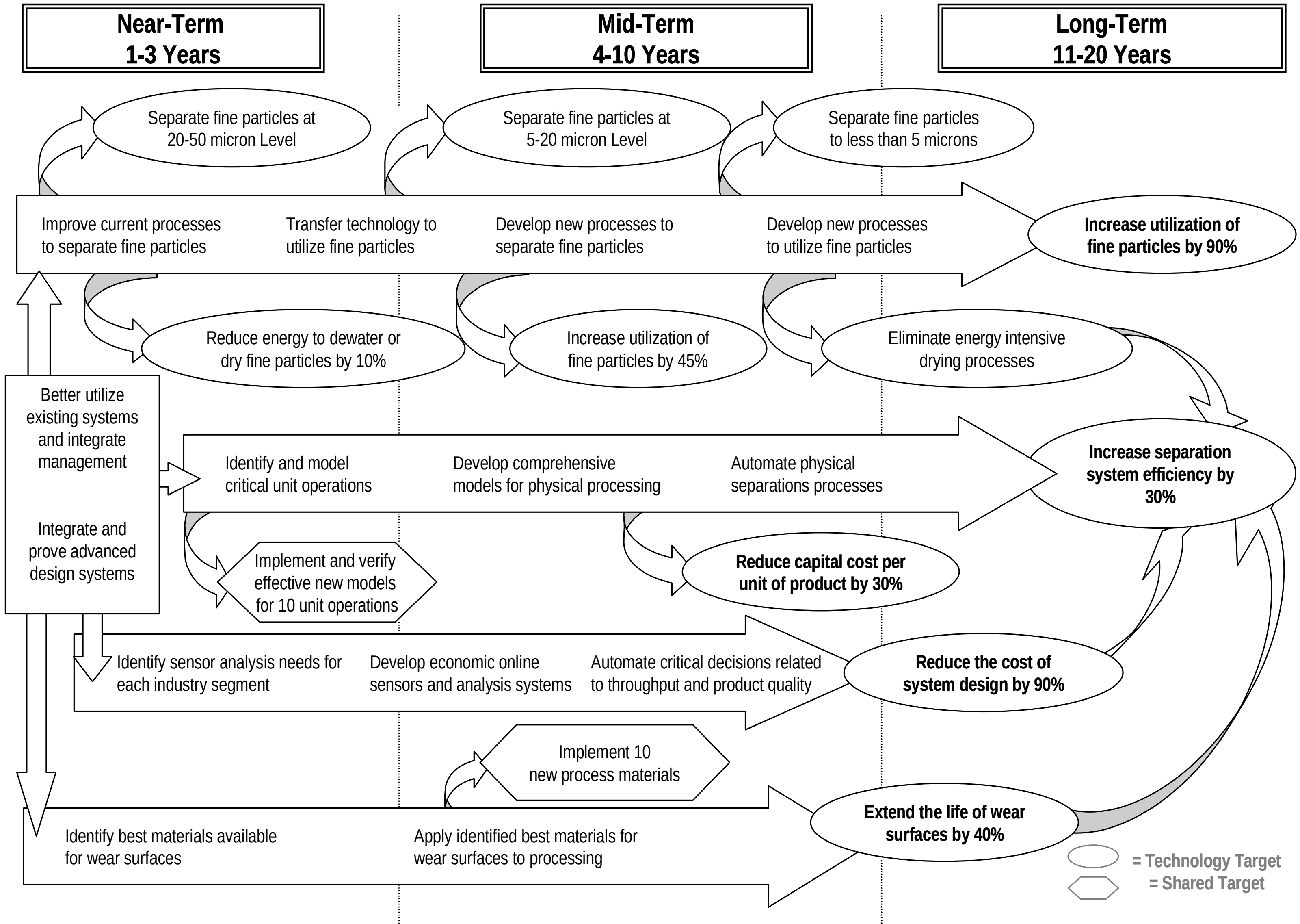
The high-level goal to increase the reserve base can be achieved by through advanced mineral processing technology by creating economic processes for material once considered waste. These materials may include easily-accessed deposits with previously unprocessable impurities, or accessing easy-to-process deposits that were previously difficult to access. They materials may also include previously processed and stored material wastes which contain products that can be recovered by new processes, both from process tailings and from post-consumer sources. New reserves may also come from brand new unrecognized or untapped resources for products our society needs to maintain our way of life.

Through this effort to lay out its own technology strategy, the US mining industry has provided the means for the entire research community to find applications for many technology efforts to improve mineral processing in keeping with the industry's top-priority needs.

Roadmap for Mineral Preparation



Roadmap for Physical Separations



Roadmap for Chemical Separations