MINE WASTE TECHNOLOGY PROGRAM: HISTORICAL PERSPECTIVES, CURRENT HIGHLIGHTS, FUTURE OPPORTUNITIES[1]

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Abstract. For the past 13 years, the Mine Waste Technology Program (MWTP) has been operated by MSE with administrative assistance from the Department of Energy (DOE)'s Western Environmental Technology Office (WETO) and technical direction from EPA's National Risk Management Research Laboratory (EPA-NRMRL). A portion of the MWTP funding has been used to perform Field Demonstrations of innovative technologies with the potential to address mine waste issues. This paper will highlight current and past MWTP successes and discuss important lessons learned.

Over 70 distinct projects have been completed or are currently being performed by MSE and Montana Tech of the University of Montana. Some issues addressed by these projects include: sustainability; acid drainage/water treatment; trace/heavy metal removal; remote locations; source control; pit lakes; and heap detoxification/closure. Other projects are focused on prediction, characterization, and modeling.

Within the past year, new MWTP management personnel have been assigned at MSE, EPA-NRMRL, and Montana Tech of the University of Montana providing an opportunity for positive evolution of the MWTP. Future strategies for MWTP success will also be presented.

Additional Key Words: acid drainage, water treatment, sustainability, source control, pit lakes, remote locations, selenium, arsenic

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Introduction

Since 1991, the Mine Waste Technology Program (MWTP) has been implemented by MSE Technology Applications (MSE) with administrative assistance from the Department of Energy (DOE) and technical direction from EPA's National Risk Management Research Laboratory (EPA-NRMRL). A portion of MWTP funds are used to perform Field Demonstrations of innovative technologies with the potential to address mine waste issues. Other funded areas include: issue identification; quality management system; project specific quality assurance/quality control; bench-scale research; training and education; and technology transfer.

Relevance

A report by Resources for the Future indicated that hardrock mining mega sites (sites with estimated cleanup costs greater than $50 million) cost about twice as much to clean up when compared to other types of sites on the National Priority List (NPL) under EPA's Superfund program (Probst and Konisky, 2001). In an effort to cut cleanup costs, the Office of the Inspector General (OIG) recommended that EPA perform a review and analysis of:

- "innovative, alternative, or promising new remediation technologies (engineered or non-engineered) that identify enhanced efficiency and effectiveness in addressing remediation of hardrock mining sites and associated waste." (EPA-OIG, 2004)

The MWTP has been fulfilling this mission over its history. A recent review of the technologies demonstrated under the MWTP to date has been performed to assist with addressing issues at Superfund mega sites, many of which are mining sites, most cost effectively.

In addition, the MWTP is virtually the only public forum for technology providers to obtain funding and have their innovative technologies that address mine waste issues tested and evaluated. Occasionally, there is a special Small Business Innovative Research (SBIR) call to address mine waste issues, but this is the only effort with long-term, steady funding for one of the biggest environmental problems facing the United States and the world.

Balance

There is a need for balance that simultaneously promotes mining and environmental protection to ensure sustainable development of the Nation's mineral resources. Mining is essential to maintain our way of life. The mining industry is also an important contributor to both national and regional economies and is critical to national defense. The benefits of mining to this country have been many, but have come at a cost to the environment:

- Nationwide there are over 200,000 inactive and abandoned mines that have a substantial aggregate impact on the environment.

- Thousands of miles of streams and rivers are impacted by acid drainage from mines in the United States.

- There are 82 abandoned hardrock mines, or mining related, sites on the Superfund National Priorities List (NPL). (EPA, 2004)

The cost of the cleanup of inactive and abandoned mines is estimated to be between $2 and $37 billion. (EPA-OIG, 2004)

In recent years, environmental practices employed by the mining industry have improved considerably. Installation of best management practices for control of storm water runoff, improvements in treatment of wastewater, better management of tailings and waste rock, and more efficient metal recovery technologies have all contributed to reduced environmental impacts from mining projects, but wastes resulting from mining activities remain a significant issue.

Approach

MSE and Montana Tech of the University of Montana (Montana Tech) implement the MWTP with assistance from the DOE and EPA-NRMRL. The MWTP Technical Integration Committee (TIC), which includes representatives from industry and state and federal regulatory communities reviews proposals and determines the direction of research within the MWTP. Projects are peer reviewed by EPA-NRMRL at least twice a year. All final reports are peer reviewed.

The MWTP is administered from MSE's Butte, Montana office. The fact that large volumes of aqueous and solid mine waste are available in Butte has provided test beds for MWTP projects. Other locations around Montana have provided the majority of additional sites for MWTP projects. While Butte and Montana's past mining history has generated ideal test beds for the majority of MWTP projects, the MWTP has had a national impact. The map shown in Fig. 1, which shows the MWTP project locations, illustrates this point.

Results

Over 70 distinct projects have been completed or are currently being performed by MSE and Montana Tech. This paper is focused on the work ongoing or completed by MSE and examines the successes and important lessons learned to date. Other information on these projects can be accessed from historical MWTP annual reports, MWTP CDs, and on the MWTP website: http://www.epa.gov/ORD/NRMRL/std/mtb/mwt/

Currently there are 16 active projects at MSE at various stages of completion. These projects are listed below under the appropriate issue area being addressed:

Sustainability
- Acid/Heavy Metal Tolerant Plants (Anaconda, Montana);

Source control/Bioavailability reduction
- Contaminant Speciation in Riparian Soils (Idaho);

Source control/Passivation
- Microencapsulation to Prevent AMD (Minnesota);

Acid drainage/Water treatment

- In-Situ Source Control of Acid Generation Using Sulfate Reducing Bacteria (SRB) at the Lilly Orphan Boy Mine (Elliston, Montana);
- Integrated Passive Biological Treatment at the Surething Mine (Elliston, Montana);
- SRB-Driven Sulfide Precipitation at Golden Sunlight Mine (Whitehall, Montana);
- Reduction of Metal Loading from the McClelland Tunnel Drainage to Clear Creek Using SRB Systems (Colorado)

Passive treatments

- Long-term Monitoring of a Permeable Treatment Wall (Idaho);
- Passive Treatment Technology Evaluation for Reducing Metal Loading (Idaho);

Trace/Heavy metal removal

- Physical Solutions for Acid Mine Drainage at Remote Sites (Arsenic focus) (Rimini, Montana);
- Thallium Removal from Mine Waste Waters (East Helena, Montana);

Pit lakes

- Integrated Process for Treatment of Berkeley Pit Water (Butte, Montana);
- Bioremediation of Pit Lakes (Gilt Edge Mine, South Dakota);
- Mine Site Telemetry—Fuel Cell (Rimini, Montana);

Caps/Covers

- Electrochemical Tailings Cover—ENPAR (Butte, Montana); and

Heap detoxification/closure

- Cyanide Heap Biological Detoxification Phase II (Nevada).

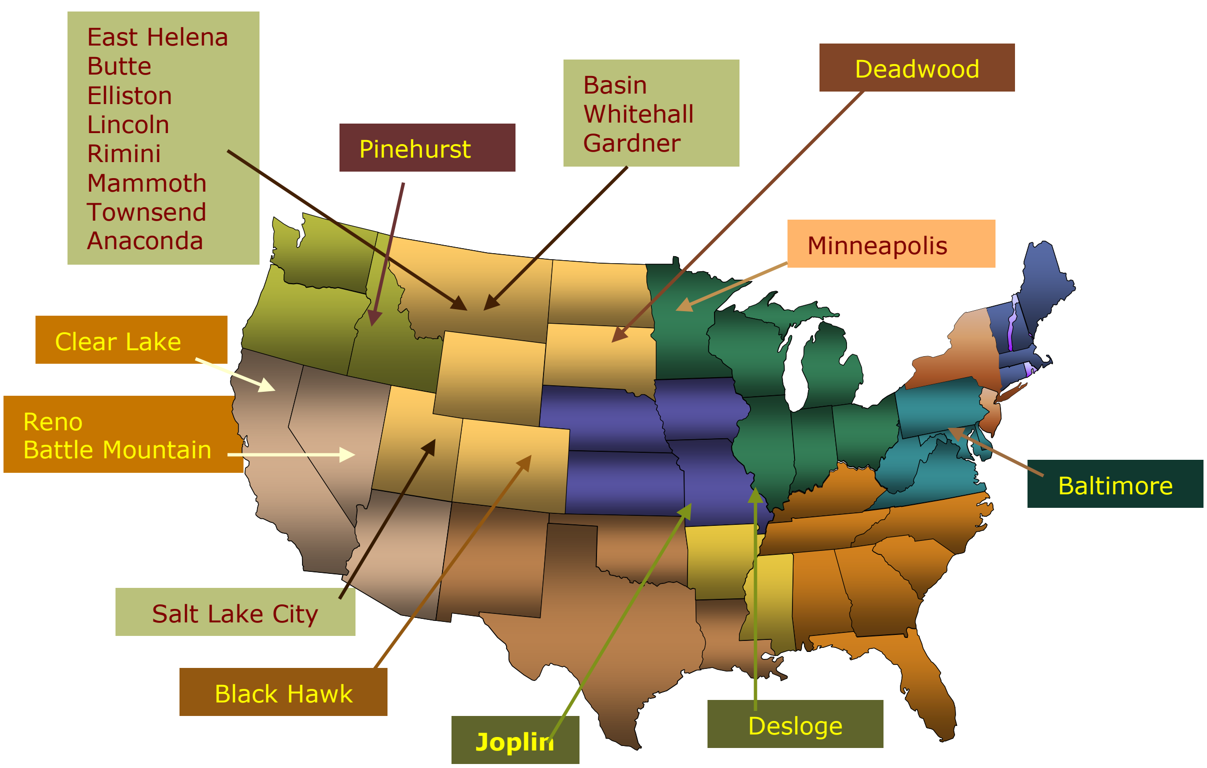

Figure 1. Map of MWTP Project Locations Performed by MSE

Because over 30 projects have been completed by MSE to date, it would be impossible to summarize all of the work completed. However, the following sections highlight results in the following areas:

- Sustainability—Acid/Heavy Metal Tolerant Plants;
- Acid Drainage Treatment—Sulfate Reducing Bacteria Related Projects;
- Trace Metal Removal—Arsenic Removal;
- Trace Metal Removal—Selenium Removal; and
- Pit Lakes—Bioremediation of Pit Lakes.

<u>Sustainability—Acid Heavy Metal Tolerant Plants</u>

Grass, forb and shrub species that were previously commercially available for reclaiming acidic/heavy metals-contaminated soils often came from outside the Northern Rocky Mountain region. Over the past several years, plant populations exhibiting acid/heavy metal tolerance have been collected from the Anaconda Smelter Superfund Site and evaluated in laboratory, greenhouse, and field studies, which are still ongoing. The State of Montana's Natural Resource Damage Program and the MWTP are jointly funding this project. The project team also includes the Deer Lodge Valley Conservation District and the United States Department of Agriculture's Bridger Plant Materials Center. The results of the study indicate that local plants are better adapted to the acidic soil conditions at the project site and were more effective than previous commercially available varieties. Seeds for the more acid tolerant plants are now commercially available for full-scale reclamation projects in the region. Seeds releases from the project include: Old Works Germplasm Fuzzy Penstemon; Prospectors Germplasm Common Snowberry; and Washoe Germplasm Basin Wildrye (Cornish, 2004)

<u>Acid Drainage Treatment—Sulfate Reducing Bacteria Related Projects</u>

For the past 10 years, a sustainable passive treatment using SRB has significantly improved the quality of water emanating from the Lilly/Orphan Boy Mine, located near Elliston, Montana. This remote, abandoned mine discharges into a tributary of the Clark Fork River. The organic nutrient applied to stimulate the naturally occurring SRBs was applied only the first year—the treatment has become self-sustaining. The physical features of the mine were used as part of the treatment eliminating the need for capital investment in equipment, and the treatment has virtually no annual operating costs. The technology has been transferred from the MWTP to various U.S. Forest Service Sites and has led to several other MWTP projects to better understand basic processes and make improvements to optimize the technology:

- Sulfate-Reducing Bacteria Reactive Wall at the Calliope Mine near Butte, Montana (Zaluski, 2002);
- SRB-Driven Sulfide Precipitation at Golden Sunlight Mine near Whitehall, Montana (James, 2004);
- Improvements in Engineered Bioremediation of Acid Mine Drainage in Butte, Montana (Zaluski et al., 2004);
- Integrated Passive Biological Treatment System at the Sure Thing Mine near Elliston, Montana

During the summer of 2004, MSE implemented modifications to the Integrated Passive Biological Treatment at the Sure Thing Mine to improve the removal of the most recalcitrant metal—manganese and alleviate plugging problems. Early indications are that the modifications were successful. The investment by the MWTP to modify this system will lead to a better understanding of how to design, operate, and maintain passive biological systems for the treatment of acid rock drainage at remote sites. Fig. 2 shows a picture of the integrated, passive biological treatment system at the Sure Thing Mine. (Park, 2004).

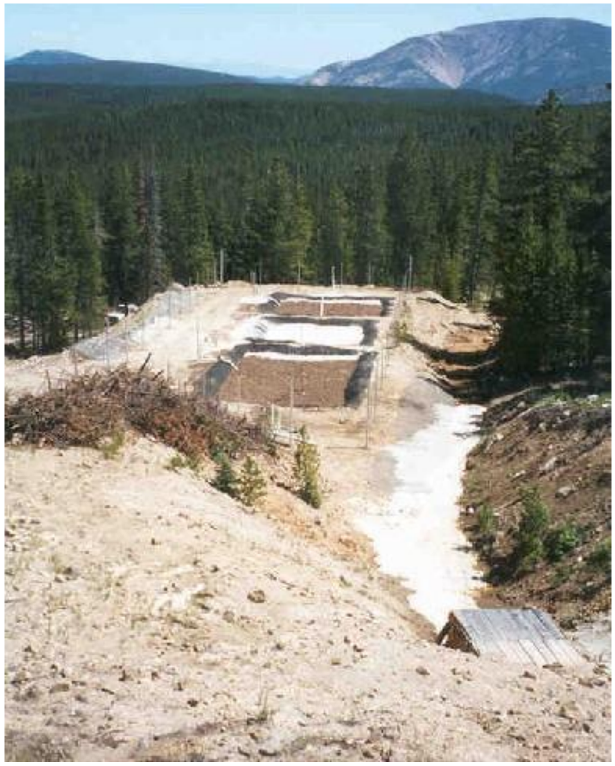

Figure 2. Integrated, passive biological treatment system at the Sure Thing Mine near Elliston, Montana.

Two patents have been acquired by MSE related to the SRB-related projects that can be used to address mine waste issues (US 6,325,923B1—Bioreactor for Acid Mine Drainage and US 6,258,261B1—Honey comb Cell Structure for Fluid-Solid Reactor). A computer simulator (BEST—Bioreactor Economics, Size, and Time of operation) was developed to design SRB bioreactors that treat AMD. This simulator addresses size of a bioreactor its economics and time of operation (Zaluski et al., 2004).

A new project initiated in 2005 will be focused on the sustainability of substrate materials used in SRB bioreactors. MSE and a researcher from the Colorado School of Mines (CSM)/Rocky Mountain Regional Hazardous Substance Research Center (RMR-HSRC) are collaborating on a project that combines the fundamental SRB process knowledge of CSM/RMR-HSRC with the SRB-related field experience of MSE personnel. This project will be performed at the McClelland Tunnel drainage to Clear Creek in Colorado. This is an example of how the MWTP is ensuring that knowledge is shared to achieve a common goal. (Zaluski, 2005)

Trace Metal Removal—Arsenic

Several MWTP projects have also focused on arsenic removal (McCloskey et al., 1997, 1998, 2003). An MWTP arsenic removal technology was deployed at a Sherwin-Williams facility in Emeryville, California in the late 1990s that is capable of removing arsenic to below 10 parts per billion, the National Primary Drinking Water Regulation that will take effect in January 2006. (CFR, 2002).

More recently, the focus has been on the Ten Mile Creek Superfund Site, near Rimini, Montana, which has several abandoned mines that are sending several gallons per minute of arsenic-contaminated water to a creek that is a drinking water source for Helena, Montana. The deposits in the Rimini Mining District are primarily composed of quartz monzonite sometimes capped by flows of Tertiary ryolite. The ore bodies are auriferous silver-lead deposits of galena with sphalerite, pyrite, and arsenopyrite. (Schrader 1929) One project will treat the water emanating from the Susie Mine. The Susie Mine is an abandoned gold-silver-lead mine, near Rimini, Montana. A semi-passive treatment system has been designed to treat this water, prior to discharge to Ten Mile Creek. Discharge requirements are based on the State of Montana's *Montana's Numeric Water Quality Standards,* WQB-7. (MDEQ, 2004)

Table 1 summarizes data for the Susie Mine discharge with appropriate treatment discharge requirements. Also presented in Table 1 are the results of bench-scale treatability studies from the optimized treatment system.

Table 1. Susie mine discharge, discharge requirements, and optimized treatment data.

Parameter	Assumed Discharge Criteria (Hardness 400mg/L) (Φg/L)	Susie Discharge Concentration (Φg/L)	Optimized Treatment System Effluent (Φg/L)
pH	6.5-8.5	3.8	11.5
Arsenic	10	8550	0.53
Iron	300	154,000	90.3
Manganese	50	15,100	Below detection
Zinc	388	36,000	Below detection

Another project at the Ten Mile Creek NPL site in Montana will use grout to shut-off or reduce the amount of flow emanating from the Lee Mountain Mine, an abandoned gold-silver-lead-zinc mine, and treat any residual water with a passive treatment system. Contaminants of concern at the Lee Mountain mine and their most recent concentrations, and probable discharge criteria are summarized in Table 2.

Table 2. Discharge criteria and recent concentrations for the Lee Mountain Mine.

Parameter	Discharge Criteria (Φg/L), unless otherwise noted	January 2005 Results (Φg/L), unless otherwise noted
PH (SU)	6.5-8.5	2.8
Dissolved Arsenic	10	8270
Dissolved Cadmium	0.27	350
Dissolved Copper	9.3	350
Dissolved Iron	300	154,000
Dissolved Lead	3.2	560
Dissolved Manganese	50	21,100
Dissolved Zinc	120	56,700

Both aforementioned projects are being performed with EPA Region 8, Montana Department of Environmental Quality, and Camp Dresser & McKee (CDM). Figure 3 is a photograph of treatability studies at the Susie Mine.

Figure 3. Arsenic Treatability Studies at Susie Mine, Ten Mile Creek, Rimini, Montana

Trace Metal Removal—Selenium

An MWTP project tested and evaluated several selenium removal technologies to reduce selenium concentrations in the Garfield Wetlands-Kessler Springs water at Kennecott Utah Copper Corporation (KUCC). KUCC's Garfield Wetlands-Kessler Springs site has a well-defined selenium contaminated artesian flow with the following characteristics: groundwater containing selenate ranging from <50 to 10,000 Φg/L; artesian flows 250–500 gpm, with selenium concentrations from 200 to 2,000 Φg/L; and varying site water quality with some naturally occurring total dissolved solids concentrations greater than 5,000 mg/L. Selenium, the primary contaminant of concern at this site, is present as selenate in the site's groundwater. Ground-water formerly surfaced from two main sources within the site into a large wet-lands area on the boundary of the Great Salt Lake. Selenium contaminated artesian flow is currently captured and routed into KUCC's process water circuit. The contamination is of a low-level, high-volume nature that makes most treatment options expensive.

Two innovative technologies as well as ferrihydrite precipitation--the Best Demonstrated Available Technology (BDAT)--were evaluated. The influent water used for the demonstration was the Garfield Wetlands-Kessler Springs ground water containing approximately 2000 Φg/L selenium. The primary objective was to reduce the concentration of dissolved selenium in the effluent waters to a level under the National Primary Drinking Water Regulation Limit for selenium of 50 Φg/L established by EPA (CFR, 2002). All three technologies removed selenium to below the project objective of 50 Φg/L under optimum conditions. The biological selenium reduction (BSeR™) technology developed by Applied Biosciences of Salt Lake City, Utah, was the most consistent process tested, with the majority of results less than the detection limit for selenium of 2 Φg/L. This technology was selected as the preferred treatment in the Record of Decision for this Superfund site. (Joyce et al., 2001). Fig. 4 is a photograph of the BSeR technology at the KUCC demonstration site.

Figure 4. BSeR system at Kessler Springs Site at Kennecott Utah Copper Corporation.

Pit Lakes—Bioremediation of Pit Lakes

Over the past three years, the Anchor Hill Pit at the Gilt Edge Mine National Priority List (NPL) site near Deadwood, SD, has been the site of a joint effort by the U.S. EPA's Region 8 Superfund Remedial Program and the MWTP. The project's aim is to demonstrate and evaluate an innovative in-situ process for treating approximately 70 million gallons of acidic mine water containing high levels of dissolved metals, selenium, nitrate, and sulfate. Data for this water prior to treatment is summarized in Table 3. Figure 5 is a photograph showing molasses addition to the Anchor Hill Pit. EPA and DOE estimate that in-situ use of this technology will avoid 20-50% of the operational costs associated with a conventional water treatment plant. Full-scale use of the pit an operational mode is anticipated in the future. Following large-scale batch treatment, water will be removed from the pit, filtered, and aerated to meet state ambient water quality requirements for discharge to surface water. The ultimate vision for the in-situ treatment is to utilize the pit as a water treatment reactor for treatment and eventual discharge of other site waters. This project was featured in the September 2004 issue of EPA's *Technology News and Trends* (Wangerud, et al., 2004). To date, 4.3 million gallons of water have been discharged from the Anchor Hill Pit. (Park, 2005).

Table 3. Initial concentrations of contaminants of concern for the Anchor Hill Pit Lake.

Parameter	Initial Concentrations (Φg/L, unless otherwise noted)
PH (SU)	3.3
Aluminum	224,000
Arsenic	73
Cadmium	576
Copper	43,300
Iron	15,700
Magnesium (mg/L)	195
Manganese	27,100
Selenium	26
Zinc	14,100
Nitrate-Nitrite as N (mg/L)	82.9
Sulfate (mg/L)	3,270
Chloride (mg/L)	37.3
Acidity (mg/L as Ca CO_3)	1295

Figure 5. Molasses addition to Anchor Hill Pit, Gilt Edge Mine South Dakota

Lessons Learned

The previous section discussed historical and recent positive outcomes of MWTP activities performed at MSE. Lessons learned have also been identified and are briefly discussed below.

- Historically, the MWTP was structured around seven activities (issues identification, quality assurance, pilot-scale demonstrations, bench-scale research, technology transfer, training and education, and program support). An evolution of the MWTP is needed to focus on issues and how to most cost effectively address them rather than focusing on funding activities.
- Similarly, the technologies evaluated should have wide applicability at problem sites rather than solutions looking for problems.
- The MWTP needs to be more forward-looking and proactive to provide the mining industry with approaches for dealing with mine wastes to encourage more domestic mining.
- Collaboration with other US and international groups involved in similar efforts is needed to ensure the most efficient use of the available dollars.
- TIC membership should be evaluated and more focused on industrial/technical side.
- Industry partners, including Placer Dome—Cortez Mine (Nevada), Placer Dome—Golden Sunlight Mine (Montana), Kennecott Utah Copper Corporation (Utah), Doe Run Company (Missouri), BP America (Arco) (Montana), and Echo Bay Mining (Nevada) have contributed significantly to technology development by providing in-kind services. Even greater participation by industry can only improve and expand the program while ensuring ongoing work addresses the needs of industry.

Future success will depend on implementing necessary improvements and addressing high-level needs for government and industry and communicating this to the regulatory and scientific communities, industry, and the general public. An immediate need is to change the focus of the technology transfer activity from producing MWTP CDs and annual reports to also include support for site visits and meetings to communicate the availability of new technologies to address pressing mine waste issues and in some cases other types of wastes. One other key to MWTP success has been identifying regulatory individuals and industry participants that are willing to try innovative approaches. There is a certain personality type that best fits the mission of the MWTP when working with regulatory and industry personnel.

Future Opportunities

A report by the United States Environmental Protection Agency (EPA)—*Acid Mine Drainage: Innovative Treatment Technologies,* featured a case study of an MWTP project near Butte, Montana. This report concluded: "Given the seriousness and scale of mine drainage it is important to continue to work towards affordable and effective treatment options…there is need for more work, some of the more pressing areas include communication, funding, and research about fundamental processes" (Costello, 2003).

The MWTP envisions an interstate, focused effort involving a cohesive group of state and federal agencies, industry, researchers, academia, and technology providers that most effectively uses available resources to address issues associated with mining wastes to mitigate the impacts of past, present, and future mining activity and ensure sustainable development of the mineral resources of the United States. The focus would be on the development of cost effective technologies in order to achieve cleanup of inactive and abandoned mines with substantial cost savings compared to traditional technologies. This will in turn lead to improved economics/sustainability for current and future mining opportunities in the United States and around the world. The new technologies developed could then be applied to address mine waste issues worldwide, effectively turning a liability into a technology export opportunity.

Other groups/technology developers involved in addressing this issue for both metal mining and coal mining would also be included in this focused effort. While many federal and state agencies, private companies, trade associations and non-government organizations, as well as academic institutions have variable focus on mining environmental problems, there is not an active, focused effort to address this significant, costly issue.

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