INVESTIGATION OF CURRENT RESEARCH RELATED TO THE REDUCTION OF ENERGY USAGE IN MINES THROUGH RECYCLING, REUSE, AND OTHER MEANS

LCG Energy Management Group

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1. Executive Summary

1.1 Preamble

Research leadership focused on creating an energy efficient mining operation is not apparent. However, current research activities can be aligned with the most energy intensive activities of mining and concentration/mineral recovery so that a road map of research toward a vision of the Energy Efficient Future Mine can be developed.

The investigation proceeded through the following phases:

- Analysis of energy usage in underground mines, base metal concentrators and gold recovery facilities
- Compilation of current global research activities related to improving energy performance at mining operations
- Development of a research landscape and vision of the energy efficient mine of the future
- Alignment of CEMI with future research niches

Researchers interviewed during the project emphasized that in current economic environment mining companies and technology suppliers are primarily interested in research projects with a 1 to 2 year return on the investment of time and money.

1.2 Energy Theory

Energy is a significant input to mining production processes and as result energy efficiency must be considered within the context of the production process that uses it. In other words the demand for energy is dependent on the characteristics of the process consuming it. Therefore, energy efficiency improvement solutions or research cannot be looked at in isolation but must consider the influence of all relevant energy demand drivers within the complete process or system. Each production process activity will require a specific amount of energy to complete the fundamental work required by the process. Consequently, any step change in energy efficiency will occur only if there is a step change reduction in the fundamental work required.

1.3 Analysis of Energy Use

Using the benchmarking study of the energy consumption in underground mines, base metal concentrators and gold recovery facilities the following assessment of energy use at mining facilities was completed.

The underground mining activities are ranked in TABLE 1.1 below in terms of their percentage contribution to the overall mining energy intensity in kwhe per tonne of ore hoisted. It is immediately obvious that the ventilation activity is the dominant contributor to the total underground mine energy intensity and therefore energy usage.

ENERGY INTENSITY RANKING		
1	Ventilation	41.8%
2	Hoisting	12.6%
3	Drilling	8.9%
4	Transport to Mill	7.3%
5	U/G Support	7.0%
6	Mucking	6.9%
7	Dewatering	4.9%
8	Backfill	4.7%
9	Transport U/G	3.5%
10	Blasting	1.4%
11	Crushing	0.9%

TABLE 1.1

Base metal concentrator activities are ranked in following table in terms of their percentage contribution to the overall concentrator energy intensity in kwhe per tonne of ore milled. Separation/flotation, grinding and filtering/drying are the most energy intensive activities with the percentage difference between grinding and filtering and drying being only 3.2%.

ENERGY INTENSITY RANKING		
1	Separation/Flotation	29.4%
2	Grinding	21.8%
3	Filtering/Drying	18.6%
4	Heating/Lighting	14.7%
5	Crushing	10.5%
6	Mill Support	2.8%
7	Tailings Disposal	2.1%

TABLE 1.2

The Energy and Cost intensities for Gold Recovery were analyzed and ranked in the same manner as Base Metal Concentration. The table displays the rankings of the production process activities. Extraction/Refining and Grinding are the dominant contributors to both the energy and cost intensities. The remaining activities cluster in the 1.8 to 6.4 % contribution range.

ENERGY INTENSITY RANKING		
1	Extraction/Refining	53.3%
2	Grinding	24.1%
3	Crushing	6.4%
4	Heating/Lighting	6.0%
5	Separation	5.7%
6	Tailings Disposal	2.5%
7	Mill Support	1.8%

TABLE 1.3

1.4 Research Landscape

The review of current global energy efficiency related research activities being carried by government agencies, public/private/academic consortiums, research centers, universities and engineering consultants which is documented in the detail in the body of the report and in Appendices 1A and 1B.These activities were used to create the research landscape shown in the FIGURE 1.1 below.

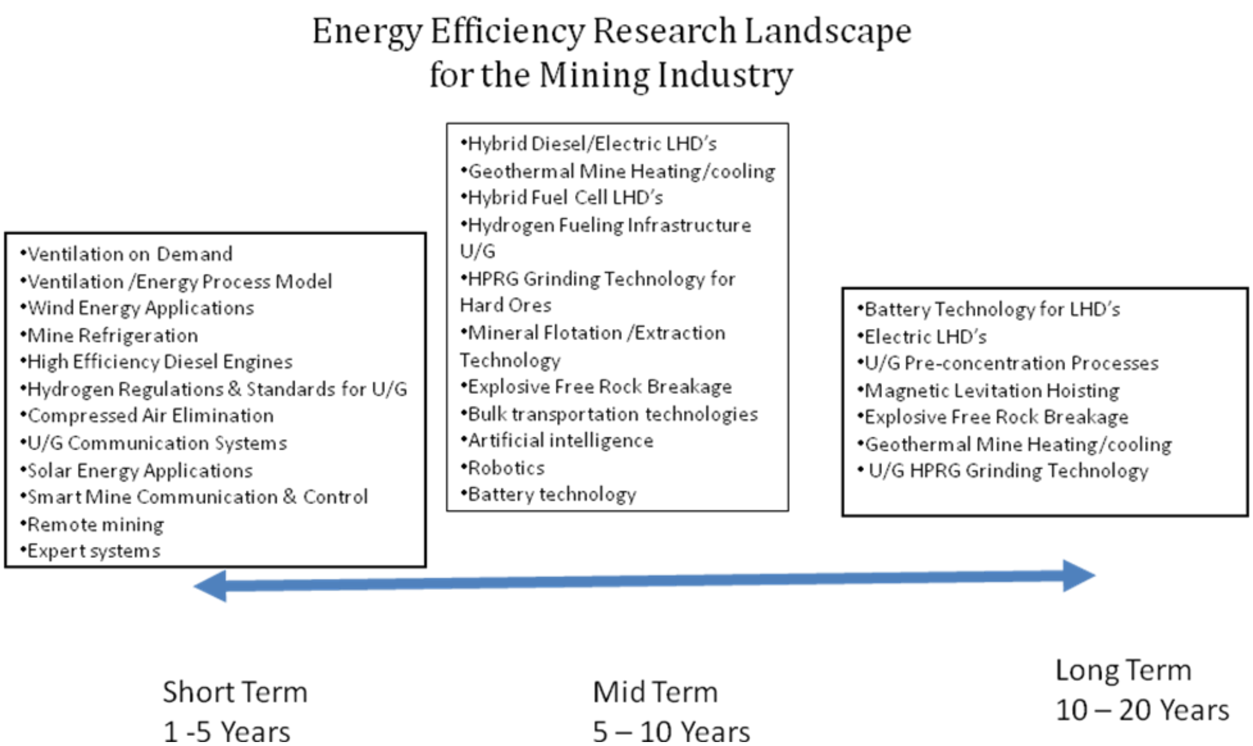

FIGURE 1.1

An analysis of the research activities with reference to energy efficiency improvement requirements stated by mine operators and a long term vision of the energy efficient mine of the future led to the identification of the following research gaps .

Short term gaps include the following niche areas of research:

- Dynamic ventilation/energy U/G mine process model or balance developed from real mine data
- Wind turbine technology for use in extreme cold - northern mines
- Smart mine communication and control developed from real mine data

Midterm gaps include the following niche areas of research

- Recovery and application of geothermal energy in operating mines
- High Pressure Roller Grinding (HPRG) technology for hard ores

- Artificial intelligence and robotics
- High capacity battery technology

Long term gaps include the following niche areas of research

- Electric LHD and service vehicles
- U/G pre-concentration of mine ore
- Magnetic levitation hoisting

The most significant barrier to applying researched technologies to the mining industry is the inability to affectively collect organize, analyze, and communicate high quality mine production process, infrastructure and environmental data in manner that the makes facility performance visible and real to mine operators and managers. Success in the area of ‘data management’ is critical to improving energy and process efficiencies. This challenge is being addressed by The Smart Mine concept, but many opportunities still exist for research efforts that focus on the capture, transmission and organization of real mine data directly associated with mining activities.

1.5 Potential Niche Energy Efficiency Research Areas for Consideration by CEMI

1. Leadership and coordination of research toward the Energy Efficient Mine of the Future
2. Dynamic ventilation/energy U/G mine process model or balance developed from real mine data
3. Smart Mine monitoring, data management, communication and control developed from real mine data
4. Recovery and application of geothermal energy in operating mines
5. High capacity battery technology
6. Electric LHD and service vehicles
7. U/G pre-concentration of mine ore
8. Magnetic levitation hoisting

2. Introduction

The Center for Excellence in Mining Innovation (CEMI) located in the Willet Green Miller Center at Laurentian University in Sudbury has commissioned this scoping study to determine what ongoing global research exists related to improving the energy efficiency of mining operations, as well as what areas present themselves as niche opportunities for future research that could be supported by CEMI

The purpose of the study is to identify research that will lead to the reduction of energy usage at mine operations through recycling, reuse, substitution, and elimination thus making the mine more energy efficient.

A mine's energy efficiency is determined by the amount of product that can be produced per unit of energy used. Typically a mining facility's energy performance is described and tracked in terms of energy intensity or units of energy used per unit of product. Energy intensity is simply the mathematical inverse of energy efficiency. Therefore improvements in energy intensity ie less units of energy per unit of product relate inversely to improvements in energy efficiency ie more units of product per unit of energy input. The energy units referred to in the study will be kilowatthours (kwh). The units of product for a mine will be tonnes of ore hoisted, while the units of product for a concentrator or extraction plant will be tonnes of ore milled.

The study was completed using a multi-step process beginning with an analysis of the energy intensities of mining and concentrating activities as presented in a benchmarking study of energy consumption in underground mines done by the Mining Association of Canada in 2000. Using the benchmarking study it was possible to clearly identify the mining and milling activities with highest energy intensities and subsequently the areas with greatest potential for energy performance improvement. The next phase was to make a comprehensive list of global research that was aligned with improving the energy efficiency of mining operations. Then input from mining companies was obtained reflecting the areas the areas where they saw the need for energy performance improvements. At this point a landscape of energy efficiency related research was developed in terms of short, mid and long term projects. Using a vision of a future energy efficient mine apparent gaps in the current research were identified. Finally, potential niche areas of supportable research and the characteristics of the leadership role were suggested for CEMI.

3. Analysis of Energy Usage in Underground Mines and Concentrators

3.1 Background

The Mining Association of Canada (MAC) commissioned the Competitive Analysis Center from Ottawa in the January of 2000 to do a study which benchmarked the energy performance of both Canadian gold and base metal underground mines. The work was jointly funded by MAC and Natural Resource Canada's (NRCan) Office of Energy Efficiency Industrial Programs Division. The project was initiated by the MAC Energy Task Force and managed by Dan Paszkowski – Vice President of Economics at MAC and Lauri Gregg, Task Force Chair -Director of Energy Management at Falconbridge Ltd. The document is titled Benchmarking the Energy Consumption of Canadian Underground Bulk mines and can be found on the NRcan Office of Energy Efficiency website in the Industrial Division Section under Publications.

The study addressed the energy usage of all underground mining activities, as well as the production processes and infrastructure systems associated base metal concentrators and gold separation, extraction and refining facilities. Six base metal operations and 5 gold mining operations took part. The cost and consumption per tonne hoisted as well as the cost and consumption per tonne milled were compared. In addition, an international comparison of the energy cost per tonne of ore hoisted, per tonne of ore milled and per unit of metal produced on a facility basis was completed.

The data and information provided within the benchmarking study provides the foundation for the analysis done in this section.

3.2 Analysis of Energy Usage and Cost for Underground Mine Production Process Activities

Energy consumption intensity data and energy cost intensity data were gathered for the following underground mining activities:

- Drilling
- Blasting
- Mucking
- Underground transport
- Underground crushing
- Hoisting
- Transport to the mill
- Ventilation
- Backfill
- Dewatering
- Underground Support (e.g compressed air, lighting etc.)

The purpose of the analysis is to organize the data from the benchmarking study in such a way that it clearly shows the production processes and systems that have the highest energy use and cost per tonne of ore hoisted. Thus, the activities where research has the greatest opportunity to improve energy efficiency will be easily identifiable.

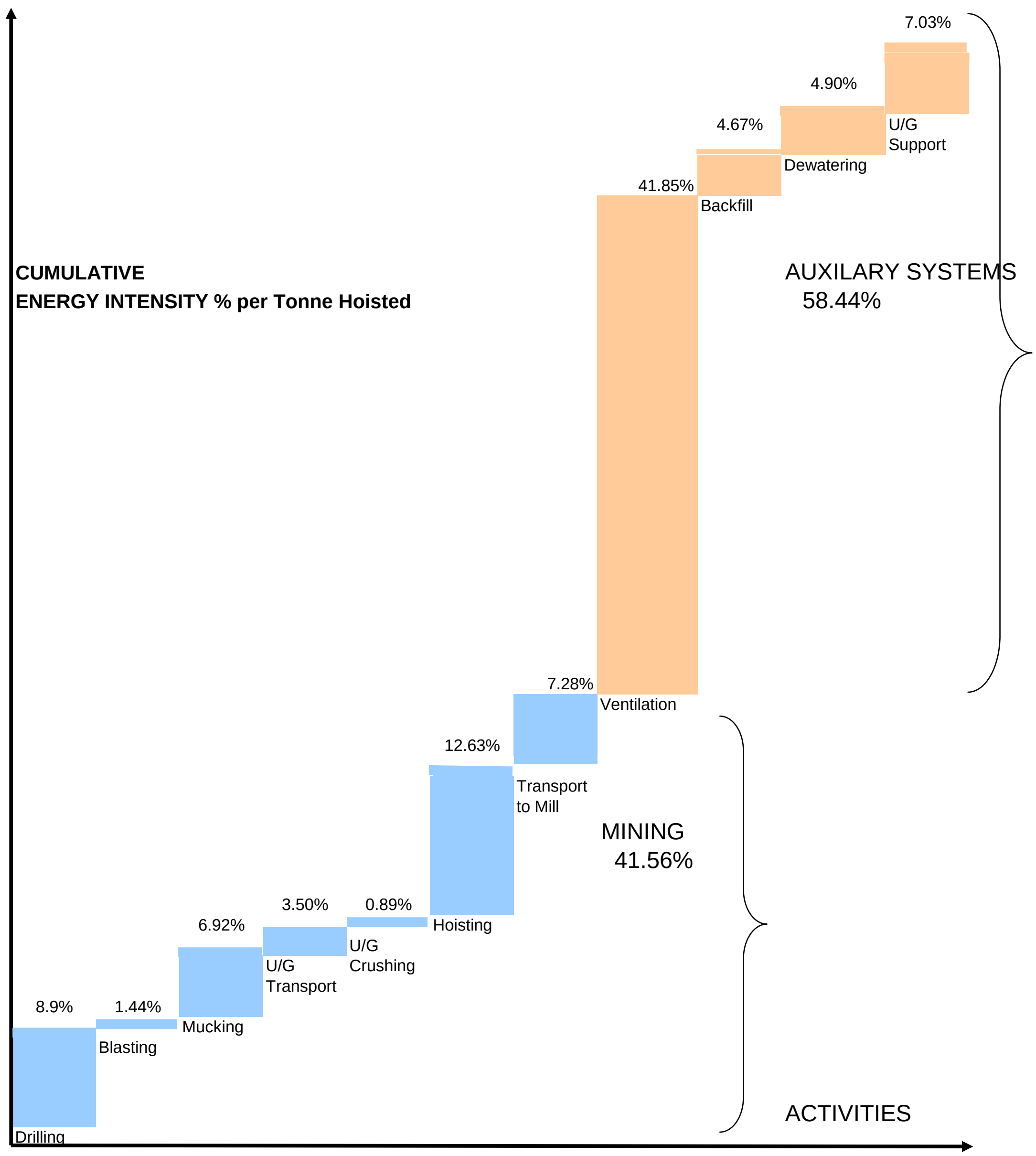

FIGURE 3.1 - Cumulative Energy Intensity % for Underground Mining Activities

In FIGURE 3.1 the total underground mining energy intensity in terms of kilowatt hour equivalent (kwhe) per tonne hoisted is divided into its component production process activity component intensities on a cumulative percentage basis. For example the energy intensity for drilling represents 8.9% of the total energy intensity for underground mining. The energy intensity used for each activity represents the mean point for that activity across the study sample.

The underground mining activities are then ranked in TABLE 3.1 in terms of their percentage contribution to the overall mining energy intensity in kwhe per tonne of ore hoisted. It is immediately obvious that the ventilation activity is the dominant contributor to the total underground mine energy intensity and therefore energy usage.

ENERGY INTENSITY RANKING		
1	Ventilation	41.8%
2	Hoisting	12.6%
3	Drilling	8.9%
4	Transport to Mill	7.3%
5	U/G Support	7.0%
6	Mucking	6.9%
7	Dewatering	4.9%
8	Backfill	4.7%
9	Transport U/G	3.5%
10	Blasting	1.4%
11	Crushing	0.9%

TABLE 3.1 Ranking by percentage of total energy intensity

In the case of the cost intensity, the picture changes somewhat, as can be seen in FIGURE 3.2, and TABLE 3.2. Blasting moves up in rank from 10th on the energy intensity table at 1.4% of the total to 2nd on the cost intensity table at 28% of the total. However, ventilation maintains its top position in terms of cost intensity representing 32.8% of the total. Hoisting retains a high ranking in both cases at either 2nd or 3rd, but its percentage contribution is at significantly lower level in the 10% range. The contribution from each of the remaining activities is less than 10%.

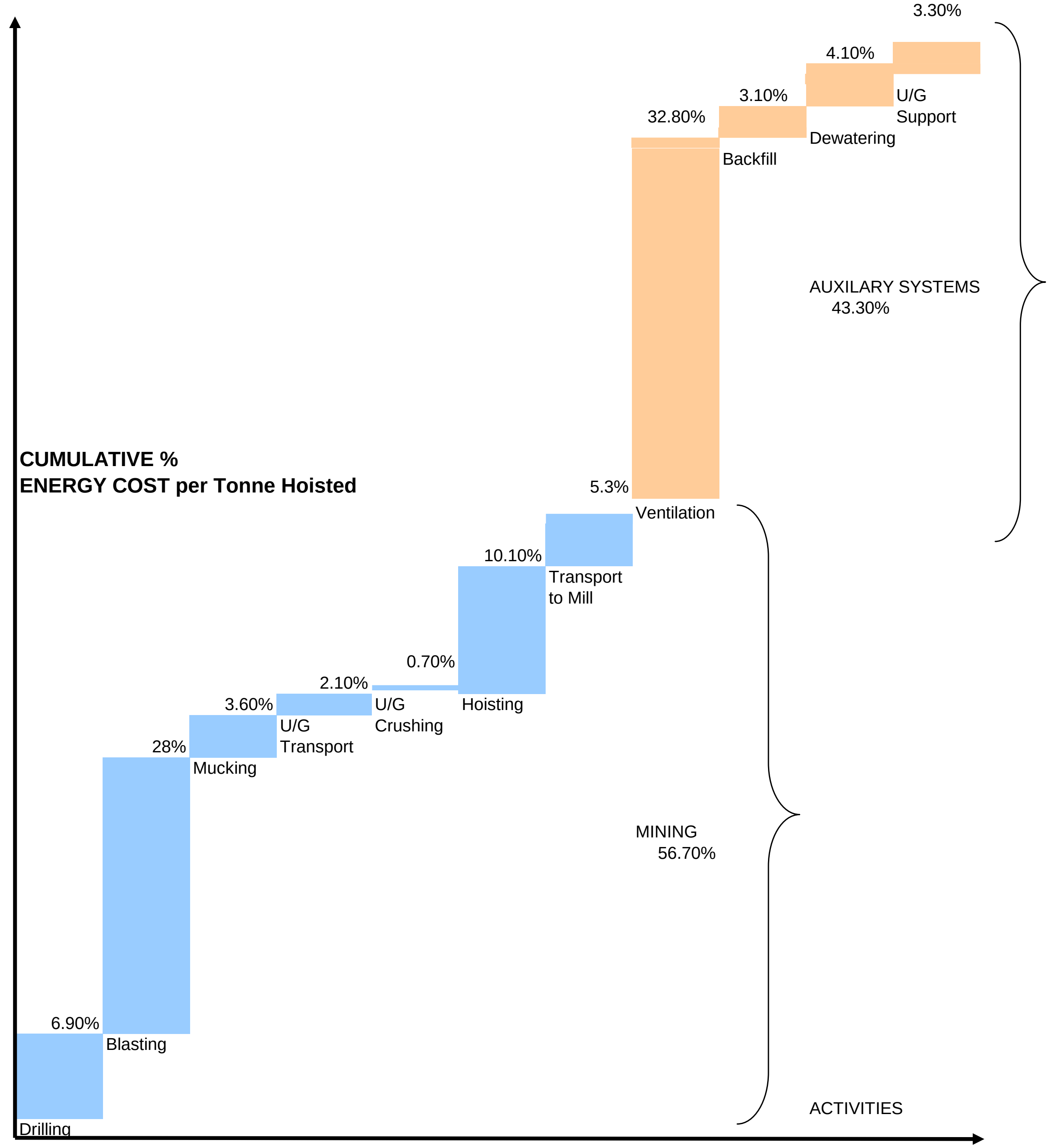

FIGURE 3.2 - Cumulative Cost Intensity % for Underground Mining Activities

COST INTENSITY RANKING		
1	Ventilation	32.8%
2	Blasting	28.0%
3	Hoisting	10.1%
4	Drilling	6.9%
5	Transport to Mill	5.3%
6	Dewatering	4.1%
7	Mucking	3.6%
8	U/G Support	3.3%
9	Backfill	3.1%
10	Transport U/G	2.1%
11	Crushing	0.7%

TABLE 3.2 Ranking by percentage of total cost intensity

The following four activities remain in the top five in terms of both energy and cost intensity: Ventilation, Hoisting, Drilling and Transport to the Mill. In the case of cost intensity Blasting displaces Underground Support Infrastructure.

For mine operators, it will be no surprise that the ventilation activity consumes the most energy per unit and is the highest cost contributor per tonne of ore hoisted. Hoisting ranks second in terms of energy intensity and third in terms of cost intensity but is in the 10% contribution range where as ventilation is at a 30 to 40% level. The cost intensity of blasting cannot be overlooked when considering the direction of research efforts. Additionally, the combined effect of blasting efficiency and drilling efficiency also directly impact the energy efficiency of underground transport, crushing, hoisting, and transport to the mill simply by determining the volume of material moved.

3.3 Ventilation Activity and Technology Discussion

Ventilation is a key element of mine design, mine development, and mine operation because of its critical importance to the health and safety of mine workers. Consequently, health and safety has to be the prime concern when efforts are made to optimize the use of ventilation energy. Temperature is another other key driver that determines ventilation demand. Not only must the temperature be maintained at an acceptable level in order to sustain human working conditions, but it also must be held within the operating temperature ranges of underground equipment and systems.

Underground mining is a labour/human intensive activity and as result air is needed to sustain life underground. The quantity of diesel fueled equipment used in the mining operation dictates the volume of air required, and thus the amount of energy required to provide fresh air for the miners. If the use of carbon fuels and human input into the mining activity could be minimized or eliminated then the potential exists to significantly reduce ventilation demand. Between 30 and 40 % of an underground mine's energy consumption and cost are related to ventilation. Typically energy represents between 10 and 15% of the mine operating cost, which means that step change reductions in ventilation requirements would mean significant cost reductions for a mining operation. Advances have been made in the application of remote controlled mining in both uranium and base metal mines. Research work is ongoing in an attempt to replace diesel vehicles with hydrogen fuel cell or hybrid vehicles. However, these technologies have not been applied widely or at all in production situations. Therefore, both remote mining and non/reduced carbon fuel vehicles provide broad areas for possible future research.

If it is assumed that the human element cannot be eliminated from underground mining, then optimized ventilation energy usage will depend on how tightly the human need for fresh air can be matched and controlled. However, before advanced ventilation control can be developed, quality production, ventilation, temperature, air quality and energy data from operating mine workplaces must be gathered and used to create an accurate, realistic, and flexible production process model that can be used to simulate and analyze new ventilation automation strategies. Research efforts could focus on ventilation system simulation and automation technologies, as well as the development of the next generation of air quality sensors.

The requirement to heat and cool mine air also adds to the overall energy intensity of mine ventilation. In most cases mines heat winter intake air at the surface with natural gas or propane. In deep mines refrigeration is needed to cool air at depth. The recovery of heating or cooling potential from mine waste water or ground water has not been studied in great depth. Thus, geothermal science related to mines has become the subject of preliminary investigations that could lead to future research.

3.3 Analysis of Energy Usage and Cost for Surface Production Process Activities – Base Metal Concentrating

Similar data to underground activities was compiled for the following surface production process activities associated with base metal concentrating:

- Crushing
- Grinding
- Separation and Flotation
- Filtering and Drying
- Heat and Lighting
- Mill Support Infrastructure
- Tailings Disposal

In FIGURE 3.3 the total energy intensity for a base metal concentrator in terms of kilowatt hour equivalent (kwhe) per tonne milled is divided into its component production process activity component intensities on a cumulative percentage basis

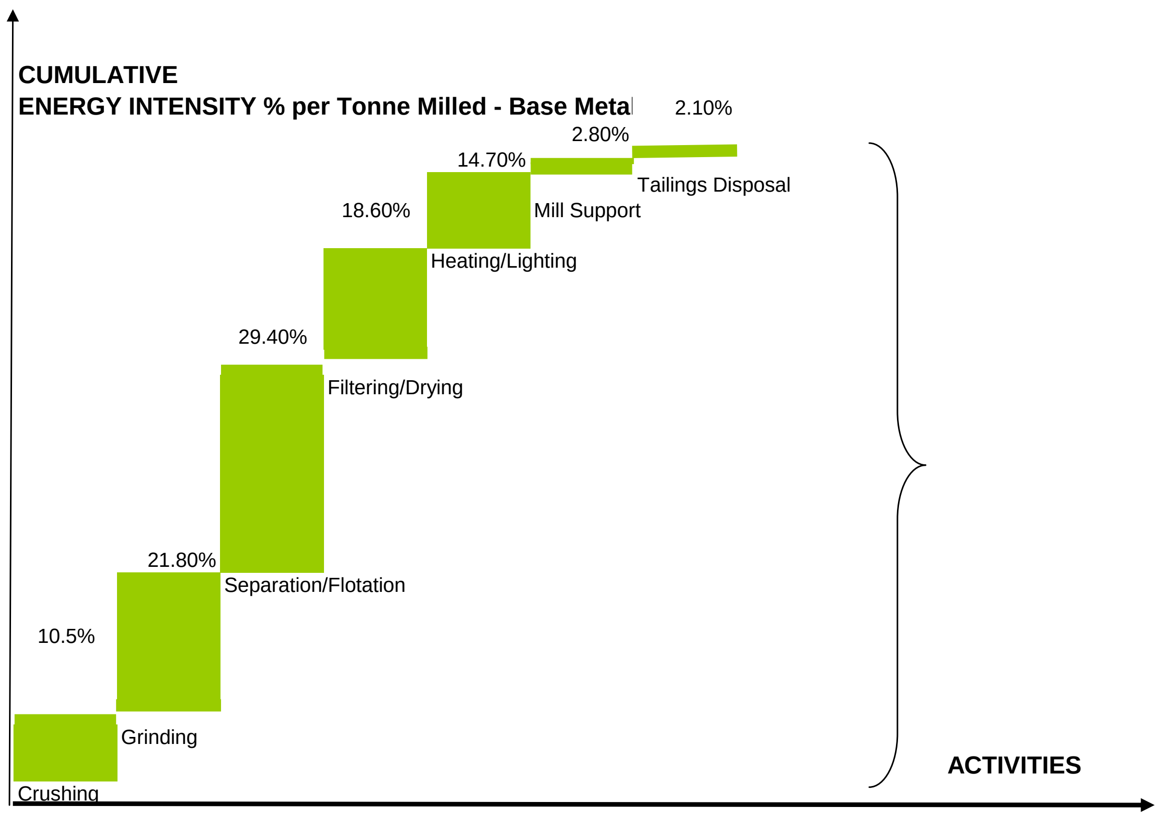

FIGURE 3.3 - Cumulative Energy Intensity % for Base Metal Concentrator

The concentrator activities are then ranked in TABLE 3.3 in terms of their percentage contribution to the overall concentrator energy intensity in kwhe per tonne of ore milled. Separation/flotation, grinding and filtering/drying are the most energy intensive activities with the percentage difference between grinding and filtering and drying being only 3.2%. Separation/flotation is made up of a complex combination of systems consisting of pumping systems, cyclones, air blowers and flotation cells while the energy users in grinding and filtering/drying are fewer in number with easily distinguishable large loads.

ENERGY INTENSITY RANKING		
1	Separation/Flotation	29.4%
2	Grinding	21.8%
3	Filtering/Drying	18.6%
4	Heating/Lighting	14.7%
5	Crushing	10.5%
6	Mill Support	2.8%
7	Tailings Disposal	2.1%

TABLE 3.3 Ranking by percentage of total energy intensity

In FIGURE 3.4 the total cost intensity for a base metal concentrator in terms of cost (Canadian Dollars) per tonne milled is divided into its component production process activity component intensities on a cumulative percentage basis

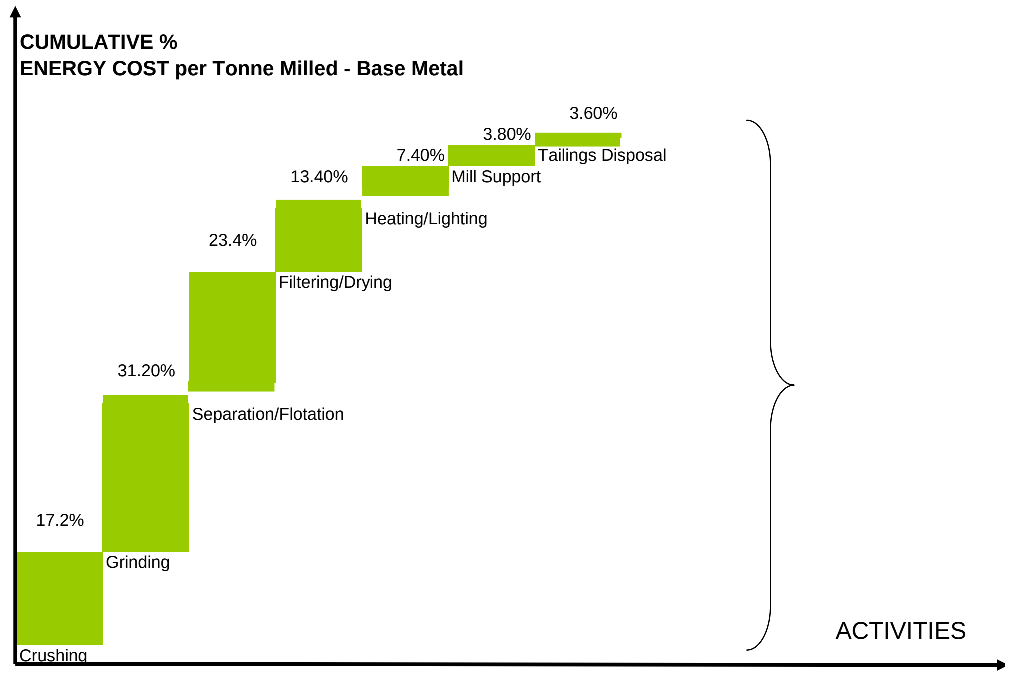

FIGURE 3.4 - Cumulative Cost Intensity % for Base Metal Concentrators

In the case of the cost intensity a number of rankings change as indicated in TABLE 3.4. Grinding displaces separation/flotation as the activity with the highest intensity and crushing moves into the number 3 position ahead of filtering and drying. These changes are not surprising considering that grinding will typically have the higher electricity demand cost associated with it, in addition to high energy consumption. Crushing moves up in ranking largely because it depends exclusively on more expensive electricity as its energy source where as filtering and drying use less costly natural gas in parts of the processes.

COST INTENSITY RANKING		
1	Grinding	31.2%
2	Separation/Flotation	23.4%
3	Crushing	17.2%
4	Filtering/Drying	13.4%
5	Heating/Lighting	7.4%
6	Mill Support	3.8%
7	Tailings Disposal	3.6%

TABLE 3.4 Ranking by percentage of total cost intensity

3.5 Analysis of Energy Usage and Cost for Surface Production Process Activities – Gold Recovery

The Energy and Cost intensities for Gold Recovery were analyzed and ranked in the same manner as Base Metal Concentration. Table 3.5 and Table 3.6 display the rankings of the production process activities. Extraction/Refining and Grinding are the dominant contributors to both the energy and cost intensities. The remaining activities cluster in the 1.8 to 6.4 % contribution range.

ENERGY INTENSITY RANKING		
1	Extraction/Refining	53.3%
2	Grinding	24.1%
3	Crushing	6.4%
4	Heating/Lighting	6.0%
5	Separation	5.7%
6	Tailings Disposal	2.5%
7	Mill Support	1.8%

TABLE 3.5 Ranking by percentage of total energy intensity

COST INTENSITY RANKING		
1	Extraction/Refining	45.5%
2	Grinding	30.1%
3	Crushing	7.7%
4	Heating/Lighting	6.0%
5	Separation	5.4%
6	Tailings Disposal	3.2%
7	Mill Support	2.2%

TABLE 3.6 Ranking by percentage of total cost intensity

3.6 Summary of Mining and Milling Production Process Activities with High Energy Efficiency Improvement Potential

In underground mining, ventilation systems and processes account for the greatest contribution to a mines energy consumption and cost. The benchmarking study indicates that the ventilation activity represents 42% of the energy consumption per tonne of ore hoisted and 33% of the cost per tonne of ore hoisted. Hoisting represents the next most energy intensive activity at 13% of the total intensity per tonne of ore hoisted and blasting represents the second most cost intensive activity at 28%.

Ventilation energy use is dependant on a complex set of drivers and operating conditions which include the following elements (not an exhaustive list):

- The design of ventilation intake and exhaust shaft arrangements
- The design of mining level configurations
- The number of pieces of mobile equipment in use and the type of equipment
- The air cooling requirement and type of refrigeration systems in place
- The size of intake, exhaust and auxiliary ventilation fans
- The shift and blasting schedules
- The air quality and temperature regulations

Consequently, the ventilation activity becomes a fertile ground for research in a number of areas which include (not an exhaustive list):

- Mine ventilation design
- Mobile equipment technology eg hybrid vehicles
- Fan drive technology
- Ventilation regulator technology
- Ventilation automation technology including data communication and management systems
- Mine refrigeration technology
- Geothermal technology for both mine air heating and cooling
- Air quality and air flow sensors and monitors

- Vehicle and personnel tracking systems
- The remote control of mining activities eg rock breaking and mucking

Hoisting ranks second in energy intensity and third in cost intensity. It is a very specific activity with the potential for research into the development of a radically different hoisting methodology from depth, as well as the potential for research into the further enhancement of conventional drum hoisting technologies.

Blasting ranks second at a 28% contribution to the total energy cost intensity for a mine plant and lends itself to research in such areas as explosive technology, blasting cap technology, blasting sequence design and drill pattern design. It also is important to note that blasting efficiency impacts the energy efficiency of underground transport, crushing/rock-breaking, hoisting, and transport to the mill simply by controlling the volume and size of rock moved.

Base metal concentrating and gold recovery facilities are typically located adjacent to their respective mining operations. These are surface metallurgical operations with metallurgical production processes that are different from mining processes and thus cannot be considered within the boundary of the mine operation. It is unrealistic to compare and rank intensities of milling activities with mining activities because the intensity factor denominators – tonnes of ore hoisted and tonnes of ore milled are not necessarily equivalent. In many cases, a mill may accept feed from several source mines. Therefore the energy, and energy cost intensities of milling activities should be looked at separately when considering research priorities. For base metal concentrators thickening/separation/flotation and grinding activities have the top two intensities. For gold recovery, extraction/refining and grinding are the top two. The separation/flotation and extraction/refining activities are complex and sophisticated metallurgical processes made up of numerous systems and sub-processes. Research in these areas is typically focused on improving metallurgical efficiency with energy efficiency improvements being a secondary result in some cases. The grinding activity on the other hand is very equipment specific and it is recognized that improved energy efficiency is a possible significant outcome of step change improvements in grinding technology.

4. Current Mining Industry Research Related to Energy Efficiency

4.1 Introduction

The purpose of this section is to first develop an understanding of the context for potential research aimed improving the energy efficiency of underground mining operations and surface milling facilities, and then inventory ongoing research activities as well as identify potential areas of future short, medium and long term research.

The investigation of research activities will begin with a focus on Canadian research and then expand to include research in North America, South America, South Africa, India, Australia and Scandinavia.

Additionally, input from mining companies regarding their thinking on the direction for future research will be included.

4.2 Discussion of Theoretical Energy Use Related to Mining and Milling Activities

Energy is a significant input to mining production processes and as result energy efficiency must be considered within the context of the production process that uses it. In other words the demand for energy is dependant on the characteristics of the process consuming it. Therefore, energy efficiency improvement solutions or research cannot be looked at in isolation but must consider the influence of all relevant energy demand drivers within the complete process or system.

Each production process activity will require a specific amount of energy to complete the fundamental work required by the process. For example in the case of hoisting the majority of the energy is needed to move the ore from depth to surface. Unless the fundamental work can be changed then any improvements in energy performance are only incremental. Therefore, any research targeted at step change improvements in energy performance must also target step changes in fundamental work that is required. In the case of Ventilation, the primary work relates to moving volumes of air. The question then is what changes in mine operations will lead to a lower air volume requirement and what research is required to expedite those changes.

The main energy requirement for hoisting relates to lifting the ore, the conveyance and the ropes vertically. The energy losses associated with the hoisting technology are insignificant relative to that needed to lift the ore mass. Therefore changes in hoisting methodology (assuming the new hoisting technology has less energy losses than conventional technology) will lead to only incremental improvements in overall energy efficiency as long as the mass lifted remains the same. Consequently, a step change in hoisting energy efficiency will occur only if there is a step change reduction in the mass to be lifted.

Principles and discussions similar to those applied above to ventilation and hoisting can be applied to grinding, separation, flotation, filtering/drying and gold extraction**.**

4.3 Summary of Global Research Activities Related to the Energy Efficiency of Mine Operations

In general, the investigation showed that ongoing research ranges from applied short and medium term research to long term research. The applied short and medium term research is being carried out by consortiums which include, mining companies government agencies, private agencies, universities, and equipment suppliers. Long term research is typically being done by universities. It was emphasized in a number of conversations that mining companies have set a priority on short term applied research with payback periods in the order of 2 years.

The information gathered in this section was obtained through literature searches, internet searches, email and discussions with researchers. It is not exhaustive and was limited by the budget allowed for the project.

A list of researchers, their affiliations and contact information will be provided in the Appendices. The Appendices will also contain matrices which cross reference research activities with research agencies or institutions.

4.4.1 Canada

CANMET – Ottawa

The following research activities are being coordinated CANMET in Ottawa:

- Hybrid hydrogen fuel cell/ nickel hydride battery loader development in conjunction with Caterpillar and Newmont Mining
- Hydrogen infrastructure development as part of a consortium which includes Vale INCO, Newmont Mining, IAMGold, Airliquide, Hydro Quebec and others
- Hydrogen regulation and standard development for vehicles and infrastructure in an underground mine as part of a consortium which includes the University of Quebec at 3 Rivers, Hatch, Airliquide and others
- Explosive Free Rock Breakage involving thermal fragmentation and microwave pre-conditioning as part of a consortium which includes, ValeINCO, Xstrata Raglan, Barrick, IAMGold, Hydro Quebec and others

CANMET – Val-d’Or

The following research activities are being coordinated CANMET in Val-d’Or:

- Hybrid diesel/electric loader
- Underground voice communication technology
- The elimination of the use of compressed air in an underground mine
- Pre-concentration in an underground environment in conjunction with University of British Columbia (UBC)

CANMET – Sudbury

The following research activities are being coordinated CANMET in Sudbury:

- Ventilation process simulation model for underground mines
- Ventilation on Demand proof of concept in conjunction with ValeINCO and Xstrata Sudbury

University of British Columbia – Norman B Keevil Institutue of Mining Engineering

The following energy efficiency impacting research activities are being undertaken by UBC:

- Artificial Intelligence in Agent-based Real-time Process Control Systems
- Comparison of Fine Grinding Technologies: Interactions with Downstream Processing
- Design of Autonomous Ground Vehicles for Mines
- Development and Integration of Mine Equipment Information Systems
- Development of Integrated Mining and Mineral Processing systems at IINCO’s McCreedy East Mine
- Integrated mining and mineral processing systems for underground mines
- Monitoring and control of Load-haul-Dump vehicles for Enhanced Productivity and Efficiency
- Underground pre-concentration of ores – evaluation process of technologies
- Geothermal Energy from Deep Mines
-

Laurentian University – Mining Automation Laboratory - Sudbury

At Laurentian University research projects are administered from the Center in Mining and Exploration Research. The University also partners with industry supported agencies located in the Willet Green Miller Center adjacent to the campus to conduct mine research work.

The following energy efficiency impacting research activities are being undertaken by Mining Automation Laboratory:

- System Architecture of Tele-remote/Automated Mining Systems
- Dispatch and Traffic Control of Vehicle Based Transportation Systems

Canadian Mining Industry Research Organization – CAMIRO – Willet Green Miller Center- Laurentian University - Sudbury

CAMIRO is an amalgamation of the following former multi-sponsored research organizations; MRD, MIROC and MITEC

The following energy efficiency impacting research activities are being undertaken by CAMIRO:

- Geothermal Energy from Deep Mines
- Underground Transportation Alternatives
- Fine Particle Flotation

McGill University Mine Engineering - Montreal

The following energy efficiency impacting research activities are being undertaken by McGill:

- Geothermal Energy from Deep Mines
- Explosive Free Rock Breakage with CANMET
- Stochastic Mine Planning

4.4.2 United States

Colorado School of Mines – Golden, Colorado

The Colorado School of Mines has recently joined a Renewable Energy Collabratory along with Colorado State University, The university of Colorado and the National Renewable Energy Laboratory

The following energy efficiency impacting research activities are being undertaken by the Colorado School of Mines:

- Hydrogen Fuel Cell Vehicles
- Hydrogen Infrastructure

- Geothermal Heat Recovery
- Wind Energy
- Solar Energy
- Large Scale Energy Storage Systems
- Compressed Air Energy Storage

US Department of Energy (DOE) – Various Campuses

The US Department of Energy sponsors energy related research at many universities and research centers across the United States

The following energy efficiency impacting research activities are being undertaken by the US DOE:

- Hydrogen Fuel Cell Vehicles
- Hydrogen Fueling Infrastructure
- Electric Vehicles
- Diesel Emission Reduction
- Geothermal Heat Recovery
- Fuels and Bio energy
- Wind Energy
- Solar Energy
- Large Scale Energy Storage Systems

4.4.3 Scandinavia

During the investigation directly mining related research was found going on in Norway or Finland. Generally, the research in these countries tends toward the non-industrial sciences, energy markets, renewable energy, energy conservation and advanced communication and control technologies.

Lulea University of Technology – Lulea Sweden

LKAB has sponsored the Hjalmar Lundbohm Research Center at the Lulea University of Technology

The following energy efficiency impacting research activities are being undertaken at Lulea University:

- Explosive Efficiency
- Deep underground mining

4.4.4 Australia

CSIRO – the Commonwealth Scientific and Industrial Research Organization

The following energy efficiency impacting research activities are being undertaken at CSIRO:

- Process modeling
- Mine equipment and drilling technology
- Mine design and sustainability
- Intelligent machines for mining
- process design and optimisation
- on-line analysis and control

CRCMining – Corporate Research Centers - Mining

CRCMining is a fully incorporated joint venture, that is a unique mining research centre that brings some of the world's largest mining and manufacturing companies together with leading research institutions and the Australian Commonwealth Government. Mining companie and equipment supporters include Xstrata, Rio Tinto, Phelps-Dodge and CaterpillarElphinstone. It coordinates activities in 4 Universities – the University of Queensland, West Australian School of Mines at Curtin University, the University of Newcastle, and the University of Sydney.

The majority of CRCMining research projects are related to open pit operations and coal mining. The following energy efficiency impacting research activities are being undertaken at CRCMining:

- Dilution control – Cave Tracking Systems
- Vehicle scheduler – Truck scheduler
- Small truck fleet monitoring
- Fragmentation optimization : percussive water jet technology
- Smart Mining Systems: dynamic modeling of principal mining areas; mine simulation systems; smart blasting system; step change mining technologies
- New Underground Haulage Systems – Curtin
- Modeling and Optimization of Mining Systems
- High Pressure Grinding Rollers (HPGR) – new energy efficient milling circuit designs – University of Queensland

University of New South Wales

The following energy efficiency impacting research activities are being undertaken at University of New South Wales:

- Mine ventilation principles and design for both hard rock and coal mining operations; gas management in mines; gas drainage; heat in mines; mine air conditioning; spontaneous combustion; mine atmosphere emergency management. Underground mine environmental management expertise. Mine ventilation simulation and monitoring; fan performance. Engineering principles of windblasts and air-blasts in mining operations; monitoring of windblast effects; instrumentation development; gas and dust in mine atmospheres.
- Mining process simulation
- Mine lighting

4.4.5 South Africa

Northwest University

The following energy efficiency impacting research activities are being undertaken at Northwest University:

- Separation technologies in hydrometallurgy
- Optimizing the operation of underground mine refrigeration plants and ventilation fans for minimum electricity cost
- Peak power control for underground winders
- Demand –side energy management of underground refrigeration systems

University of Witwatersrand

The following energy efficiency impacting research activities are being undertaken at University of Witwatersrand:

- Investigation into the explosive effect on rock for designing preconditioning blasts in deep level gold mines
- Data mining techniques for industrial process development

Council for Scientific and Industrial Research(CSIR) – South Africa

The following energy efficiency impacting research activities are being undertaken at CSIR:

- An architecture for underground measurement and control networks
- The Nederburg Miner – technology for remote mining of narrow veins
- Smart Mine – efficient underground data collection and organization to support decision making
- Smart Mine – stope sensor to communication network link
- Smart Mine– data organization using cognitive science techniques
- Fuel cells
- Mobile Intelligent Autonomous Systems
- Industrial Process Optimization

University of Cape Town

The following energy efficiency impacting research activities are being undertaken at University of Cape Town:

- Froth flotation processes
- Grinding technology

Bluhm Burton Engineering - Gauteng

The following energy efficiency impacting research activities are being undertaken at BBE:

- Mine ventilation and air refrigeration systems
- Ventilation system simulation and analysis
- Computational fluid dynamics

4.4.6 International - Other

AMIRA

The following energy efficiency impacting research activities are being undertaken at AMIRA:

- Improved thickener technology
- Enhanced selectivity in flotation using polymers

- SAG mill monitoring using vibrations
- Optimization of mineral processing through modeling and simulation
- Planning & Rapid Integrated mine optimization

Central Institute of Mining and Fuel Research – India

The main focus of CIMFR is the coal mining sector.
The following energy efficiency impacting research activities are being undertaken at CIMFR:

- Application of numerical methods to mining problems

University of Chile – Santiago

The following energy efficiency impacting research activities are being undertaken at University of Chile:

- Mine ventilation control
- Evaluation of mineral concentration processes

Centro de Tecnologia de Brasil

The following energy efficiency impacting research activities are being undertaken at CETEM:

- Gold recovery processes
- Evaluation of mineral concentration processes
- Applied technologies for the recovery of specific metals

HATCH Engineering

The following energy efficiency impacting research activities are being undertaken at HATCH:

- Hydrogen infra structure and U/G regulation development
- Mine energy efficiency analysis

4.4.7 Mining Company Research Interests

A limited survey which included 5 Canadian mining companies and a total of 7 respondents was completed via email and telephone conversation in order to get a sense of the research areas they felt would help them improve the energy efficiency of their operations.

What follows is a compilation of the comments ranked by the number of respondents associated with each one::

1. Alternatives for heating mine ventilation air - 2 Respondents
2. Geothermal energy for heating or cooling - 2 Respondents
3. Wind power – 2 Respondents
4. Water power - 2 Respondents
5. Ventilation on Demand – VOD - 1 Respondent
6. Refrigeration/cooling systems for deep mines - 1 Respondent
7. Reduce underground ventilation and diesel transportation energy requirements by 50% - 1 Respondent
8. Diesel engine thermal efficiency improvement - 1 Respondent
9. Diesel engine fuel efficiency improvement for large vehicles - 1 Respondent
10. Reduce the dependency on diesel equipment - 1 Respondent
11. Compressed air usage reduction by elimination or distributed compression - 1 Respondent
12. Ore grinding technologies - 1 Respondent
13. Electric induration furnaces - 1 Respondent
14. Improved primary crusher technology - 1 Respondent
15. Blasting methodologies toward the elimination of the primary crusher - 1 Respondent
16. Co-generation - 1 Respondent
17. Energy storage - 1 Respondent

5. Alignment of Research Landscape with Mining Industry Energy Efficiency Improvement Priorities

5.1 A Landscape of Research Toward Energy Efficient Mining

A landscape of the mining related energy efficiency research activities identified in this study is presented diagrammatically in FIGURE 5.1.

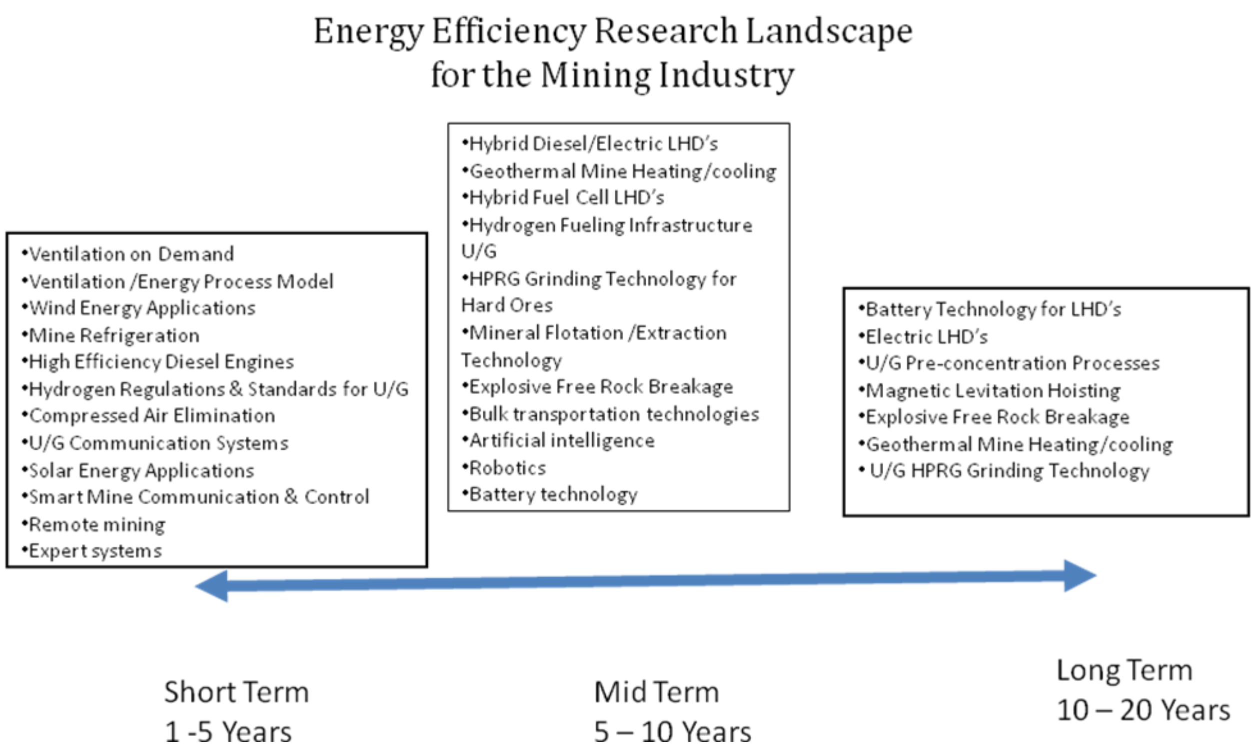

FIGURE 5.1

From the diagram it is possible to create a vision of the energy efficient mining operation of the future and the road map of research activities that will lead over time to the full implementation of the vision. Subsequently, the most appropriate research and research agencies can be aligned with the roadmap of evolution toward the vision.

5.2 A Future Vision of the Energy Efficient Mine

A long term vision of an energy efficient mine must address a minimization of the energy demand of all existing mining activities recognizing that the priority should be on those that have the highest energy intensities, such as ventilation, hoisting, grinding, and mineral extraction.

One long term vision of the energy efficient mine of the future where battery technology displaces a hydrogen fuel cell infra-structure could have the following characteristics :

- Explosive free rock breakage using thermal fragmentation
- Robotic mucking
- Bulk U/G ore transportation
- Remote controlled Electric LHD's
- Electric service vehicles
- U/G HPRG grinding
- U/G Pre-concentration of minerals
- Magnetic levitation hoisting of concentrate
- Geothermal heating and cooling of mine air
- Ventilation on Demand controlled by expert systems and dependant on work place air quality, temperature, vehicle position and human activity
- Compressed air free infra-structure
- Total Smart Mine monitoring, data management, communication , and control

In this vision, robotic mucking, bulk ore transportation, electric vehicles, geothermal heating and cooling, ventilation control will all contribute to reducing the ventilation energy demand. More efficient grinding and the U/G pre-concentration of minerals, and alternative hoisting technologies will lead to optimized hoisting and mineral extraction energy use. Critical to the success of reaching this operating structure is the Total Smart Mine concept. The level of automation and technology suggested demands that a data management infrastructure be established that accurately gathers necessary operating and energy data , organizes and analyzes the data in a manner that creates timely production process information, and then communicates the information to real time control systems and mine operators. The implementation of this vision in terms of the current estimates of component energy reductions could lead to a 50% decrease in overall energy use. Sustaining this reduction will require continuous monitoring and control of energy use within defined operating limits.

The following Long/Mid Term research would lead to the long term vision above:

- Explosive free rock breakage using thermal fragmentation
- High capacity battery technology
- Robotics and artificial intelligence

- U/G pre-concentration of minerals
- U/G HPRG grinding
- Magnetic levitation hoisting of concentrate
- Geothermal energy

A midterm vision of the energy efficient mine which could be implemented within 10 years and depends on hydrogen fuel cell vehicles and infra-structure could have the following characteristics :

- Pre- conditioning of the rock face before breakage
- Bulk U/G ore transportation
- Remote controlled fuel cell LHD's
- Fuel cell service vehicles
- Geothermal heating and cooling of mine air
- Ventilation on Demand controlled by expert systems and dependant on work place air quality, temperature, vehicle position and human activity
- Compressed air free infra-structure
- HPRG grinding on surface
- High efficiency flotation and extraction on surface
- Total Smart Mine monitoring, data management, communication, and Control

The following Short/Mid Term research would lead to the midterm vision above:

- Pre- conditioning of the rock face before breakage using microwave pre-conditioning
- Fuel cell LHD and service vehicles
- U/G Hydrogen infra-structure and regulations
- Ventilation on Demand including ventilation/energy process simulations, expert systems, air quality sensors, vehicle/person locating
- U/G communication systems
- HPRG grinding
- Geothermal energy
- Compressed air elimination
- Total Smart Mine monitoring , data management, communication and control

5.3 Aligning Research with Energy Efficiency Improvement Priorities

Three operational perspectives have been created with which to align potential research: the energy and cost intensities of mining activities; input from mine operators; and a mid/long term vision of the energy efficient mine

In terms of energy/cost intensity improvements in the following 4 mining areas will have the highest impact on improved mine energy efficiency:

- Ventilation
- Hoisting
- Drilling
- U/G and surface transport

The production processes having the highest efficiency improvement potential associated with base metal concentrators and gold extraction facilities are flotation/extraction and grinding.

The majority of the input from mining companies, 8 out of 13 comments related directly to improving the energy efficiency of ventilation systems or indirectly through diesel engine performance improvements.

The long/mid term visions of a future mine contain advanced ventilation control, heating and cooling solutions, non-diesel vehicles, non-explosive rock breaking or pre-conditioning, the elimination of compressed air usage, sophisticated smart mine, data management, communication and control technologies and more efficient hoisting solutions.

Now, it is possible to align mining industry operational priorities with clusters of research activities and the associated agency or institution by reviewing the sections describing international research above, and the summary matrices appearing in APPENDIX 1A and 1B.

Doing so leads to the observation that CANMET and the University of British Columbia are pursuing clusters of research projects that capture many of evolutionary steps that will lead to addressing the required mine energy efficiency improvement priorities.

University of British Columbia

- Artificial Intelligence in Agent-based Real-time Process Control Systems
- Comparison of Fine Grinding Technologies: Interactions with Downstream Processing
- Design of Autonomous Ground Vehicles for Mines
- Development and Integration of Mine Equipment Information Systems
- Integrated mining and mineral processing systems for underground mines
- Monitoring and control of Load-haul-Dump vehicles for Enhanced Productivity and Efficiency
- Underground pre-concentration of ores – evaluation process of technologies
- Geothermal Energy from Deep Mines

CANMET

- Ventilation process simulation model for underground mines
- Ventilation on Demand proof of concept
- Hybrid diesel/electric loader
- Underground voice communication technology
- The elimination of the use of compressed air in an underground mine
- Pre-concentration in an underground environment in conjunction with University of British Columbia (UBC)
- Hybrid hydrogen fuel cell/ nickel hydride battery loader
- Hydrogen infrastructure development
- Hydrogen regulation and standard development for vehicles and infrastructure in an underground mine
- Explosive Free Rock Breakage involving thermal fragmentation and microwave pre-conditioning

The combination of the US Department of Energy and the Colorado School of Mines also represents a significant cluster of relevant research.

- Hydrogen Fuel Cell Vehicles
- Hydrogen Infrastructure
- Geothermal Heat Recovery
- Wind Energy
- Solar Energy
- Large Scale Energy Storage Systems
- Compressed Air Energy Storage
- Electric Vehicles
- Diesel Emission Reduction
- Geothermal Heat Recovery
- Fuels and Bio energy

Additionally, the following institutions are focused on Smart Mine development; or production process simulation and modeling; or data mining techniques:

- Council for Scientific and Industrial Research (CSIR) – South Africa
- Bluhm Burton Engineering
- University of Witwatersrand
- University of New South Wales
- CRCMining – Australia
- Commonwealth Scientific and Industrial Research Organization (CSIRO) – Australia

In conclusion, global research projects align well with identified mining energy efficiency improvement priorities. In addition, specific institutions or agencies are engaged in clusters of research projects that directly address many of the next steps toward reaching the vision of an the Energy Efficient Mine of the Future. However, research gaps that could impede progress toward the ultimate vision in the long term exist at all points on the time continuum – short, mid, and long term.

Short term gaps include the following niche areas of research:

- Dynamic ventilation/energy U/G mine process model or balance developed from real mine data
- Wind turbine technology for use in extreme cold - northern mines
- Smart Mine data management, communication and control developed from real mine data

Midterm gaps include the following niche areas of research

- Recovery and application of geothermal energy in operating mines
- High Pressure Roller Grinding (HPRG) technology for hard ores
- Artificial intelligence and robotics
- High capacity battery technology

Long term gaps include the following niche areas of research

- Electric LHD and service vehicles
- U/G pre-concentration of mine ore
- Magnetic levitation hoisting

6. Alignment of CEMI with the Mining Industry Energy Efficiency Improvement Research Landscape

Research activity is being led by government agencies, public/ private / academic agencies or research centers, universities, consulting engineering firms, technology suppliers and mining companies. Short to midterm applied research is typically being carried out by consortiums of agencies, mining companies and technology suppliers. Examples of this are the DEEP Consortium and the Explosive Free Rock Breakage Consortium . Specific technology development is progressing in a similar manner. For example, the Fuel Cell LHD is being developed by CANMET, Caterpillar and a number of mining companies. Long term research is ongoing within university departments or at research centers. Examples of this are the development of ore U/G pre-concentration and geothermal energy concepts at the University of British Columbia. The long term research projects may have minor support from agencies or companies.

CEMI's strategic objective is to lead in specific research niches that the mining industry feels are priority areas. The greatest contributor to the slow development of improvements in energy efficiency at mining operations is the lack of leadership which can develop a long term vision and a roadmap of logical steps toward the vision of a Future Energy Efficient Mine. Also lacking is the co-ordination of the necessary actions and resources to make the journey. Any one of the research gaps identified in the previous section provides opportunities for CEMI to play an effective leadership role and create a research niche.

In terms of short term gap elements, the most significant barrier to applying researched technologies to the mining industry is the inability to affectively collect organize, analyze, and communicate high quality mine production process, infrastructure and environmental data in manner that the makes facility performance visible and real to mine operators and managers. Success in the area of 'data management' is critical to improving energy and process efficiencies. This challenge is being addressed by The Smart Mine concept, but many opportunities still exist for research efforts that focus on the capture, transmission and organization of real mine data directly associated with mining activities.

As noted earlier, ventilation provides the largest potential for improving energy intensity, thereby freeing energy for other productive uses. The research gap in this area relates specifically to the absence of a ventilation process model and ventilation energy balance. The development of the process model is largely due to the inability to collect accurate mine data. The ventilation process model/energy balance is also a fundamental building block of the Smart Mine concept. Leadership in this research niche could be achieved by coordinating a consortium which includes mining companies, and CANMET, as well as hardware and software technology providers.

Another short term gap issue is the application of large scale wind power installations at remote locations in the far north. This has stalled due to inability of the turbine technologies to withstand extreme cold, as well as the logistical problems associated with the installation and maintenance of the equipment. Leadership in this area would require the co-ordination of the technology suppliers like Siemens and GE, federal and provincial energy agencies, power developers, and mining companies.

In terms of mid and long term gap elements some research has been done or is being done but generally, it is minimal and fragmented work. However, UBC has been particularly progressive with geothermal energy, magnetic levitation hoisting and the pre-concentration of mine ores. Curtain University in Australia is working with AMIRA on a laboratory scale version of HPR Grinding. Laurentian University is positioned to address artificial intelligence and robotics within its Mine Automation Center. As a result of the current focus on hydrogen fuel cell vehicles there does seem to be a lack of interest in the development of fully electric mine vehicles like LHD's and service transport. Consequently, there is little attention paid by the mining community to high capacity battery technology development. The general opinion is that this technology will take at least 20 years to mature.

In order to establish a research niche in the above mentioned mid/long term research areas CEMI could join or create a consortium of active university research centers and potential industry sponsors, or in the case of battery and electric vehicle development initiate a dialogue with the electric vehicle transportation sector.

6.1 Potential Niche Energy Efficiency Research Areas for Consideration by CEMI

1. Leadership and coordination of research toward the Energy Efficient Mine of the Future
2. Dynamic ventilation/energy U/G mine process model or balance developed from real mine data
3. Smart Mine monitoring, data management, communication, and control
4. Recovery and application of geothermal energy in operating mines
5. High capacity battery technology
6. Electric LHD and service vehicles
7. U/G pre-concentration of mine ore
8. Magnetic levitation hoisting

APPENDICES

APPENDIX 1A

Research Activity Matrix Part 1

REGION	AGENCY/INSTITUTION	Energy Performance Related Research Areas											
		Hydrogen Fuel Cell Vehicles	Hydrogen Fueling Infrastructure	Electric Vehicles	Vehicle/Person Monitoring & Control/Dispatch	Diesel Hybrid LHD's or Diesel Emission Reduction	U/G Transportation Alternatives &Robotic Vehicles	Geothermal Heat Recovery	Ventilation Systems / Heating Refrigeration / Air Quality Sensors / VOD	Compressed Air Elimination	Hoisting Technology	Explosive Technology	Explosive Free Rock Breaking Practices & Dilution Control
CANADA	CANMET - Ottawa	X	X										X
	CANMET - Sudbury								X				
	CANMET - Val D'or					X				X			
	CAMIRO DEEP DMRC						X	X					
	Laurentian U				X		X						
	MIRARCO LU												
	McGill U							X					X
	UBC	X			X		X	X			X		
	HATCH Engineering		X										
USA	Colorado School of Mines	X	X					X					
	US DOE	X	X	X		X		X					
SWEDEN	Lulea U - Sweden											X	
AUSTRALIA	CSIR												
NEW ZEALAND													
	CRCMining				X		X						X
	U of New South Wales								X				
	Massey U NZ										X		
SOUTH AFRICA	North West U								X		X		
	U of Witwatersrand											X	
	CSIR South Africa	X					X						
	U of Cape Town												
	Bluhm Burton Engineering								X				
INTERNATIONAL	AMIRA												
INDIA	CIMFR												
BRASIL	Centro de Tecnologia de Mineral												
CHILE	U of Chile						X		X				

APPENDIX 1B

Research Activity Matrix Part 2

REGION	AGENCY/INSTITUTION	Energy Performance Related Research Areas															
		U/G Regulations and Standards	Process Modelling and Simulation	Communication & Control Systems Technology	Maintenance Systems and Practices	Artificial Intelligence and Expert Systems	Mine Mineral Processing System Integration	U/G Pre-concentration of Mine Ore	Fuels & Bio Energy	Wind Energy	Solar Energy	Energy Storage Systems & Battery Technology	Compressed Air Energy Storage	Crushing	Grinding	Flotation	Paste Backfill
CANADA	CANMET - Ottawa	X							X								
	CANMET - Sudbury		X														
	CANMET - Val D'or			X				X									
	CAMIRO DEEP DMRC															X	X
	Laurentian U																
	MIRARCO LU								X								
	McGill U																
	UBC			X	X	X	X	X						X	X	X	
USA	Colorado School of Mines									X	X	X	X				
	US DOE								X	X	X	X					
SWEDEN	Lulea U - Sweden													X	X		
AUSTRALIA NEW ZEALAND	CSIR		X			X	X										
	CRCMining		X				X								X		
	U of New South Wales		X														
	Massey U NZ																
SOUTH AFRICA	North West U																
	U of Witwatersrand		X														
	CSIR South Africa		X	X			X										
	U of Cape Town														X	X	
INTERNATIONAL	AMIRA						X								X	X	
INDIA	CIMFR		X														
BRASIL	Centro de Tecnologia de Mineral															X	
CHILE	U of Chile		X		X											X	

APPENDIX 2
Contact Matrix

REGION	AGENCY/INSTITUTION	Contact Name	Business Telephone	Email Address	Web Address
CANADA	CANMET - Ottawa	Marc Betournay	613 995 1147	marc.betournay@nrcan-rncan.gc.ca	
	CANMET - Sudbury	Michel Grenier	705 677 7815	Michel.Grenier@nrcan-rncan.gc.ca	
	CANMET - Val D'or	Marcel Laflamme	819 736 4331	marcel.laflamme@nrcan-rncan.gc.ca	
	CAMIRO DEEP DMRC	Charlie Graham	705 673 6595	info@camiro.org	www.camiro.org
	Laurentian U - Mine Automation	Nick Vayenas	705 675 1151 x 2341	nvayenas@laurentian.ca	
	MIRARCO LU	Louis Mercier	705 675 1151 x 2111	lmercier@laurentian.ca	
	McGill U				
	UBC	Norman B Keevil Institute		www.mining.ubc.ca	
		Mory Ghomshei		mory@interchange.ubc.ca	
		John Meech	604 822 3984	cerm3dir@mining. ubc.ca	
	HATCH Engineering	Jon Feldman	905 465 4927	jfeldman@hatch.ca	
USA	Colorado School of Mines	Division of Engineering	**303 273 3650**		http:/engineering.mines.edu/research
		Neal Sullivan		nsulliva@mines.edu	www.coloradofuelcellcenter.org
	US DOE	Energy Efficiency & Renewable Energy			www1.eere.energy.gov/financing
SWEDEN	Lulea U - Sweden	Finn Ouchterlony	469 2049 1000 (General)	FinnOuchterlony@swebrec.se	www.ltu.se
AUSTRALIA	CSIR	Cooperative Research Centers			www.csiro.au/org/CooperativeResearch Centers.html
NEW ZEALAND					
	CRCMining	Jackie Nash	+61 7 3365 5640	j.nash@crcmining.com.au	www.crcmining.com.au
	U of New South Wales	Research	61293851000		www.unsw.edu.au/research/res/research.html
	Massey U NZ	Ralph Sims	+ 64 6 350 5799	R.E.Sims@massey.ac.nz	www.energy.massey.ac.nz
SOUTH AFRICA	North West U	Potchefstroom			www.nwu.ac.za
	U of Witwatersrand	School of Mining Engineering	27 (0) 11 717 1000	bekir.genc@wits.ac.za	www.wits.ac.za
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		Paul Schutte		pschutte@csir.co.za	
	U of Cape Town	Center for Mineral Research - C.T O'Connor		Cyril.Oconnor@uct.ac.za	
	Bluhm Burton Engineering	Ventilation & Refrigeration	+ 27 11 706 9800	bbe@bbe.co.za	www.bbe.co.za
INTERNATIONAL	AMIRA	Metallurgical			www.amira.com
INDIA	CIMFR				
BRASIL	Center for Mineral Technology		55 21 3865 7222	webmaster@cetem.gov.br	www.cetem.gov.br
CHILE	U of Chile	Mining Research Tech Center			www.uchile.cl
		Rodrigo Pascual	56 2 9782000 x 84467	rpascual@ing.uchile.cl	