Chapter 1
Introduction

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Abstract The goal of this book is to present the current knowledge regarding energy efficiency implications of mining processes and future research directions. This introductory chapter explains the purpose and motivation for this book, provides highlights of the book, provides strategies that a reader can use to read the book, and identifies the key unanswered questions that require further research. It is my hope that this book will be a valuable resource for industry professionals and researchers and stimulate further discussions on energy efficiency in mining.

Keywords Energy efficiency · Energy · Mining · Minerals industry

1.1 Introduction

Total energy costs are high for most mines because mining is an energy intensive activity. Energy cost is a key consideration for mining professionals and researchers that drive decisions on research and initiatives on energy efficiency. As pointed out by Levesque and co [1], the prevalence of energy efficiency initiatives in the minerals sector is closely correlated with energy prices. In recent years, however, concerns about climate change, the carbon footprint of products, and the related internalizing of associated costs are also driving decisions related to energy consumption and efficiency in the minerals sector. Finally, energy costs are important to mining professionals because the overall energy efficiency of mining is affected by the efficiency of all parts of a mineral project. Energy is consumed by all the processes in the mineral life cycle.

A volume like this one that discusses best practices and provides research directions for the future is long overdue. As energy consumption, the associated climate change impacts, and costs have become increasingly important, mineral

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industry professionals and researchers have had to look at a variety of sources to gather information about best practices and ongoing and future research initiatives. To the best my knowledge, no volume like this exists in the English literature that collates contributions from various experts into one resource for industry professionals and researchers.

This volume presents the current state of the art regarding energy efficiency implications of mining processes. The book is divided into four main sections: ground fragmentation; material handling; mineral processing and extractive metallurgy; and miscellaneous topics. The main sections follow, to a large extent, the unit processes of mining so that the reader can instinctively know where to find things. Besides attempting to explain the purpose and motivation for this volume, this introductory chapter tries to summarize the highlights of the chapters contained in this book, provide strategies that a researcher or an industry professional can use to read the book and identify the key unanswered questions that require further research.

1.2 Highlights

The first section of this book includes five chapters that discuss energy efficiency implications of blasting and ground fragmentation in mining [2–6]. The section starts with an overview of the energy distribution during ground fragmentation by blasting [2]. This chapter provides a basic introduction to the basic theories on the energy content of explosives, how that energy is released to the surrounding rock mass during detonation, and the different forms that energy is transformed into during explosives. By itself, the discussions in this chapter can inform a mining engineer's decisions on explosive selection, blast design, and execution. However, the chapter also serves as a useful introduction to the next four chapters in this section.

The last of these chapters experimentally examines the energy efficiency of rock fragmentation using blasting [6]. The researchers determined the proportion of the explosive energy transformed into seismic wave energy, kinetic energy, and fracture energy transferred during the blasting process. They conducted experiments at two quarries to determine the energy proportions using the seismic field from seismograph records, initial velocity of the blasted rock face obtained from high-speed video footage, and fragment size distributions from image analysis of the muckpile material, respectively. Their work shows that the maximum total energy measured, in these experiments, accounts for at most 26% of the available explosive energy, indicating that the energy efficiency of blasting is rather low.

One of the remaining three chapters deals with the energy efficiency of drilling, which is the method for creating a means of loading explosives into rock for fragmentation [5]. The remaining two chapters deal with the effect of hole stemming and detonation wave collision on fragmentation results and energy efficiency of blasting [3, 4].

The second section of the book, which covers material handling, contains four chapters that deal with the energy efficiency of material handling operations [7–10]. The section opens with an overview of energy efficiency implications of loading and hauling equipment [7]. The next two chapters deal, respectively, with shovels and trucks, which together constitute the most common loading and hauling method [8, 9]. The first of the two provides a review of the current literature on cable shovel energy efficiency while the second deals with approaches for benchmarking energy efficiency of trucks.

The final chapter in this section presents a framework for assessing dragline energy efficiency using equipment monitoring data [10]. The authors present a three-step approach involving: (1) assess energy efficiency using data from dragline monitoring systems to estimate an overall performance indicator; (2) quantify the relationship between different operating parameters and the energy efficiency indicator; and (3) improve the energy efficiency performance of operators by using the results to optimize operator training.

The third section deals with energy efficiency implications of mineral processing and extractive metallurgy and contains four chapters [11–14]. Given the significance of comminution energy in any discussion of energy efficiency in mining, it is perhaps befitting that this section begins with a chapter on the best practices and future research needs for energy efficient comminution [11]. The next chapter discusses electrical energy consumption in electrowinning of metals from solution [12]. The chapter shows that to achieve energy efficient electrowinning a plant has to maximize current efficiency and optimize electrolysis parameters. The chapter also concludes that significant energy savings can only be achieved by changing one of the underlying electrochemical reactions or reducing the anode overpotential. The next chapter deals with plant process control and real-time optimization approaches that are used to achieve lower specific energy requirements by lowering variability in key process variables and determining more appropriate operating points [13]. The chapter also presents case studies to illustrate the current state of the art in process plant automation for energy efficiency. The final chapter in this section presents the case of the Atlantic Copper in Huelva, Spain, which was the first copper smelter in the world to receive ISO 50001 energy management certification [14]. The chapter presents Atlantic Copper's experience, process, and results in energy management.

The final section, which includes three chapters, deals with renewable energy in mining and other miscellaneous topics [15–17]. The use of renewable energy in mining is one of the major energy innovations in the last decade. The first chapter in this section discusses the integration of solar energy in mines' energy supply to enable them address energy and sustainability challenges [15]. The chapter discusses recent developments in solar energy in the mining industry and presents case studies where this framework has been successfully applied to incorporate solar energy into the mining energy supply mix. The second chapter in this section deals with energy efficient practices in mine ventilation [16]. Mine ventilation is an ancillary operation in underground mining that can have significant energy efficiency implications. The second chapter of this section discusses the energy efficiency implications of this important aspect of underground mining systems.

The final chapter of the section investigates the technical and economic feasibility of installing an energy recovery system (ERS) on diesel electric drive mine haul trucks [17]. On a mine haul truck, an ERS saves energy by recovering energy when the truck brakes during descent into the pit and puts that energy back into the system during ascent out of the pit. The chapter evaluates the technical and economic viability of various ERS technology using simulation. The work shows that lithium-ion batteries are infeasible because of poor charging rate while electrolytic double-layer capacitors are infeasible because of its low cycle life. Electromechanical flywheels are judged the most cost-effective option.

1.3 How to Use This Book

This book intended to be a resource for mine managers and engineers who want to improve the energy efficiency of their operations and, thereby, increase production efficiency and sustainability. It is also intended to be a resource for researchers looking for a comprehensive review of the literature on energy efficiency in the minerals industry. Each chapter is written by subject-matter experts who have contributed to the literature on the topics they have written in this book and are familiar with the current knowledge and outstanding questions that need further research. I anticipate that there will be two kinds of users for this book: industry practitioners and researchers.

For industry professionals, I suggest they start with this introduction. They can take note of the description of the various sections of the book as outlined in Sect. 1.2. The professional can then refer to the particular section of the book or the particular chapter that is of interest. It is my hope that each chapter provides an adequate overview of the energy efficiency consideration in the particular area for an industry professional. However, in case further reading on the subject is required, the list of references in the chapters is a good starting point for any professional.

For researchers, this volume is a good starting place for research on various energy efficiency topics in mining. Each of these chapters is a good review paper that summarizes the state of the art and provides citations to the relevant literature in the area. For the beginning graduate student or the seasoned researcher, the chapters in this book represent a valuable resource for energy efficiency research in the minerals sector. In some cases, complimentary chapters (especially, those in the same section) can provide additional resources that will be useful for any energy efficiency research endeavor.

1.4 Future Research Directions

This volume provides many suggestions for industrial best practices that managers and engineers across the mine life cycle can use to improve the energy efficiency of the mines. Each of these suggestions is backed by sound research. However, many other areas still require further research so we can bridge the gap between theoretical benchmarks and actual energy efficiency performance.

Comminution and material handling are still the main areas that show the most potential for energy efficiency improvement. The gap between theoretical benchmarks and current best practice is still wide. For example, as I have pointed out earlier, Sanchidrián and colleagues estimate that the maximum total energy measured during a blast does not exceed 26% of the available explosive energy [6]. We will need to reimagine how we remove in situ material and reduce its fragment sizes to the sizes required to liberate valuable minerals from gangue in order to bridge this gap.

Certainly, research that uses holistic, systems-based approaches (e.g., mine-to-mill techniques) that lead to globally optimal systems should be encouraged over approaches that optimize subsystems alone [4, 11, 18, 19]. At a minimum, any energy efficiency improvement initiative should evaluate the effect of improving a subsystem along the mining energy chain on the global energy efficiency of the mine. Management should not pursue any energy improvement initiative that improves a subsystem but does not result in overall energy improvement. Hence, future research that aims to improve mining energy efficiency should always consider the system-wide effects of any efforts to optimize energy efficiency.

Specific areas that can provide the necessary improvement in energy efficiency of comminution and material handling include research that helps us improve our understanding of energy transformations during blasting so that we can direct more of the explosives energy toward useful work. Also, we need better understanding of how operators affect energy efficiency of material handling machines. This is necessary to clarify the relationship between specific operator practices and energy efficiency. Finally, to facilitate more energy efficient comminution, we need to better understand fracture mechanics in rocks.

In addition to comminution and material handling, especially in light of climate change and its implications for mining, there is a need for research that facilitates optimal integration of renewable energy sources into mines. We need more research that provides means for determining optimal hybrid systems for different operating and economic conditions [20]. This is particularly important for mines in remote areas where there is little to no energy infrastructure.

Finally, as I have argued elsewhere [21], we need research that properly articulates the return on investment for public policy that facilitates energy efficiency in the minerals industry. Typically, manufacturing and residential energy consumers get the bulk of the policy attention when it comes to energy efficiency. However, mining is very energy intensive and a significant energy consumer in many economies. In particular, electricity consumption by the mining industry makes up a significant portion of the energy use in developing countries with significant extractive industries [22]. Hence, it will be of public interest to increase the energy efficiency of mines in order to improve the energy efficiency of the entire economy.

1.5 Conclusions

It is my hope that this volume will be a valuable resource for industry professionals and researchers. The work in this volume represents the state of the art regarding key topics in energy efficiency in the minerals sector. The breadth of coverage and the depth in each of the chapters make it a useful resource for all managers and engineers interested in energy consumption and efficiency at the mine site. Above all, I hope that this volume will spur on further discussions on all aspects of energy efficiency in mining.

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