CIPEC

BENCHMARKING THE ENERGY CONSUMPTION OF

CANADIAN UNDERGROUND BULK MINES

PREPARED FOR THE MINING ASSOCIATION OF CANADA
AND NATURAL RESOURCES CANADA

Natural Resources Canada | Ressources naturelles Canada

Canada

For more information or to receive additional copies of this publication, write to:

Canadian Industry Program for Energy Conservation
c/o Natural Resources Canada
580 Booth Street, 18th Floor
Ottawa ON K1A 0E4

Tel.: (613) 995-6839
Fax: (613) 992-3161
E-mail: cipec-peeic@nrcan.gc.ca
Web site: oee.nrcan.gc.ca/cipec

or

Mining Association of Canada
350 Sparks St., Suite 1105
Ottawa ON K1R 7S8

Tel: (613) 233-9391
Fax: (613) 233-8897
Web site: www.mining.ca

Library and Archives Canada Cataloguing in Publication

Main entry under title :

Benchmarking the energy consumption of Canadian underground bulk mines

Issued also in French under title: Analyse comparative de la consommation d'énergie des mines souterraines toutes teneurs du Canada.

ISBN 0-662-39539-5
Cat. No. M144-71/2005E

1. Mines and mineral resources – Energy consumption – Canada.
2. Mines and mineral resources – Energy conservation – Canada.
3. Mining engineering – Energy consumption – Canada.
4. Mining engineering – Energy conservation – Canada.
5. Energy conservation – Canada.
6. Energy consumption – Canada.
7. Energy auditing – Canada.

I. Canadian Industry Program for Energy Conservation.
II. Mining Association of Canada.

TN275.A2B46 2005   622'.2'086   C2005-980103-4

FOREWORD

On behalf of the Mining Industry's Task Force of the Canadian Industry Program for Energy Conservation (CIPEC), the Mining Association of Canada (MAC) retained the Competitive Analysis Centre Inc. to work with mining companies to establish energy benchmarks for underground bulk mining. Companies participating in this project paid for the on-site services of the consultancy and have received individualized reports on the findings.

CIPEC consists of 26 task forces, representing the various industrial sectors in Canada. It is a partnership of industrial associations and the Government of Canada, represented by Natural Resources Canada's Office of Energy Efficiency. The Mining Task Force comprises members of MAC's Energy Committee. The CIPEC Task Forces act as focal points for identifying energy efficiency potential and improvement opportunities, establishing sector energy efficiency targets, reviewing and addressing barriers, and developing and implementing strategies to meet the targets.

This publication is one of a series of MAC publications demonstrating the mining industry's commitment to reducing greenhouse gas emissions – a commitment essential to our common well-being. Among our members, good energy practices are simply accepted as being good business practices.

Leading Canadian to Energy Efficiency at Home, at Work and on the Road

The Office of Energy Efficiency of Natural Resources Canada
strenghens and expands Canada's commitment to energy efficiency
in order to help address the challenges of climate change.

CONTENTS

1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background

Energy costs represent a significant component of the total costs of operations for Canada's mining sector. Directly and indirectly, energy use in the mining sector is a significant contributor to Canada's greenhouse gas (GHG) emissions. There are, therefore, compelling economic and environmental reasons for mining and milling operations to examine their energy consumption comprehensively.

The Mining Association of Canada (MAC) has sponsored this energy benchmarking project. The focus is a detailed comparison of the energy consumption for the main mining and concentration activities. The Office of Energy Efficiency of Natural Resources Canada (NRCan) has provided assistance for this study, which is a part of NRCan's ongoing efforts to promote more efficient energy use in Canada.

1.2 Focus

The focus of this analysis is the mining and concentration operations of underground bulk mines of MAC members. Eleven mining/milling operations participated in the project, and the sample specifically included the operations of both base metals and precious metals establishments.

The project involved a detailed inter-facility comparison of the energy consumed in mining (drilling through to hoisting) and concentration (crushing through to conveying). Approximately 20 categories of energy cost and usage information were examined.

Given the differences between operations for base metals and precious metals, energy comparisons have been subdivided into these two categories.

1.3 International Comparisons

It was agreed among MAC members that it was important to provide an international context for a detailed Canadian analysis. Specifically, the objective was to compare the unit (e.g. $/tonne hoisted) energy costs of Canadian operations with those in other competing countries, such as Australia, the U.S., etc.

With the help of NRCan and AME Mineral Economics, the Competitive Analysis Centre Inc. (CACI) has been able to compare the energy costs for a sample of Canadian mines with a sample in other countries for gold, copper and lead/zinc operations.

1.4 Layout of Report

We begin by outlining our methodology in **Chapter 2**. We describe our approach for developing energy cost comparisons ($/tonne hoisted; $/tonne milled [or concentrate produced]; $/unit of metal produced) between Canadian operations and those in other competing countries. The focus in this chapter is on outlining our energy benchmarking for analysing the operations of the Canadian participants.

Chapter 3 presents the results of the analysis of the competitiveness of the unit energy costs for Canadian mining operations with those in other countries.

The results of the detailed benchmarking of energy costs and usage for the 11 participating establishments are provided in **Chapter 4**. Inter-establishment comparisons are presented at the mine and mill levels as well as for each stage of production.

Chapter 5 presents the estimated potential savings that companies may achieve based on a comparison of each participant's costs with those from the lowest-cost operation.

2 METHODOLOGY

6

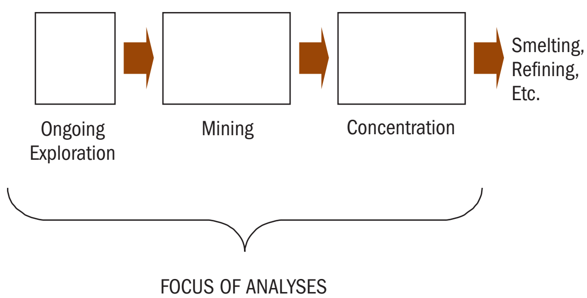
2.0 METHODOLOGY

2.1 Boundaries of the Analysis

The focus of the analysis of comparative energy costs and usage is as follows.

2.1.1 Base Metals

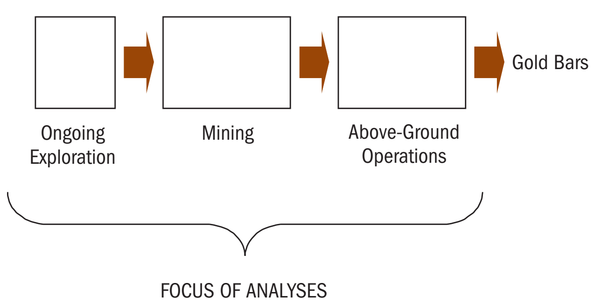
The Canadian base metals energy analysis focused on mining and milling operations, including ongoing exploration at existing mines. Smelting and refining operations were excluded.



International comparisons were possible for copper and lead/zinc, but not for nickel. Energy cost comparisons include cost/tonne hoisted, cost/tonne concentrate, and cost/pound of metal.

2.1.2 Gold

The comparisons of Canadian gold operations include both mining operations and above-ground operations (from crushing to the production of gold bars).



The international comparisons include cost/tonne hoisted, cost/tonne milled, and cost/troy ounce of gold produced.

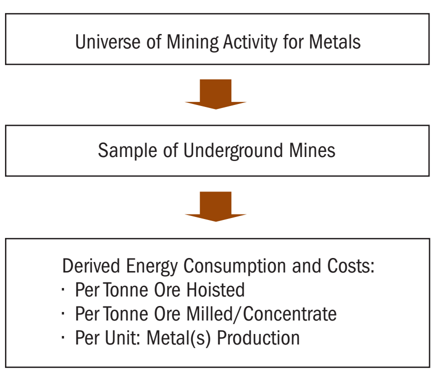
2.2 International Comparisons

The comparative energy costs between Canadian mines and their international competitors is of great interest to all mines participating in the Mining Association of Canada Benchmarking Study. With the assistance of NRCan, CACI has obtained the information necessary to compare Canadian bulk underground mines with those in competing countries for the following metals: gold, copper and lead/zinc. The energy cost comparisons are based on mine cost surveys by AME Mineral Economics.[1]

The energy cost comparisons are limited to those countries where comparable cost data exist; comparisons with China and Russia are not possible. Comparisons have been restricted to underground mining activity. Comparative energy costs have been developed for Canadian underground mines and underground facilities in the following countries:

GOLD	COPPER	LEAD/ZINC
Australia	Australia	Australia
South Africa	Chile	Peru
U.S.		U.S.

For each of the above countries, deriving energy costs has involved the following for each of the above three metal groupings.



[1] AME Mineral Economics, *Lead and Zinc 2000, Gold 2000, and Copper 2000 – Mine Costs 1994–2005*, 1999.

2.2.1 The Sample

The international comparisons of underground mines in this study focused on the five leading metal-producing countries. A description of the sample for gold, copper and lead/zinc is provided below. The sample description includes the following: the producing country, the number of mines in the sample, sample mine production, total domestic production for each country, the percentage of domestic production accounted for by the sample, and each country's production as a percentage of world production. A complete list of the individual mines for each metal and each country can be found in Appendix 2-1 (p. 70). For those countries where the sample coverage is low, the main producers are open-pit mines.

Gold

Table 2.1 – Description of Sample: Gold Mines

Country	Sample Mines	Gold Produced by Sample ('000 oz.)	Total Domestic Production ('000 oz.)	Sample as % of Domestic Production	Domestic Production as % of World Production
			1999		
Canada	14	2 483.4	5 235.6	47.4	6.3
Australia	11	1 604.0	10 053.6	16.0	12.1
South Africa	27	11 530.0	14 357.6	80.3	17.3
U.S.	5	1 520.9	11 563.2	13.2	13.9

SOURCE: AME MINERAL ECONOMICS, *GOLD 2000.*

Copper

Table 2.2 – Description of Sample: Copper Mines

Country	Sample Mines	Copper Produced by Sample ('000 t)	Total Domestic Production ('000 t)	Sample as % of Domestic Production	Domestic Production as % of World Production
			1999		
Canada	5	653.1	705.2	92.6	5.8
Australia	5	424.1	604.0	70.2	5.0
Chile	4	416.0	3 687.0	11.3	30.3

SOURCES: AME MINERAL ECONOMICS, *COPPER 2000*; NRCAN, *CANADIAN MINERALS YEARBOOK*, 1998.

Lead/Zinc

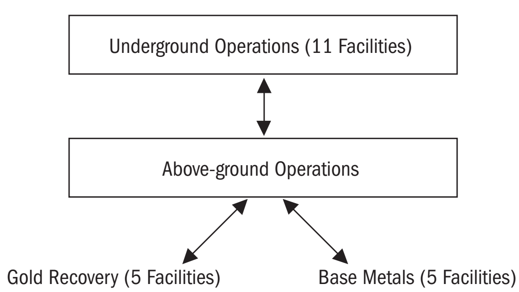
Table 2.3 – Description of Sample: Lead/Zinc Mines

Country	Sample Mines	Lead/Zinc Produced by Sample ('000 t)	Total Domestic Production ('000 t)	Sample as % of Domestic Production	Domestic Production as % of World Production
			1999		
Canada	11	1 029.9	1 245.7	82.7	22.5
Australia	11	1 543.9	1 563.9	98.7	28.3
Peru	6	518.0	570.5	90.8	10.3
U.S.	7	551.1	1 072.9	51.4	19.4

SOURCES: AME MINERAL ECONOMICS, *LEAD & ZINC 2000*. PRODUCTION FIGURES ARE FOR 1999. STATISTICS CANADA – CAT. NO. 26-202-XIB.

2.3 Mining Association of Canada (MAC) Sample

A total of 11 establishments participated in this project. Each case study included an underground bulk mining facility. For 10 of the 11 mines, energy information was provided for above-ground operations. These included five gold recovery operations producing gold bars and five base metals operations producing concentrates.



2.3.1 Analysis: Overview

The objective of the analysis is to provide a detailed inter-facility comparison of the unit costs and unit energy consumption for:

Underground Mining

All operations, including the transport of ore to an above-ground crusher. Eleven mining operations will be compared.

Above-Ground Operations

Separate analyses will be conducted for:

a) Gold Recovery Operations: Energy consumption and costs for the five gold recovery facilities will be compared from crushing to gold refining.

b) Base Metals Operations: Energy consumption and costs for the five base metals facilities will be compared from crushing to drying.

Combined Operations

Total energy consumption and costs will be compared, separately, for the five gold mining/refining operations and the five base metals operations

In all cases, energy consumption will be based on kilowatt hour equivalents (kWh_e). The conversion factors for other categories of energy are illustrated below.

Table 2.4 – Conversion Factors (kWh_e)

Energy	Units	kWh_e/Unit
Diesel	L	10.74
Gasoline	L	9.63
Natural Gas	m^3	10.31
Explosives	kg	1.06
Light Fuel Oil	L	10.40
Bunker C	L	11.59

The inter-facility comparisons are based on the following unit costs and disaggregation into components for underground and above-ground facilities.

Underground

$$\left[\frac{\$}{\text{tonne ore hoisted}}\right] = \left[\frac{\$}{kWh_e}\right] \text{X} \left[\frac{kWh_e}{\text{tonne ore hoisted}}\right]$$

Above Ground

a) Gold

$$\left[\frac{\$}{\text{tonne milled}}\right] = \left[\frac{\$}{kWh_e}\right] \text{X} \left[\frac{kWh_e}{\text{tonne milled}}\right]$$

b) Base Metals

$$\left[\frac{\$}{\text{tonne milled}}\right] = \left[\frac{\$}{kWh_e}\right] \text{X} \left[\frac{kWh_e}{\text{tonne milled}}\right]$$

Total Complex

For the **total complex**, the unit energy costs and consumption will be based on a roll-up of the above. Given that some above-ground facilities process ore from more than one mine, the data for the total complex are based on:

- the mining costs for the facility in the study; and
- average costs (and consumption) for the energy used in above-ground operations.

Given the above assumptions, the total energy costs can be broken down as follows:

a) Gold

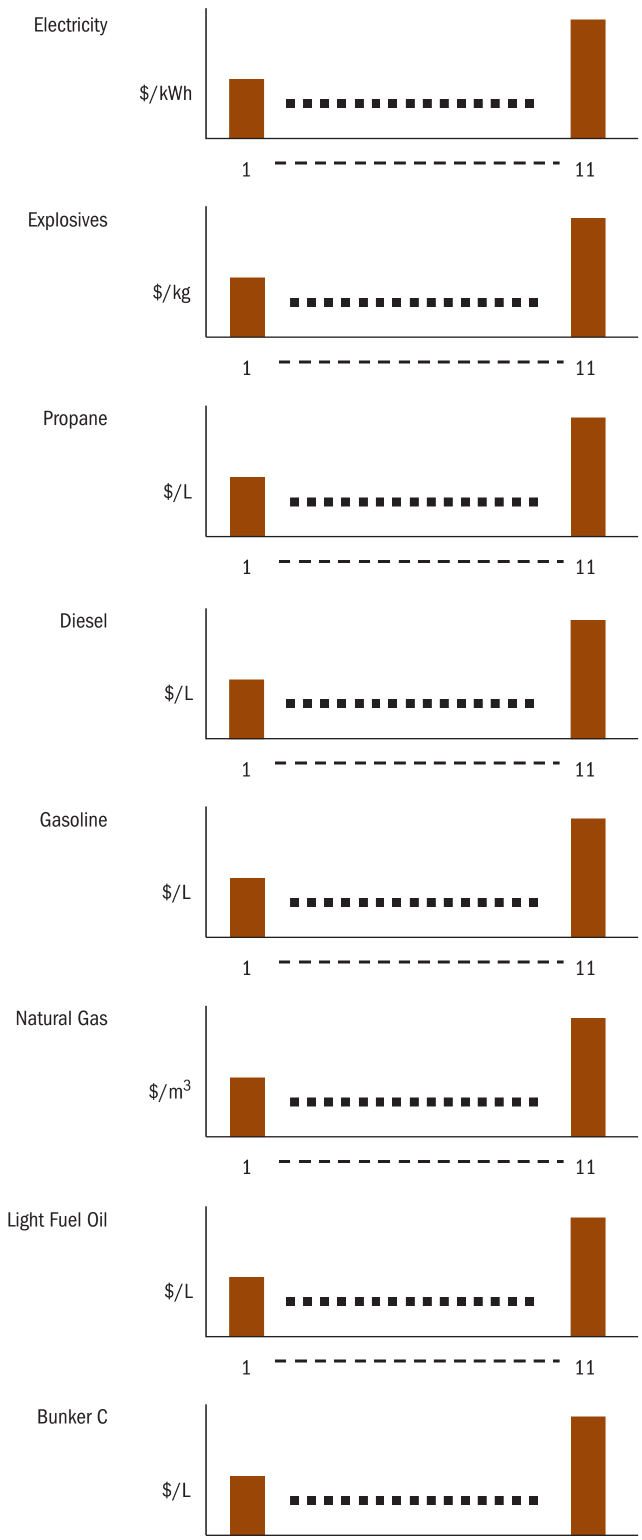
$$\left[\frac{\$}{\text{tonne ore milled}}\right] = \left[\frac{\$}{kWh_e}\right] \text{X} \left[\frac{kWh_e}{\text{tonne ore milled}}\right]$$

b) Base Metals

$$\left[\frac{\$}{\text{tonne ore milled}}\right] = \left[\frac{\$}{kWh_e}\right] \text{X} \left[\frac{kWh_e}{\text{tonne ore milled}}\right]$$

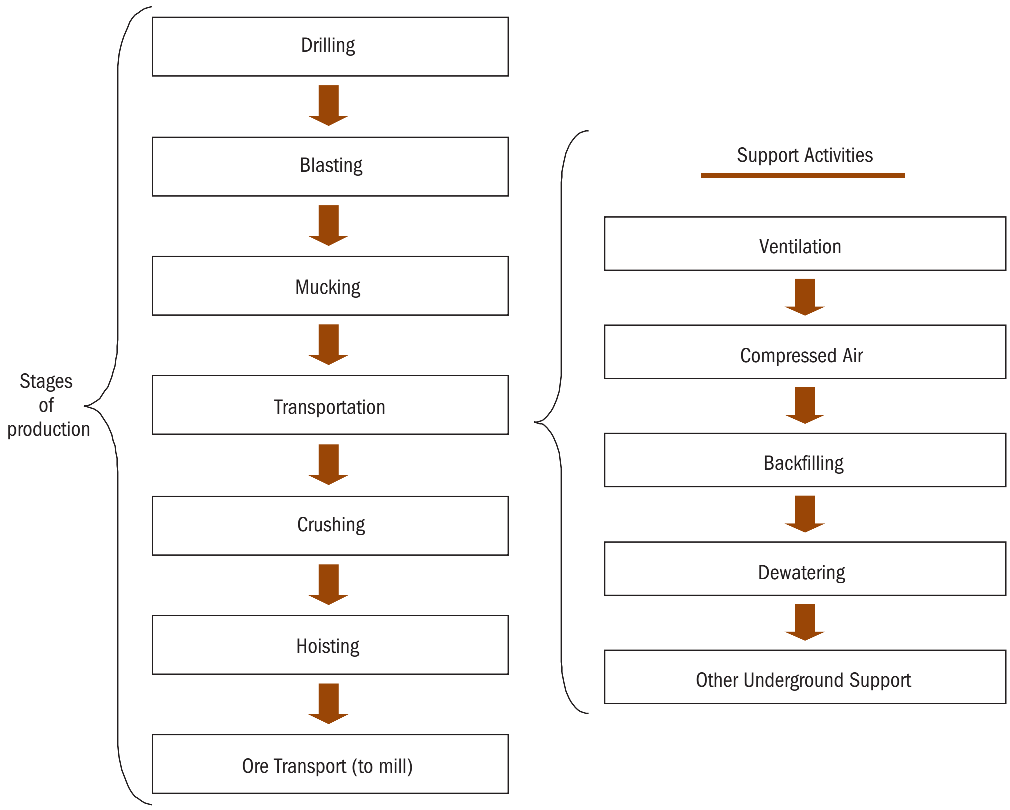
2.3.2 Analysis: Comparative Energy Costs

It was anticipated that there would be differences between the 11 facilities in the average costs of the energy used.

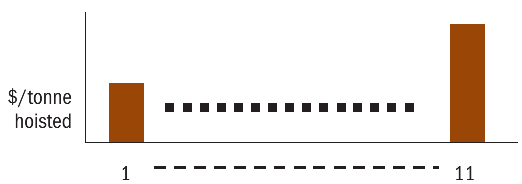


2.3.3 Analysis: Underground Operations

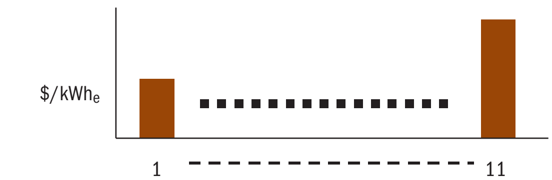
The underground mining operations were subdivided into seven stages of production and five support activities. These categories are shown below.



The total energy costs for underground mining operations for the 11 operations were compared.

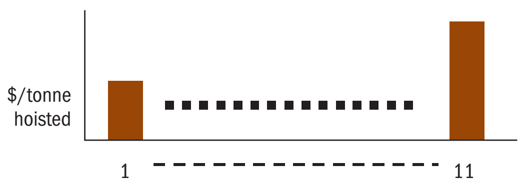


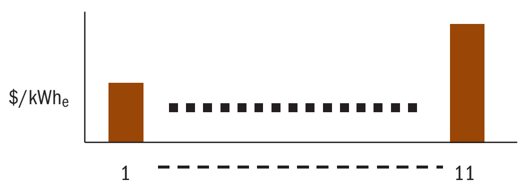
These energy costs were, in turn, subdivided into two components: $\$/\text{kWh}_e$ and kWh_e/tonne hoisted.

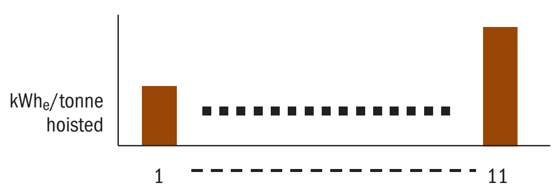


Similarly, the individual energy costs and consumption were compared for the 11 operations by stage of production and for the individual support activities.

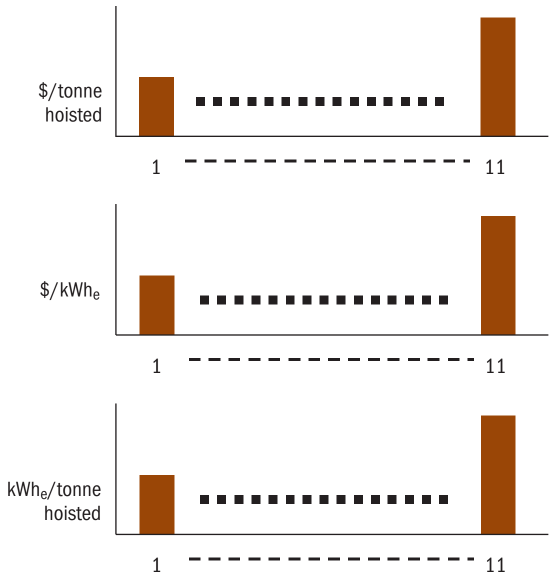
Drilling





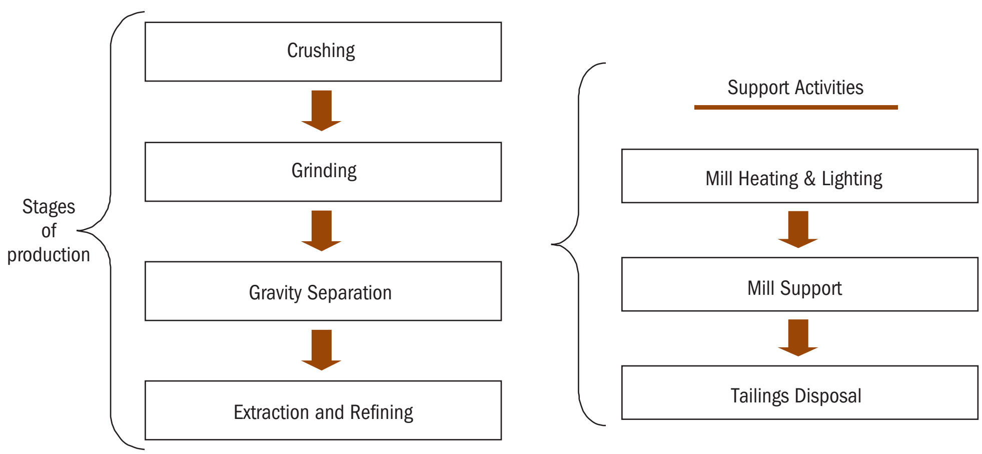


Underground Support

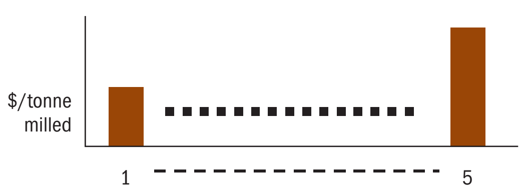


2.3.4 Analysis: Above-Ground Operations – Gold Recovery

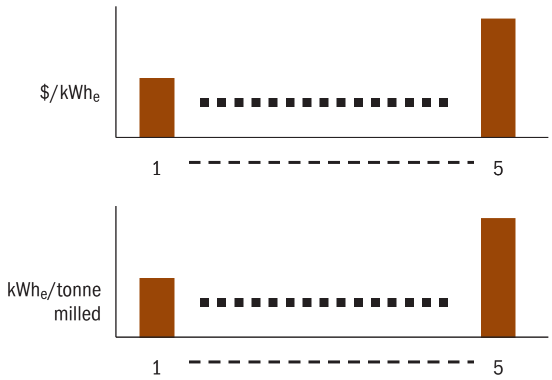
The above-ground gold recovery operations were subdivided into the following stages of production and support activities.



The total energy costs for the above-ground operations for the five gold recovery operations were compared.

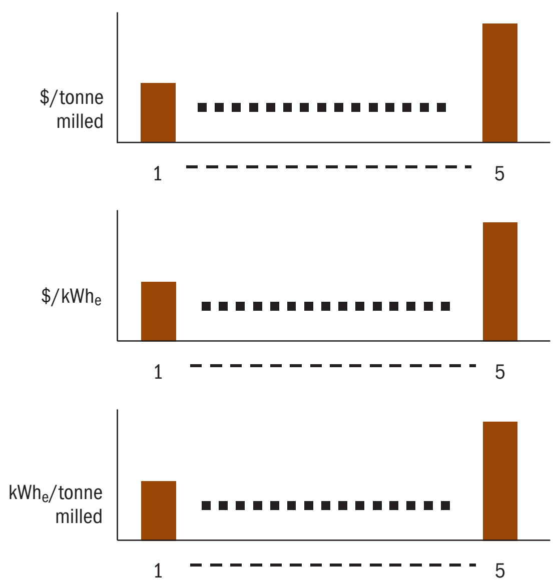


These energy costs were, in turn, subdivided into two components: $/kWh$_e$ and kWh$_e$/tonne ore milled.

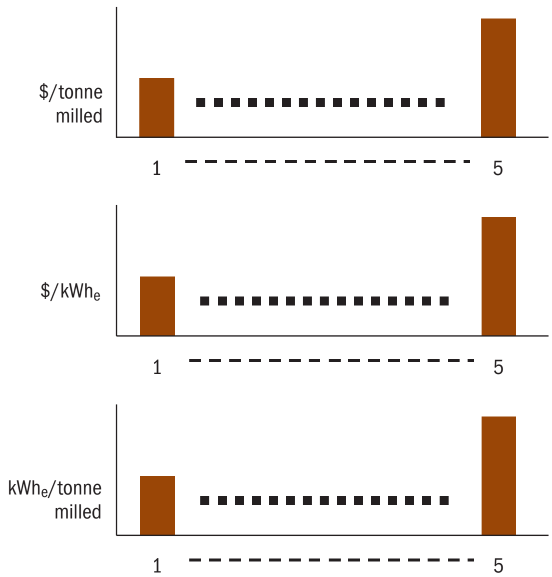


The total energy costs were compared for each of the above-ground gold recovery operations.

Crushing

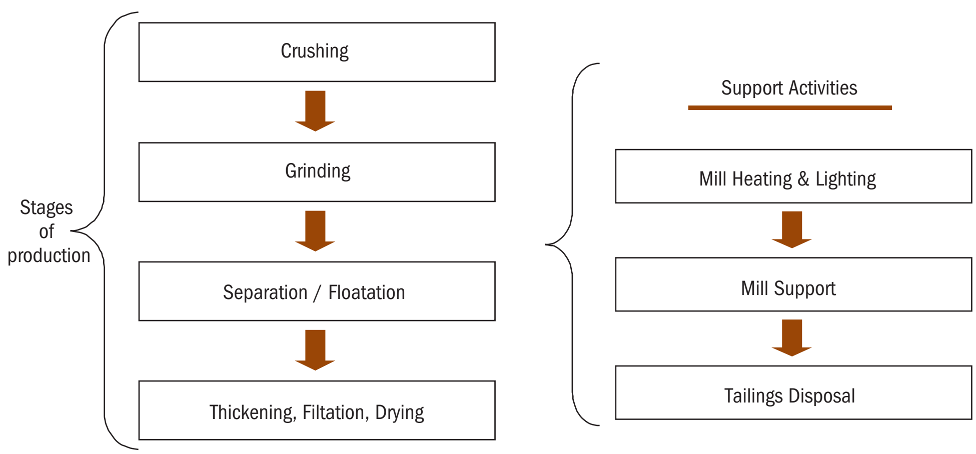


Tailings Treatment and Disposal

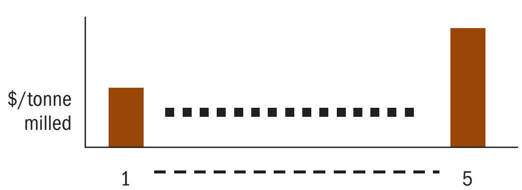


2.3.5 Analysis: Above-Ground Operations – Base Metals Milling

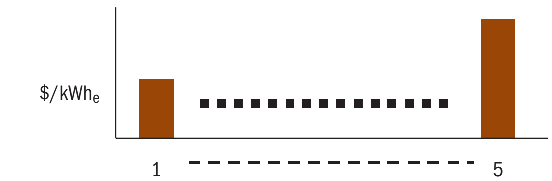
The base metals concentration facilities were subdivided into the following stages of production and support facilities.



The total energy costs for the five base metals milling operations were compared.

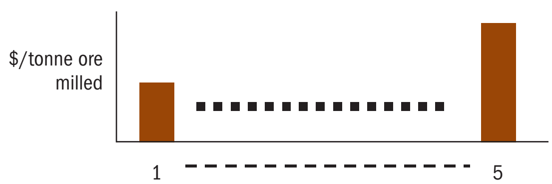


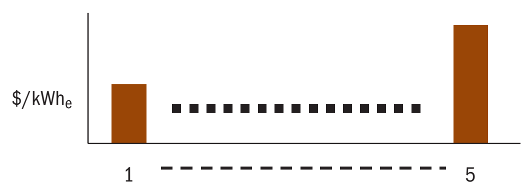
These energy costs were, in turn, subdivided into two components: $\$/\text{kWh}_e$ and $\text{kWh}_e/\text{tonne}$ milled.

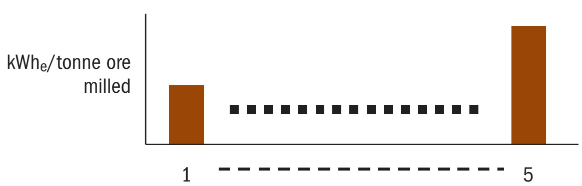


The total energy costs were compared for each stage of the milling operations.

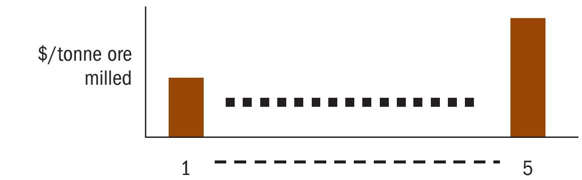
Crushing

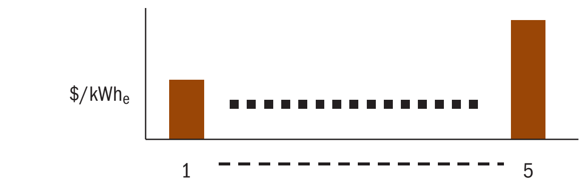


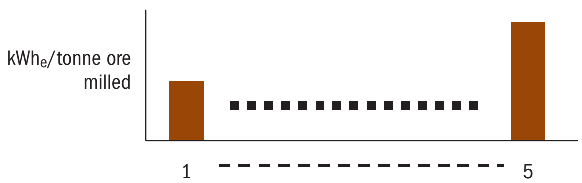




Tailings Recovery and Disposal



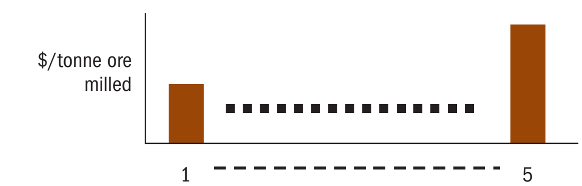


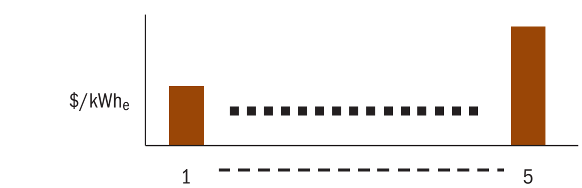


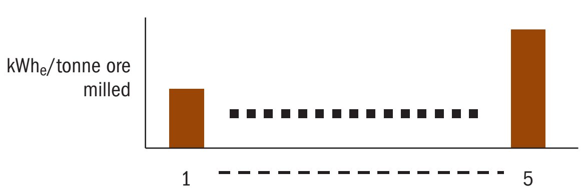
2.3.6 General and Administration

The costs for general and administration activities were compared separately for the gold mining operations and base metals operations.

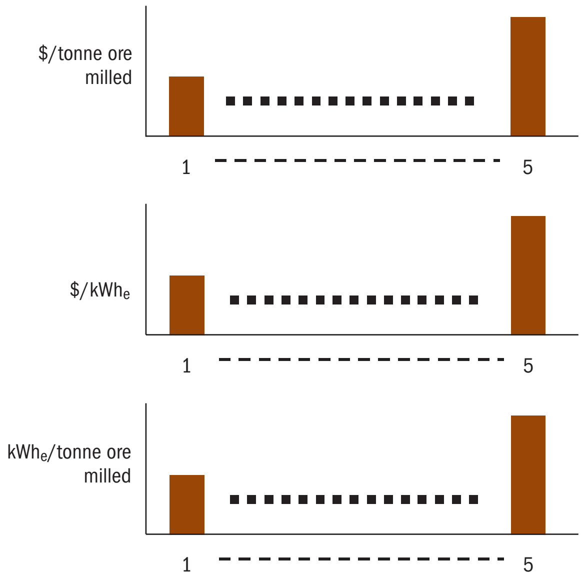
Gold Mining







Base Metals



2.4 Greenhouse Gas (GHG) Analysis

Although this study has focused on energy efficiency, it is important to underline the links with ongoing efforts to achieve GHG reductions. The database assembled for the 11 participants in this study provides a starting point for any GHG reduction efforts at the facilities. Applying the following GHG conversion factors, it is possible to determine emission levels for the above-ground and underground facilities.

Table 2.5 – Conversion Factors: GHG Equivalents

Energy	Units: tonnes of CO_2 per	CO_2 Conversion Factor (tonnes)
Electricity	MWh	0.19
Natural Gas	1 000 m^3	1.88
Gasoline	1 000 L	2.83
Diesel	1 000 L	2.73
Furnace Oil	1 000 L	2.83
Propane	1 000 L	1.53
ANFO (ammonium nitrate and fuel oil)	tonne	0.189

SOURCE: ENVIRONMENT CANADA, *TRENDS IN CANADA'S GREENHOUSE GAS EMISSIONS 1990–1995.*

Any improvements in energy efficiency will have the added benefit of GHG reductions. The level of impact will, of course, depend on the specific circumstances of each case.

3

ENERGY COSTS: COMPETING COUNTRIES

3.0 ENERGY COSTS: COMPETING COUNTRIES

Having identified the competing countries, we determined the energy costs for underground mining complexes. See Appendix 2-1 for a list of mining complexes by country.

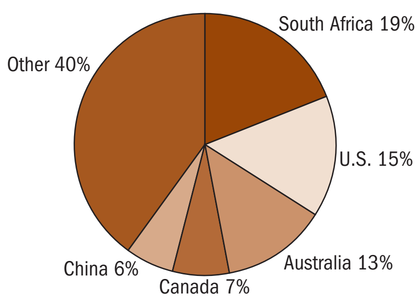
We begin by showing the relative importance of each producing country in the world market for each metal. We then illustrate the energy costs based on:

- costs per tonne of ore hoisted
- costs per tonne of ore milled
- costs per unit of metal produced

3.1 Gold

The relative importance of the leading gold-producing countries is illustrated below. Percentages are based on 1997 figures.

Figure 3.19 – Leading Gold-producing Countries (1998)*



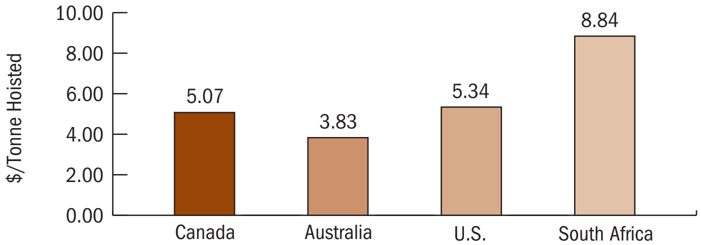
* SOURCE: MINING ASSOCIATION OF CANADA, "IT'S A FACT," *1999 FACTS AND FIGURES.*

The comparative energy costs for the leading gold-producing countries, expressed in U.S. dollars, are as follows.

3.1.1 Average Energy Cost per Tonne of Ore Hoisted

In 1999, Canada's gold mines had energy costs of $5.07 per tonne of ore hoisted. South Africa, the largest producer in the world, had energy costs of $8.84 per tonne hoisted, the highest of the four countries in the sample. The U.S. was next highest at $5.34 per tonne hoisted. Australia had the lowest energy cost per tonne hoisted – $3.83. Canada's energy costs per tonne of ore hoisted were therefore 32 percent higher than those for Australia.

Figure 3.20 – Average Energy Cost per Tonne of Ore Hoisted* (1999 U.S. Dollars)

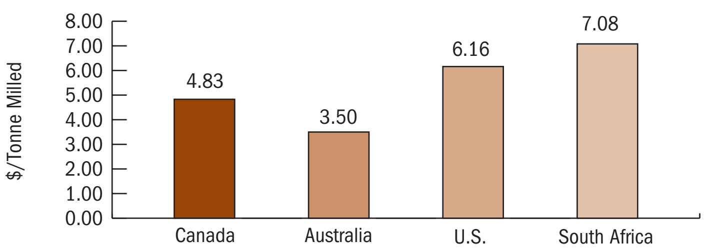


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.1.2 Average Energy Cost per Tonne of Ore Milled

Canada's gold mines paid on average $4.83 in energy costs per tonne of ore milled in 1999. South African mines averaged costs of $7.08 per tonne milled, the highest of the four countries in the sample. The U.S. was next highest at $6.16 per tonne milled. Australia was the lowest-cost producer: its mines averaged just $3.50 in energy costs per tonne of ore milled. Canada's energy costs per tonne of ore milled were therefore 37 percent higher than those for Australia.

Figure 3.21 – Average Energy Cost per Tonne of Ore Milled* (1999 U.S. Dollars)

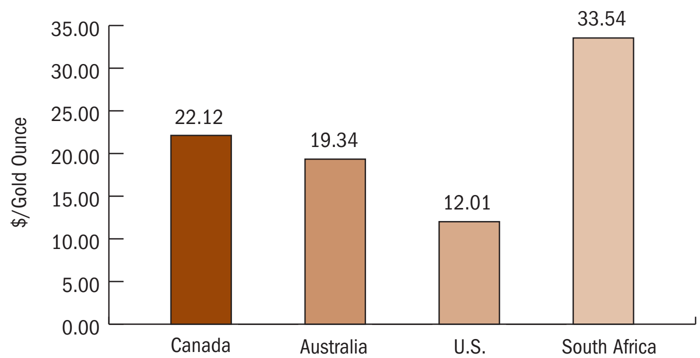


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.1.3 Energy Costs per Ounce of Gold Produced

Canada's gold mines paid on average $22.12 in energy costs per troy ounce of gold in 1999. South Africa, the largest producer in the world, had energy costs of $33.54 per ounce, the highest of the four countries in the sample. The U.S. had the lowest cost, $12.01 per ounce. Australia was the second lowest of the four, at $19.34. Canada's energy costs per ounce of gold were therefore 84 percent higher than those for the United States. Note that although U.S. gold mines had a higher cost than Canadian and Australian gold mines on the basis of tonnes hoisted and milled, they achieved the lowest energy cost per ounce of gold produced. This is attributable to higher ore grades at these mines than at Canadian and Australian mines.

Figure 3.22 – Average Energy Cost per Troy Ounce of Gold Produced* (1999 U.S. Dollars)

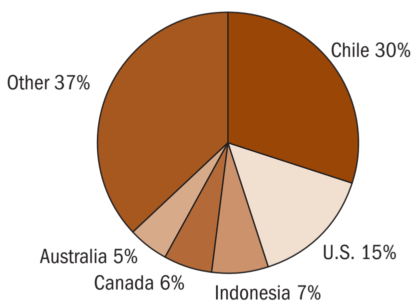


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.2 Copper

The relative importance of the leading copper-producing countries is illustrated below. Percentages are based on 1998 data.

Figure 3.23 – Leading Copper-Producing Countries (1998)*



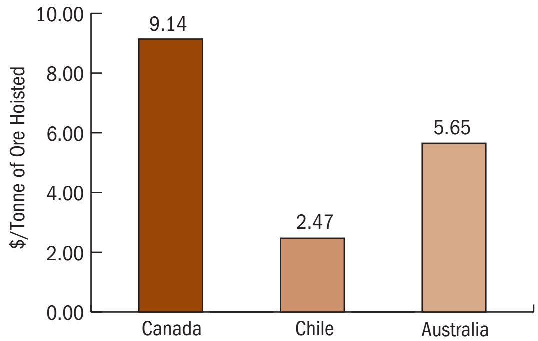
* SOURCE: MINING ASSOCIATION OF CANADA, "IT'S A FACT," *1999 FACTS AND FIGURES.*

The comparative energy costs for leading copper-producing countries, expressed in U.S. dollars, are as follows.

3.2.1 Average Energy Cost per Tonne of Ore Hoisted

Canada's copper mines had energy costs of $9.14 per tonne of ore hoisted in 1999. This was the highest of the leading countries for which data were available. Chile, the world's largest producer of copper, had costs of just $2.47 per tonne hoisted. Australian mines averaged $5.65 in energy costs per tonne of ore hoisted. Thus, energy costs per tonne hoisted at the Canadian mines were 270 percent higher than those for the Chilean mines.

Figure 3.24 – Average Energy Cost per Tonne of Ore Hoisted* (1999 U.S. Dollars)

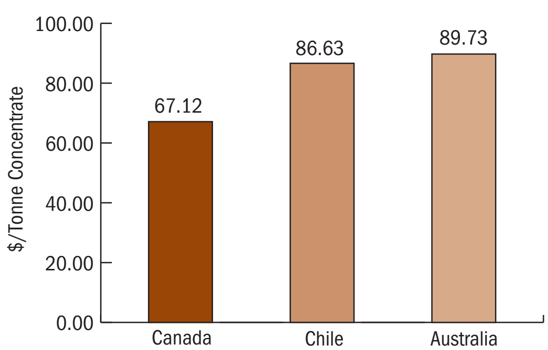


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.2.2 Average Energy Cost per Tonne of Concentrate Produced

In 1999, Canadian copper mines' energy costs per tonne of concentrate were $67.12. Chilean mines averaged costs of $86.63 per tonne of concentrate; Australia's production was the most costly of the three sample countries, at $89.73 per tonne of concentrate. Although Canadian mines were the highest-cost energy consumers per tonne of ore hoisted, they achieved the lowest energy costs per tonne of concentrate. The range in per-unit energy costs is much smaller for concentrate produced than for tonnes hoisted: Australian per-unit energy costs are just 33.6 percent higher than those for Canada.

Figure 3.25 – Average Energy Costs per Tonne of Concentrate* (1999 U.S. Dollars)

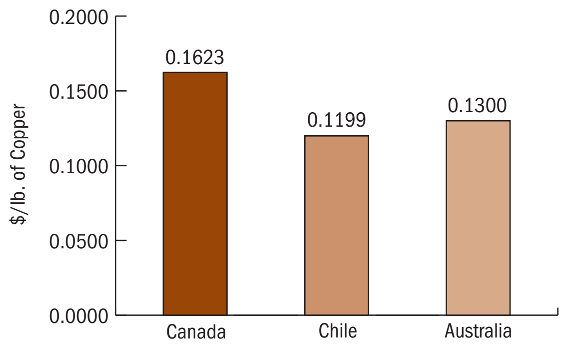


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.2.3 Average Energy Cost per Pound of Copper Produced

In 1999, Canadian copper mines' energy costs per pound of copper were $0.1623. Chile, the largest producer in the world, had energy costs of $0.1199 per pound and Australian mines had costs of $0.1300 per pound.

Figure 3.26 – Average Energy Costs per Pound of Copper Produced* (1999 U.S. Dollars)

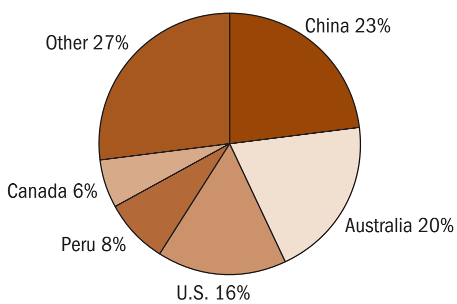


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.3 Lead and Zinc

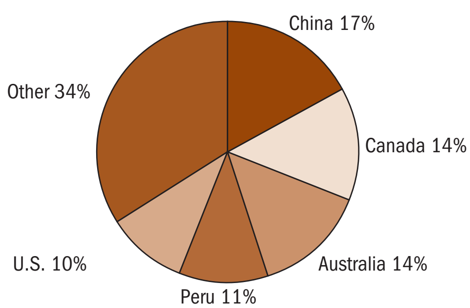
The relative importance of the leading lead- and zinc-producing countries is illustrated below.

Figure 3.27 – Leading Lead-Producing Countries (1998)



* SOURCE: MINING ASSOCIATION OF CANADA, "IT'S A FACT," *1999 FACTS AND FIGURES.*

Figure 3.28 – Leading Zinc-Producing Countries (1998)

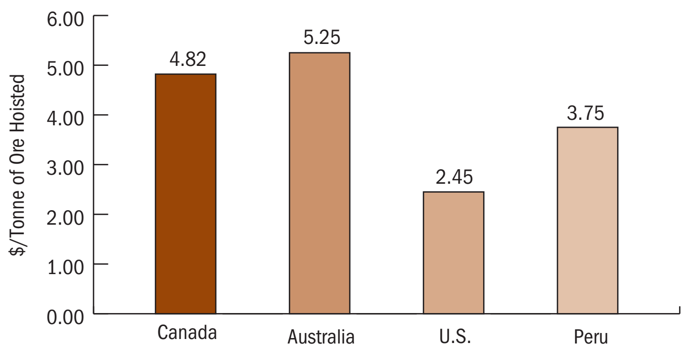


* SOURCE: MINING ASSOCIATION OF CANADA, "IT'S A FACT," *1999 FACTS AND FIGURES.*

3.3.1 Average Energy Cost per Tonne of Ore Hoisted

In 1999, Canada's lead and zinc mines had energy costs of $4.82 per tonne of ore hoisted. These costs were the second highest of those countries for which data were available. American mines averaged $2.45 per tonne of ore hoisted, the lowest cost of the group. Peru was next at $3.75 per tonne hoisted; Australian mines were the most costly at $5.25 per tonne hoisted. Energy costs per tonne hoisted at Canadian mines were therefore on average 97 percent higher than for American mines.

Figure 3.29 – Average Energy Cost per Tonne of Ore Hoisted* (1999 U.S. Dollars)

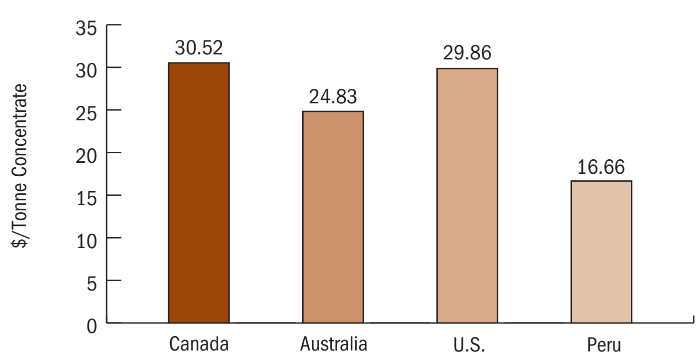


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.3.2 Average Energy Cost per Tonne of Concentrate Produced

In 1999, Canada's lead/zinc mines had energy costs of $30.52 per tonne of concentrate, the highest of the four countries. Peruvian mines had the lowest average costs ($16.66 per tonne of concentrate). Australia mines had costs of $24.83. Per-unit energy costs per tonne of concentrate for Canadian mines were therefore 83 percent higher than for the lowest-cost producer (Peru).

Figure 3.30 – Average Energy Cost per Tonne of Concentrate* (1999 U.S. Dollars)

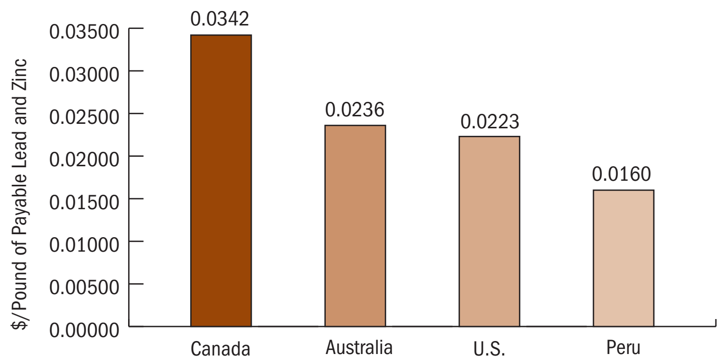


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.3.3 Energy Costs per Pound of Payable Lead and Zinc Produced

In 1999, Canada's lead/zinc mines spent on average $0.0342 in energy costs per pound of lead and zinc. Peru, the lowest-cost producer, had costs of just $0.0160 per pound. American and Australian mines had costs of $0.0223 and $0.0236 per pound respectively. Per-unit energy costs in Canada were therefore 114 percent higher than those of the lowest-cost producer (Peru).

Figure 3.31 – Energy Costs per Pound of Payable Lead and Zinc Produced* (1999 U.S. Dollars)

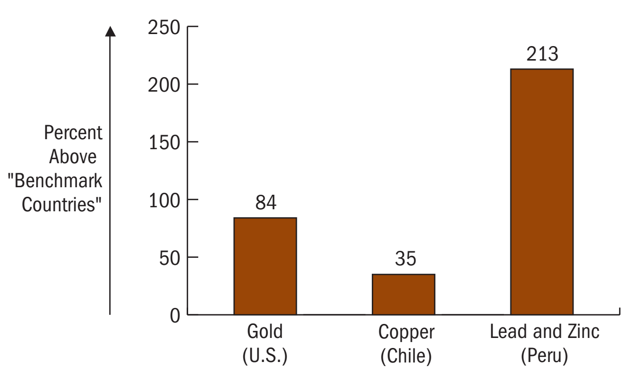


* NOTE: BASED ON THE SAMPLE OF MINES IN APPENDIX 2-1.

3.4 Summary

Canadian unit energy costs, based on the sample of facilities described in Chapter 2.0, are appreciably higher than those for the lowest-cost competitor countries. The comparisons below relate Canadian costs to those of the "benchmark countries."

Figure 3.32 – Canadian Energy Costs: International Comparison (Percent Above "Benchmark Countries")*



NOTES: * BASED ON METAL PRODUCTION.

4

RESULTS: BENCHMARKING PARTICIPATING MINES

4.0 RESULTS: BENCHMARKING PARTICIPATING MINES

The energy benchmarking results will be presented as we compare:

- the costs across the 11 participants for the individual energy sources
- the results for the mining operations of the 11 establishments
- the results for the concentration operations of the five base metals facilities
- the results for the five gold recovery establishments

4.1 Comparative Energy Costs

The unit energy costs are compared in Figure 4.1.2. There are very significant differences between the lowest- and highest-cost operations. As illustrated in Figure 4.1.1 below, the range of unit costs for each energy category is very wide (from 158 to 699 percent).

Figure 4.1.1 – Range of Unit Energy Costs

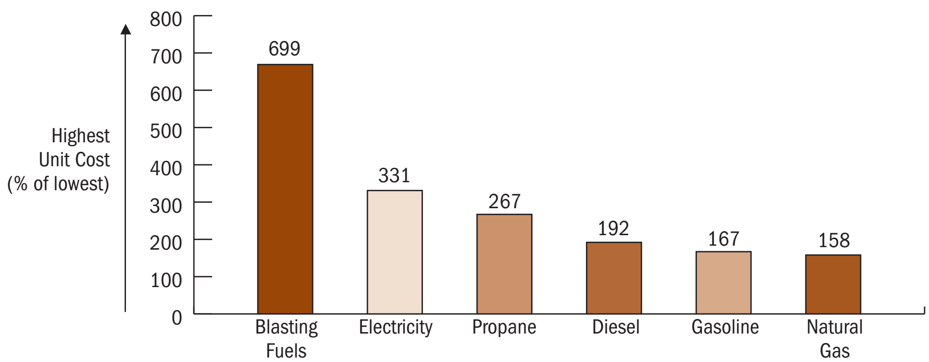
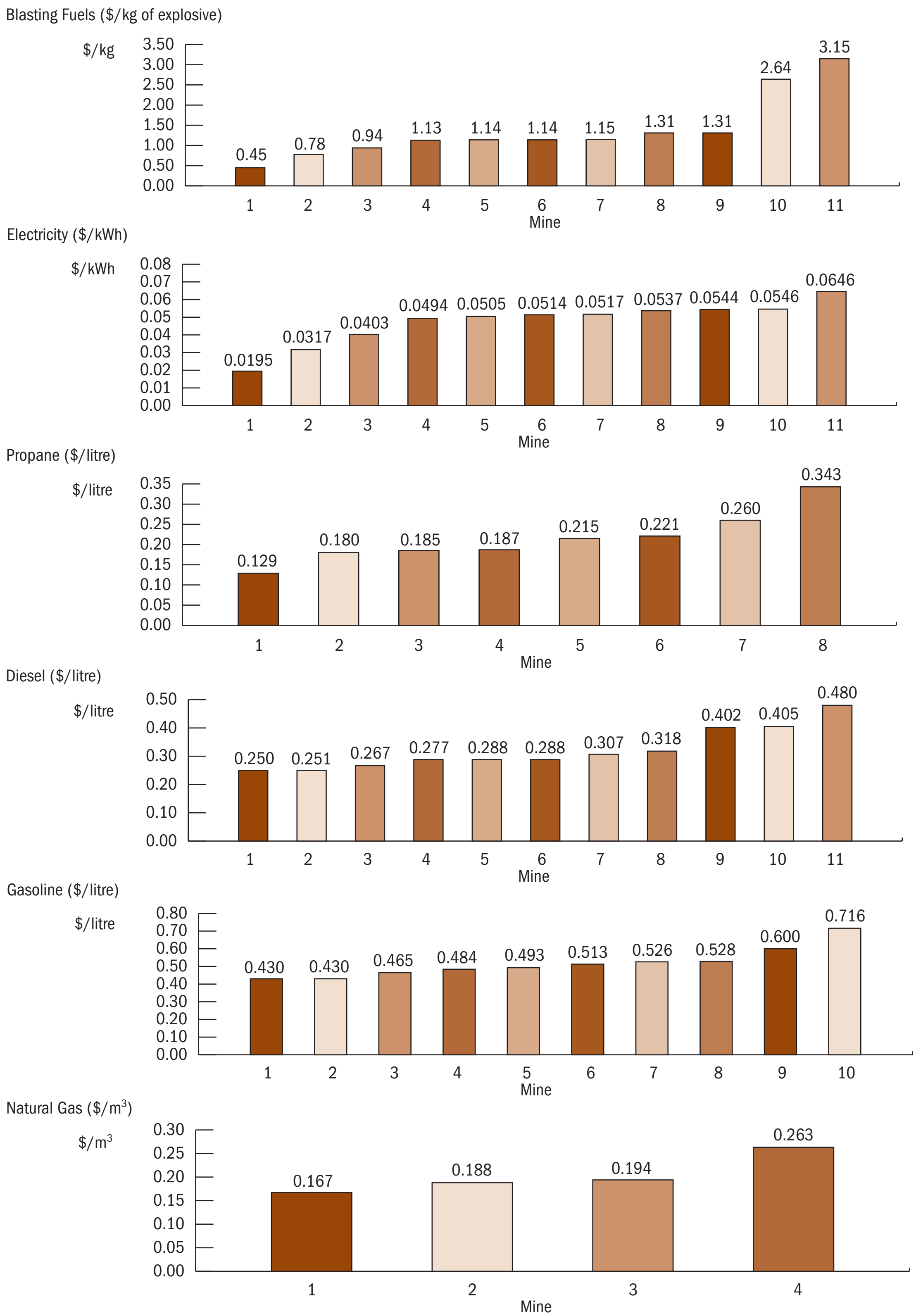


Figure 4.1.2 – Comparative Unit Energy Costs



4.2 Mining: Inter-Mine Comparative Energy Costs

Information was received from all underground operations, so it was possible to make comparisons at the aggregate level (costs and consumption per unit of ore hoisted). For 10 of the 11 mines, we received the information needed to disaggregate the comparisons by stage of production (drilling through to hoisting) and by support category (ventilation, backfill, etc.). In all cases, the energy costs were compared on the basis of Canadian dollars per tonne hoisted; these costs, in turn, were subdivided into an energy cost component (dollars per kWh equivalent) and a usage component (kWh equivalents per tonne hoisted).

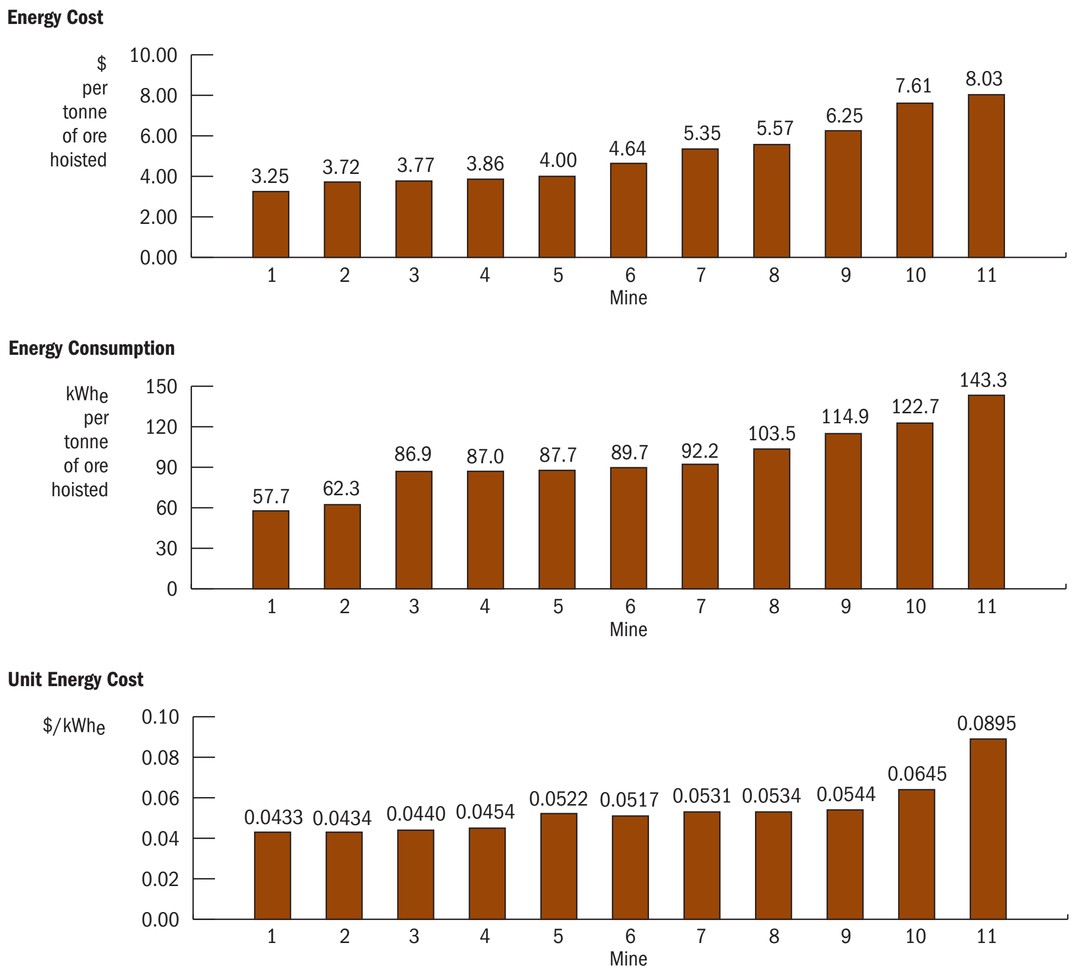
$$\frac{\$}{\text{tonne ore hoisted}} = \begin{cases} \left[\dfrac{kWh_e}{\text{tonne ore hoisted}} \right] \\ \left[\dfrac{\$(Cdn)}{kWh_e} \right] \end{cases}$$

4.2.1 Total Underground Mining

The total energy costs for underground mining for the 11 operations are illustrated in Figure 4.2.1. The unit costs vary from $3.25 per tonne hoisted to $8.03 per tonne hoisted. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	8.03 : 3.25	247
Energy Consumption (kWh_e/tonne of ore hoisted)	143.31 : 57.73	248
Unit Energy Cost ($/$kWh_e$)	0.0895 : 0.0433	207

Figure 4.2.1 – Comparisons: Total Mine Energy Costs



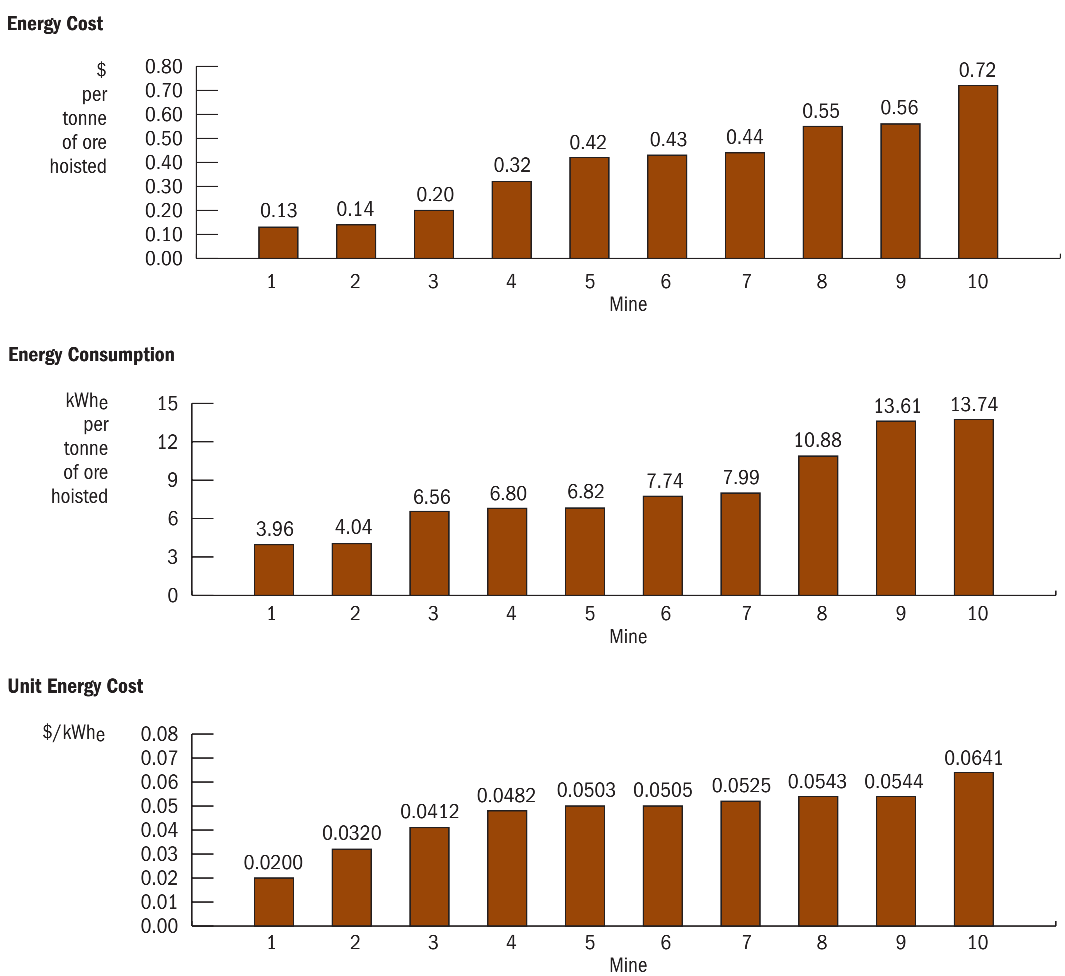
4.2.2 Underground Mining: Stages of Production

Drilling

The drilling energy costs varied from $0.13 to $0.72 per tonne hoisted for 10 drilling operations, as illustrated in Figure 4.2.2. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.72 : 0.13	554
Energy Consumption (kWh_e/tonne of ore hoisted)	13.74 : 3.96	347
Unit Energy Cost ($/$kWh_e$)	0.0641 : 0.0200	321

Figure 4.2.2 – Inter-Mine Comparisons: Drilling

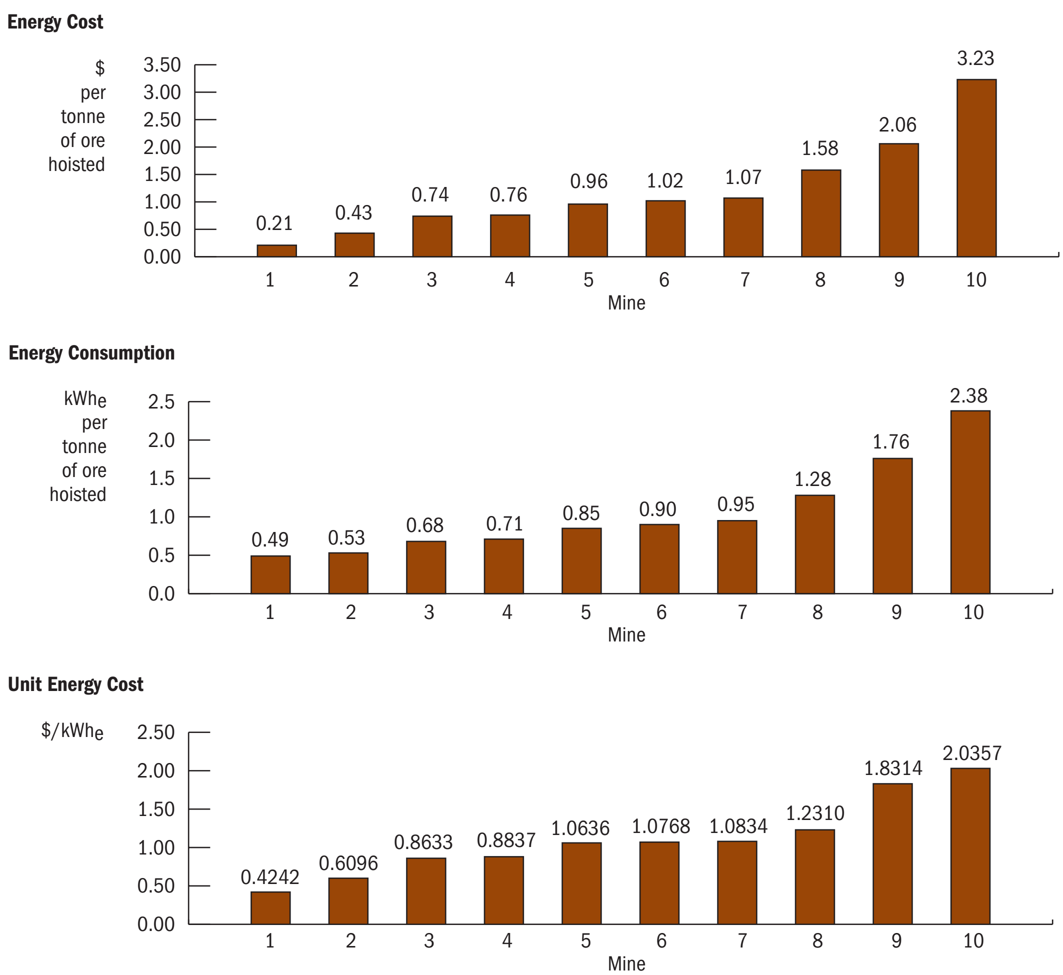


Blasting

The blasting energy costs varied from $0.21 to $3.23 per tonne hoisted, as illustrated in Figure 4.2.3. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	3.23 : 0.21	1538
Energy Consumption (kWh_e/tonne of ore hoisted)	2.38 : 0.49	486
Unit Energy Cost ($/$kWh_e$)	2.0357 : 0.4242	480

Figure 4.2.3 – Inter-Mine Comparisons: Blasting

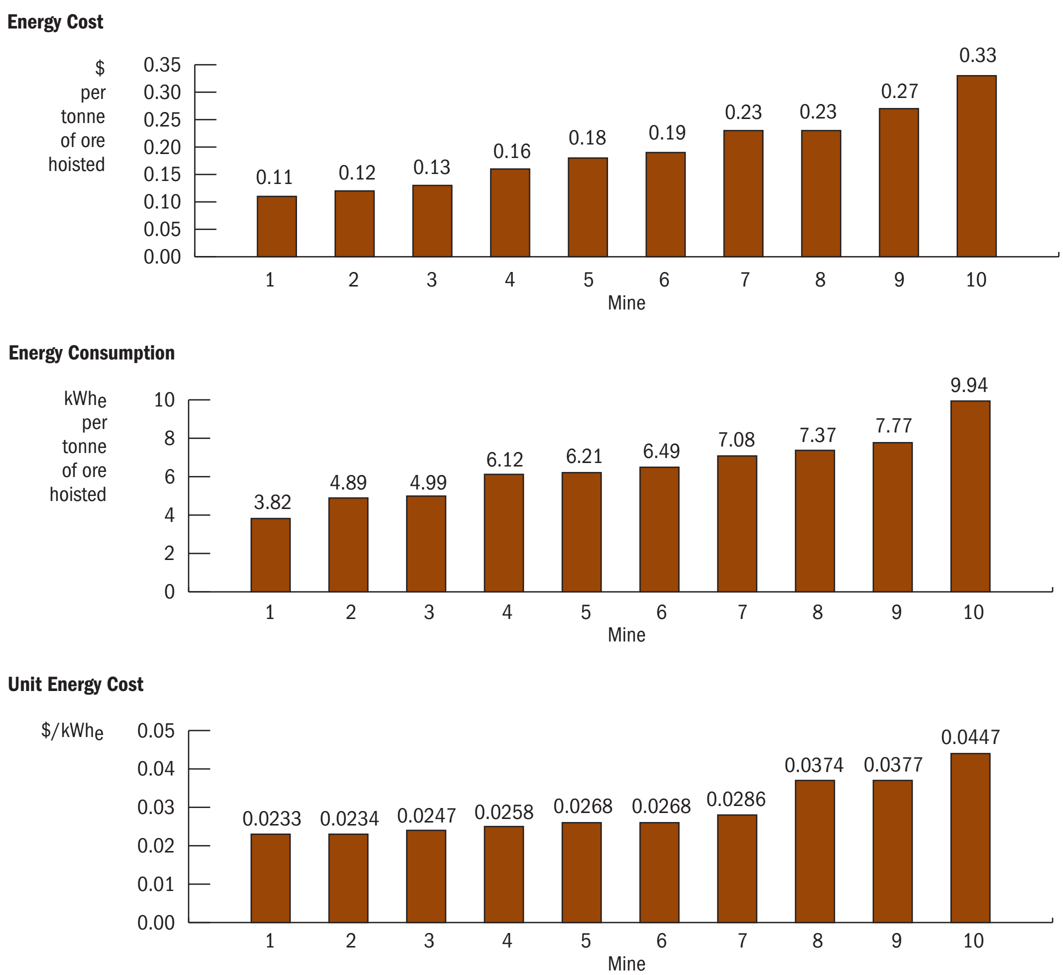


Mucking

The mucking energy costs varied from $0.11 to $0.33 per tonne, as illustrated in Figure 4.2.4. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.33 : 0.11	300
Energy Consumption (kWh_e/tonne of ore hoisted)	9.94 : 3.82	260
Unit Energy Cost ($/$kWh_e$)	0.0447 : 0.0233	192

Figure 4.2.4 – Inter-Mine Comparisons: Mucking

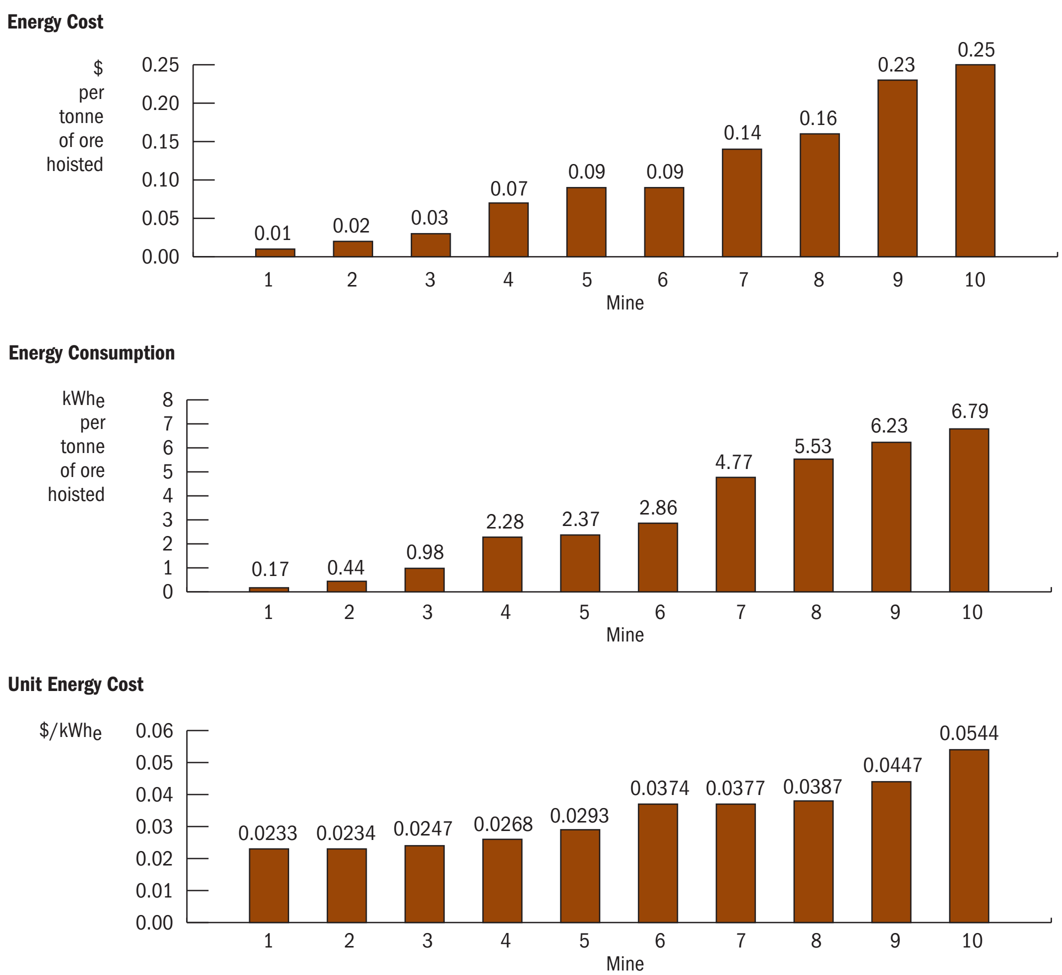


Underground Ore Transport

Underground ore transport energy costs varied from $0.01 to $0.25 per tonne hoisted, as illustrated in Figure 4.2.5. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.25 : 0.01	2500
Energy Consumption (kWh_e/tonne of ore hoisted)	6.79 : 0.17	3995
Unit Energy Cost ($/$kWh_e$)	0.0544 : 0.0233	233

Figure 4.2.5 – Inter-Mine Comparisons: Underground Ore Transport

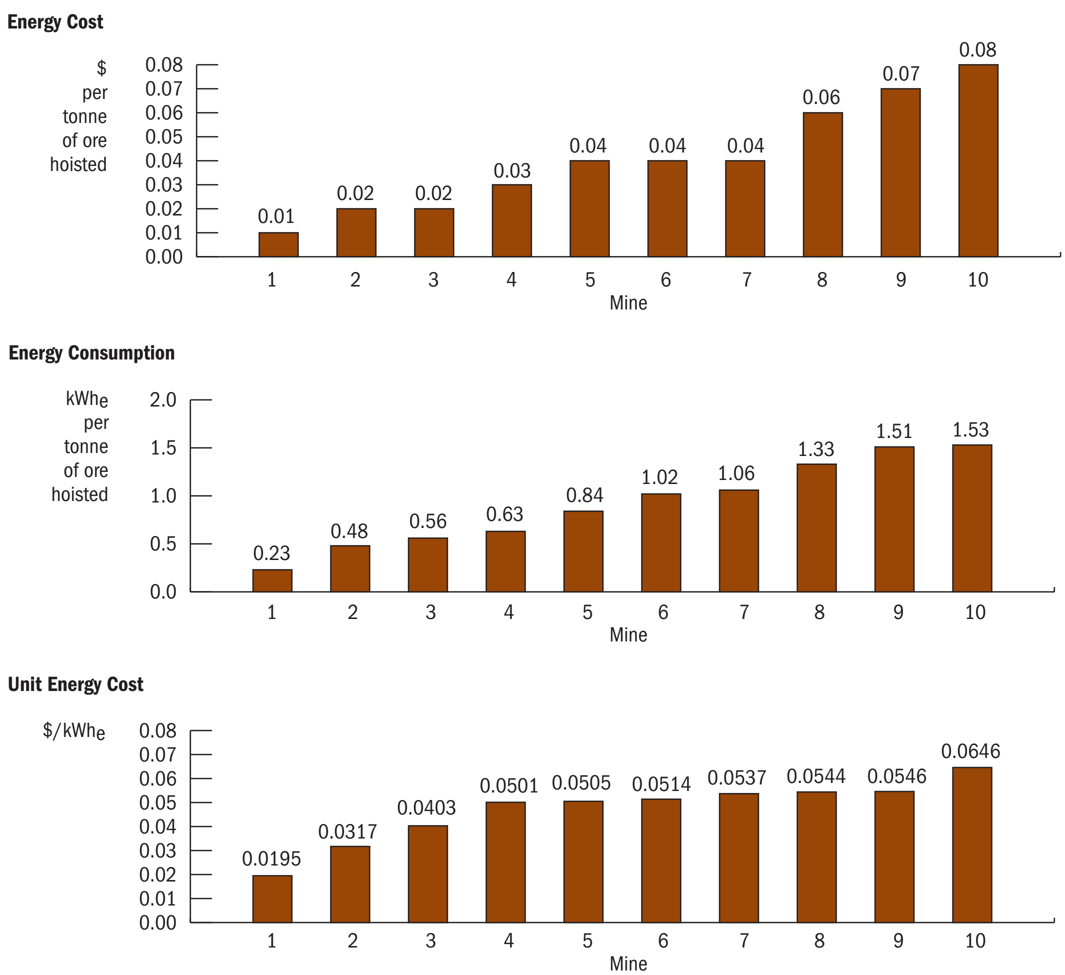


Underground Crushing

Underground crushing energy costs varied from $0.01 to $0.08 per tonne hoisted, as illustrated in Figure 4.2.6. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.08 : 0.01	800
Energy Consumption (kWh_e/tonne of ore hoisted)	1.53 : 0.23	665
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0195	331

Figure 4.2.6 – Inter-Mine Comparisons: Underground Crushing

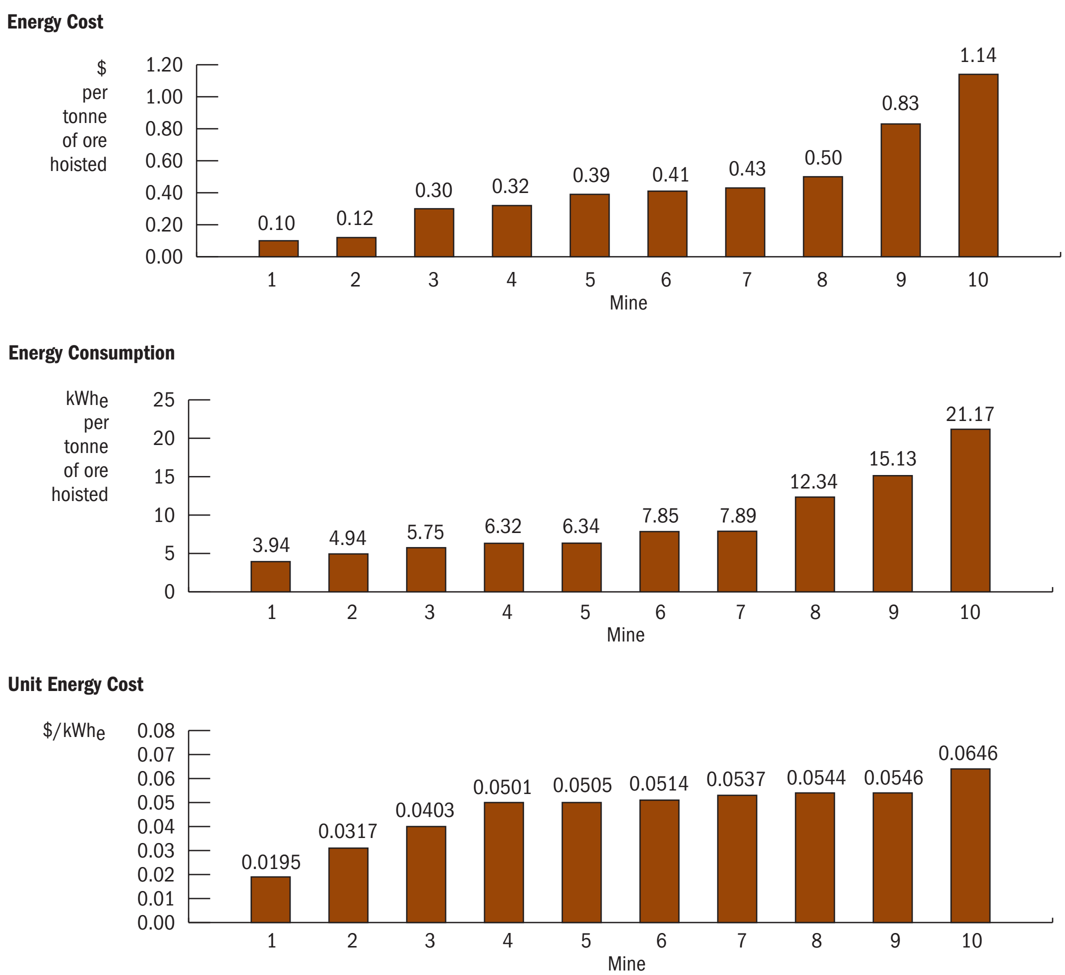


Hoisting

Hoisting energy costs varied from $0.10 to $1.14 per tonne hoisted, as illustrated in Figure 4.2.7. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	1.14 : 0.10	1140
Energy Consumption (kWh_e/tonne of ore hoisted)	21.17 : 3.94	573
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0195	331

Figure 4.2.7 – Inter-Mine Comparisons: Hoisting

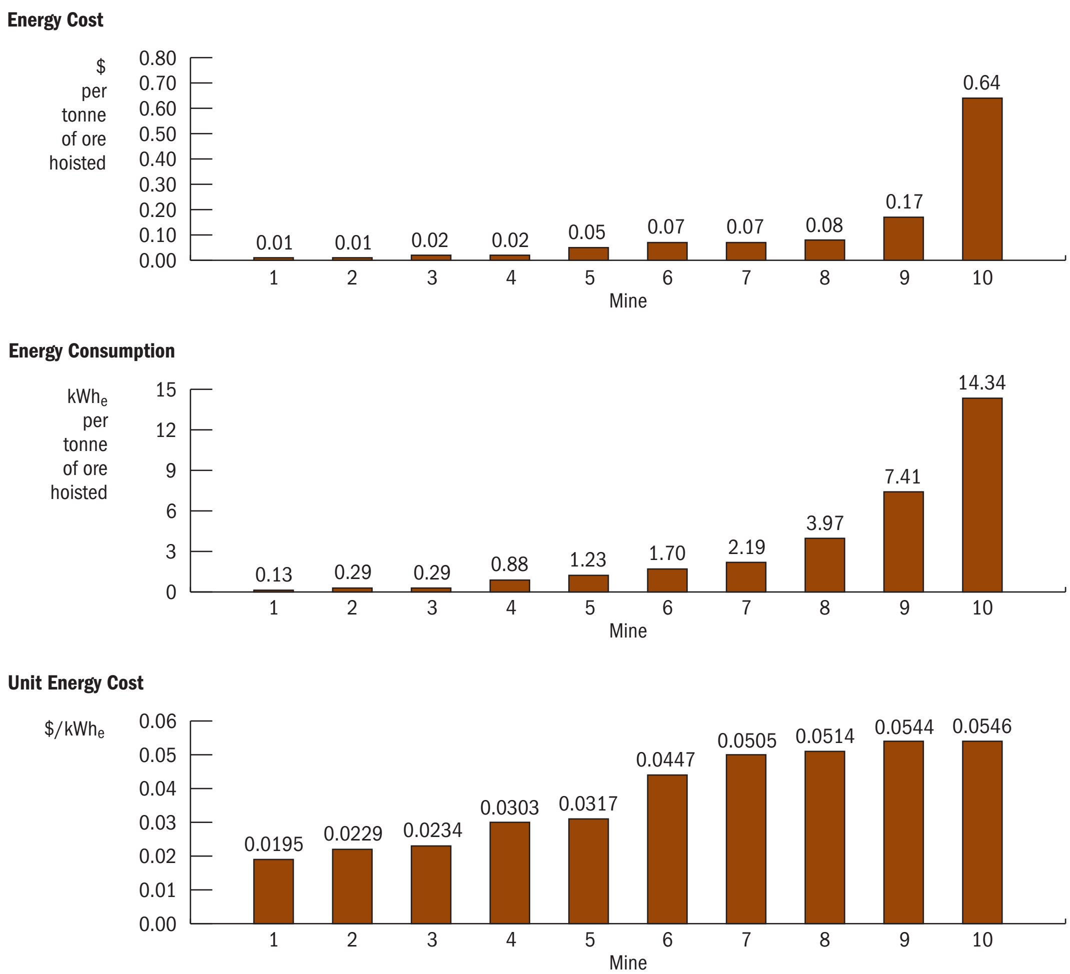


Ore Transport to Mill

The energy costs for transporting the ore to the mill varied from $0.01 to $0.64 per tonne hoisted, as illustrated in Figure 4.2.8. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.64 : 0.01	6400
Energy Consumption (kWh_e/tonne of ore hoisted)	14.34 : 0.13	1103
Unit Energy Cost ($/$kWh_e$)	0.0546 : 0.0195	280

Figure 4.2.8 – Inter-Mine Comparisons: Ore Transport to Mill

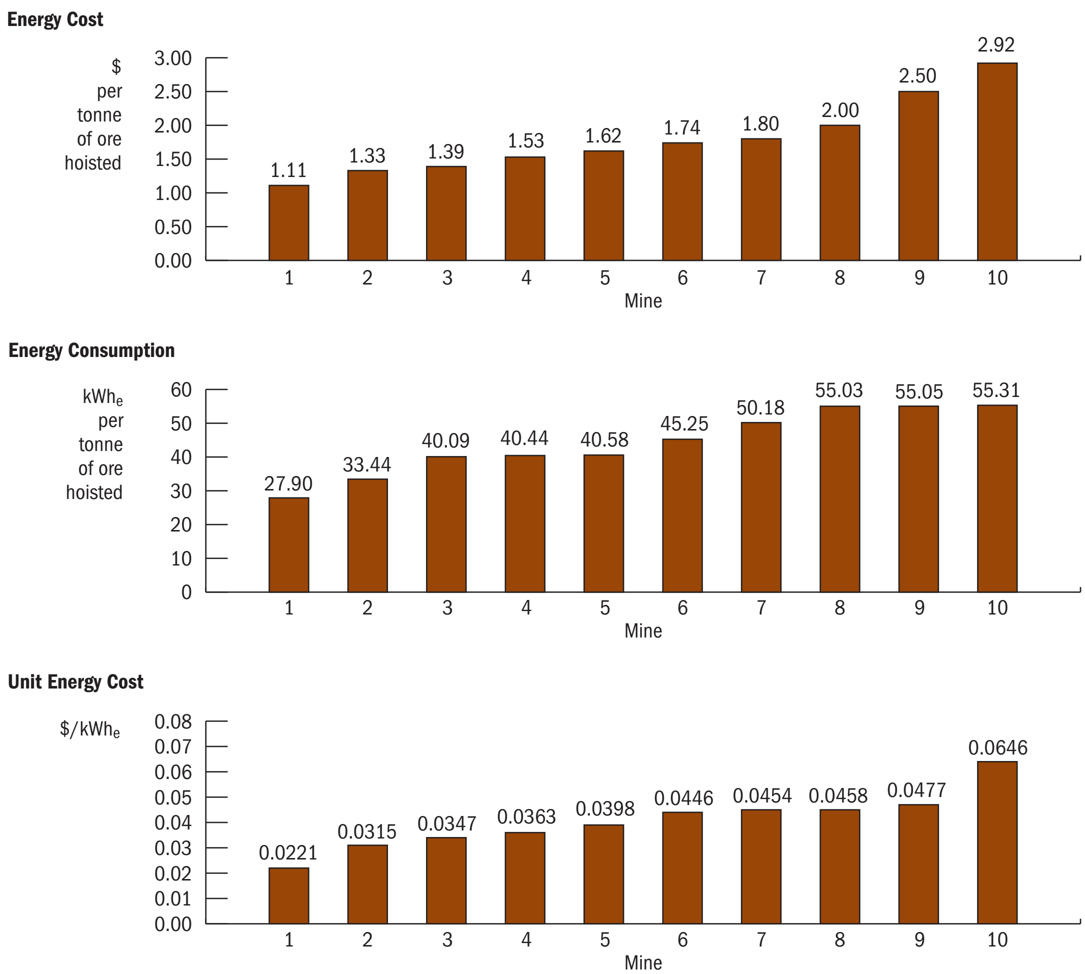


Ventilation

The ventilation energy costs varied from $1.11 to $2.92 per tonne hoisted, as illustrated in Figure 4.2.9. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	2.92 : 1.11	263
Energy Consumption (kWh_e/tonne of ore hoisted)	55.31 : 27.90	198
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0221	292

Figure 4.2.9 – Inter-Mine Comparisons: Ventilation

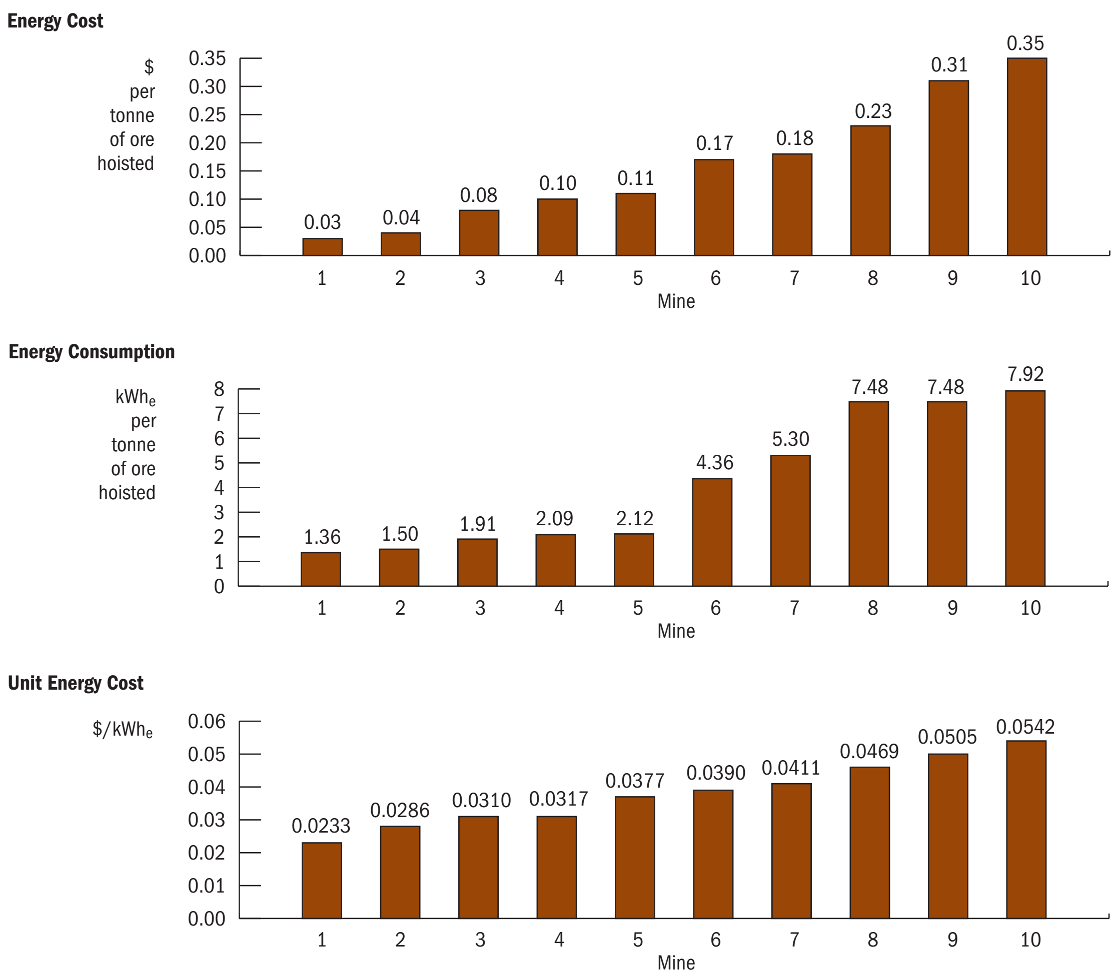


Backfill

The backfill energy costs varied from $0.03 to $0.35 per tonne hoisted, as illustrated in Figure 4.2.10. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.35 : 0.03	1167
Energy Consumption (kWh_e/tonne of ore hoisted)	7.92 : 1.36	582
Unit Energy Cost ($/$kWh_e$)	0.0542 : 0.0233	233

Figure 4.2.10 – Inter-Mine Comparisons: Backfill

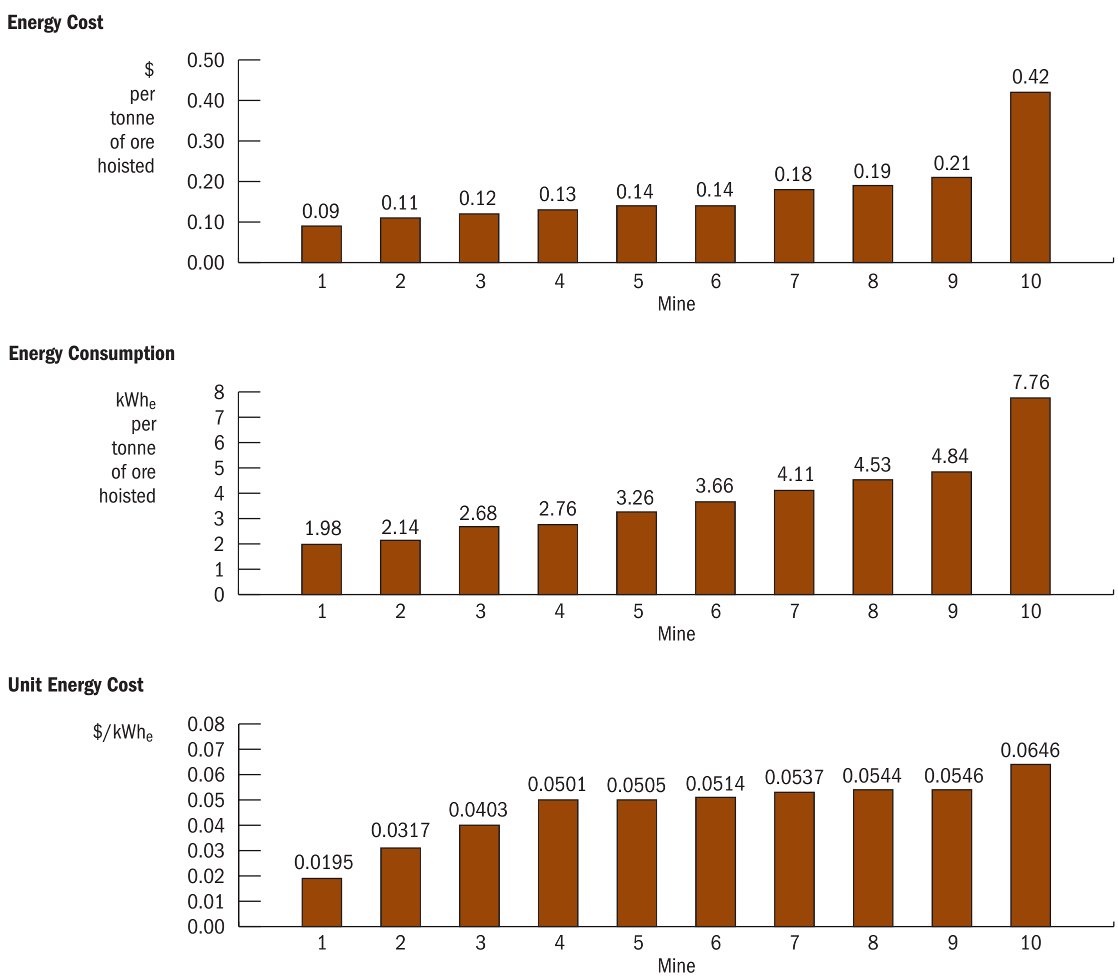


Dewatering

The dewatering energy costs varied from $0.09 to $0.42 per tonne hoisted, as illustrated in Figure 4.2.11. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.42 : 0.09	467
Energy Consumption (kWh_e/tonne of ore hoisted)	7.76 : 1.98	392
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0195	331

Figure 4.2.11 – Inter-Mine Comparisons: Dewatering

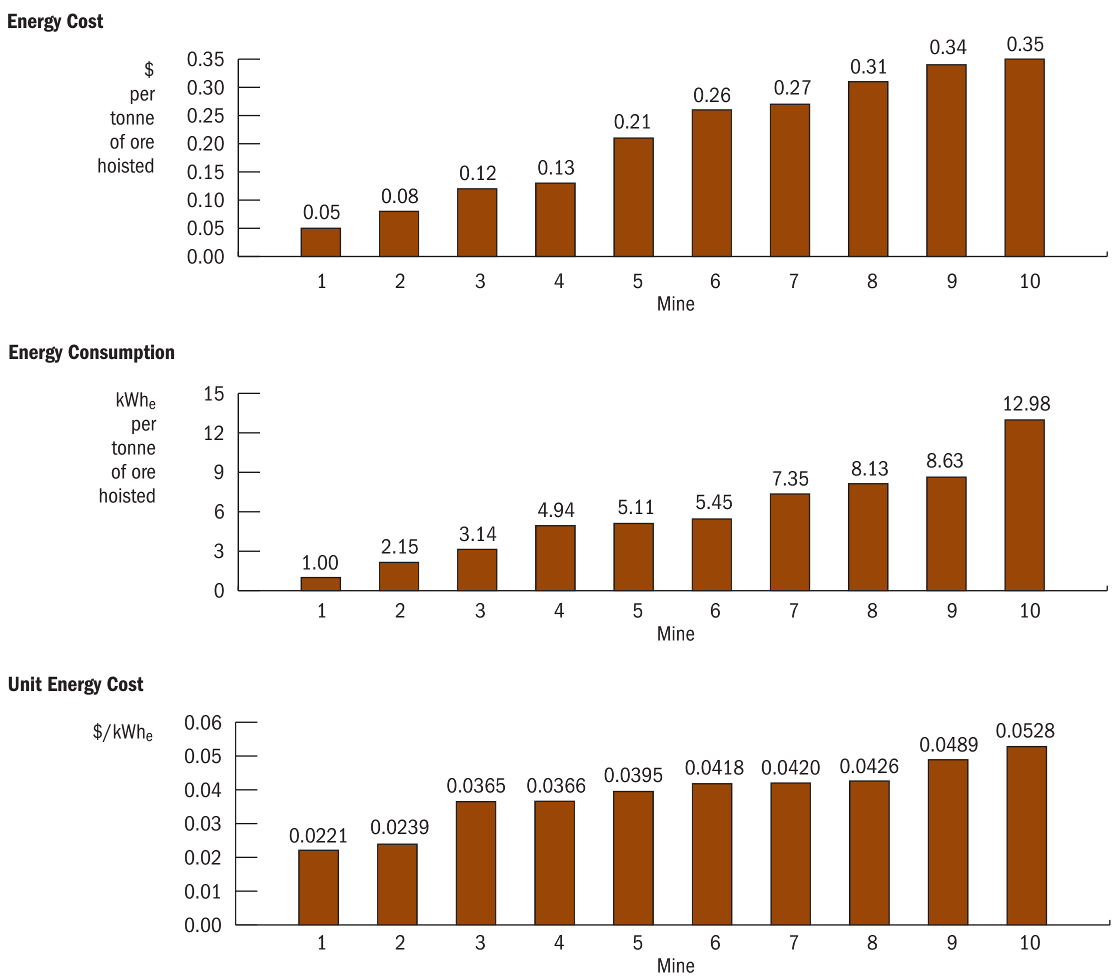


Other Underground Support

The energy costs for other underground support varied from $0.05 to $0.35 per tonne hoisted, as illustrated in Figure 4.2.12. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne of ore hoisted)	0.35 : 0.05	700
Energy Consumption (kWh_e/tonne of ore hoisted)	12.98 : 1.00	1298
Unit Energy Cost ($/$kWh_e$)	0.0528 : 0.0221	239

Figure 4.2.12 – Inter-Mine Comparisons: Other Underground Support



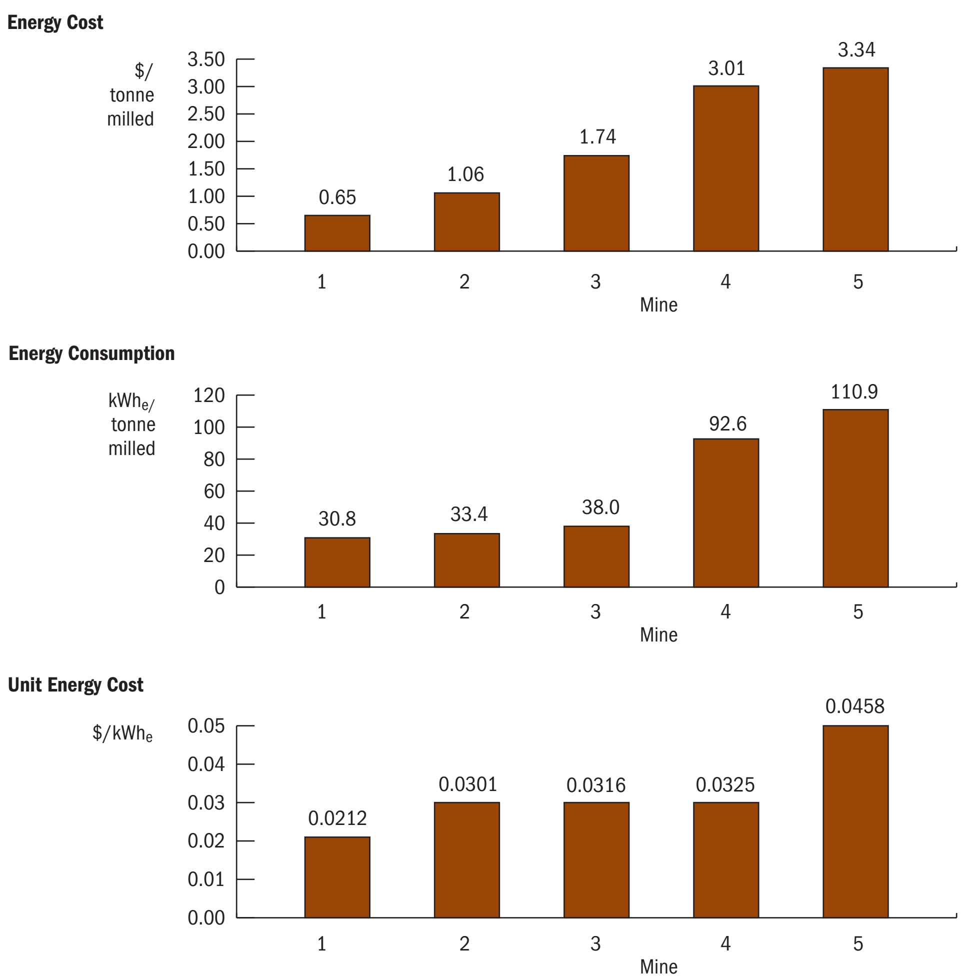
4.3 Concentration Operations: Base Metals

4.3.1 Total Energy Costs: Concentration

Five participants provided data on their base metals concentration operations. The energy costs were compared on the basis of tonnes of ore milled. As illustrated in Figure 4.3.1, the unit energy costs for the milling operation varied from $0.65 to $3.34 per tonne of ore milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	3.34 : 0.65	514
Energy Consumption (kWh_e/tonne milled)	110.87 : 30.75	360
Unit Energy Cost ($/$kWh_e$)	0.0458 : 0.0212	216

Figure 4.3.1 – Total Energy Costs: Concentration



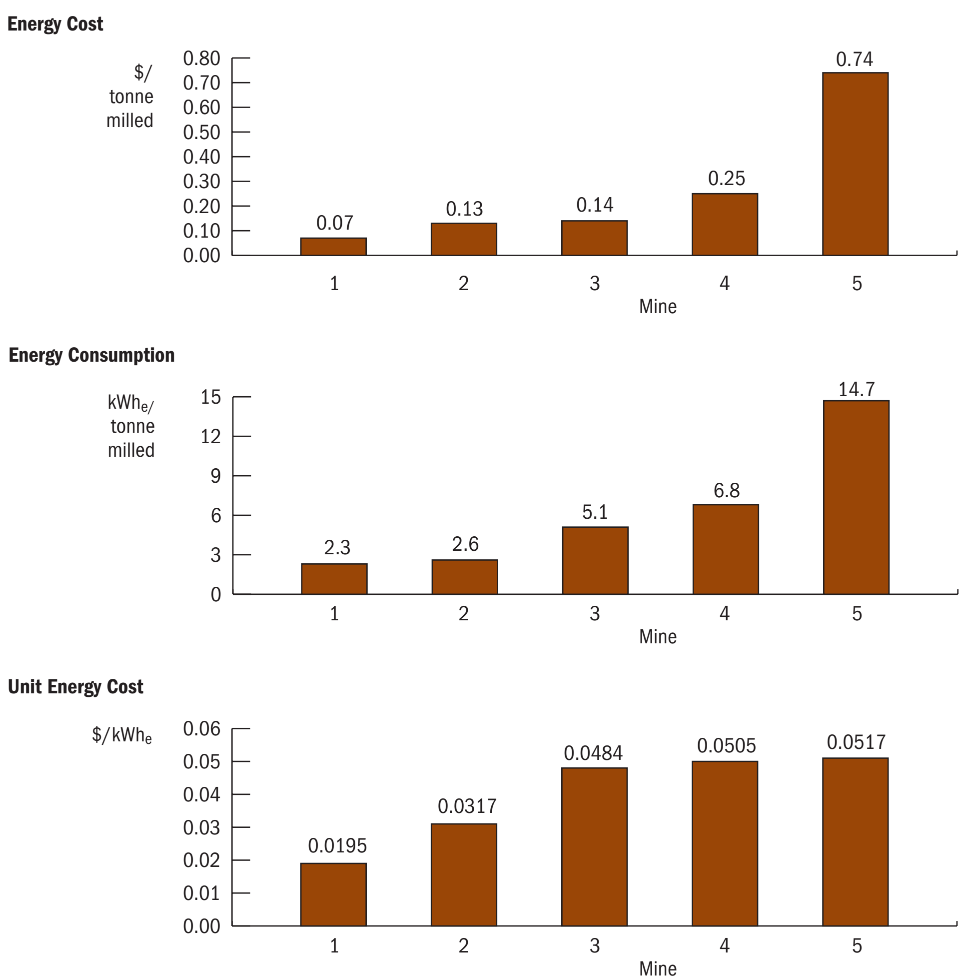
4.3.2 Energy Costs: Concentration – Stage of Production

Crushing

The crushing energy costs varied from $0.07 per tonne of ore milled to $0.74 per tonne of ore milled, as illustrated in Figure 4.3.2. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.74 : 0.07	1057
Energy Consumption (kWh_e/tonne milled)	14.7 : 2.3	639
Unit Energy Cost ($/$kWh_e$)	0.0517 : 0.0195	265

Figure 4.3.2 – Energy Costs: Crushing

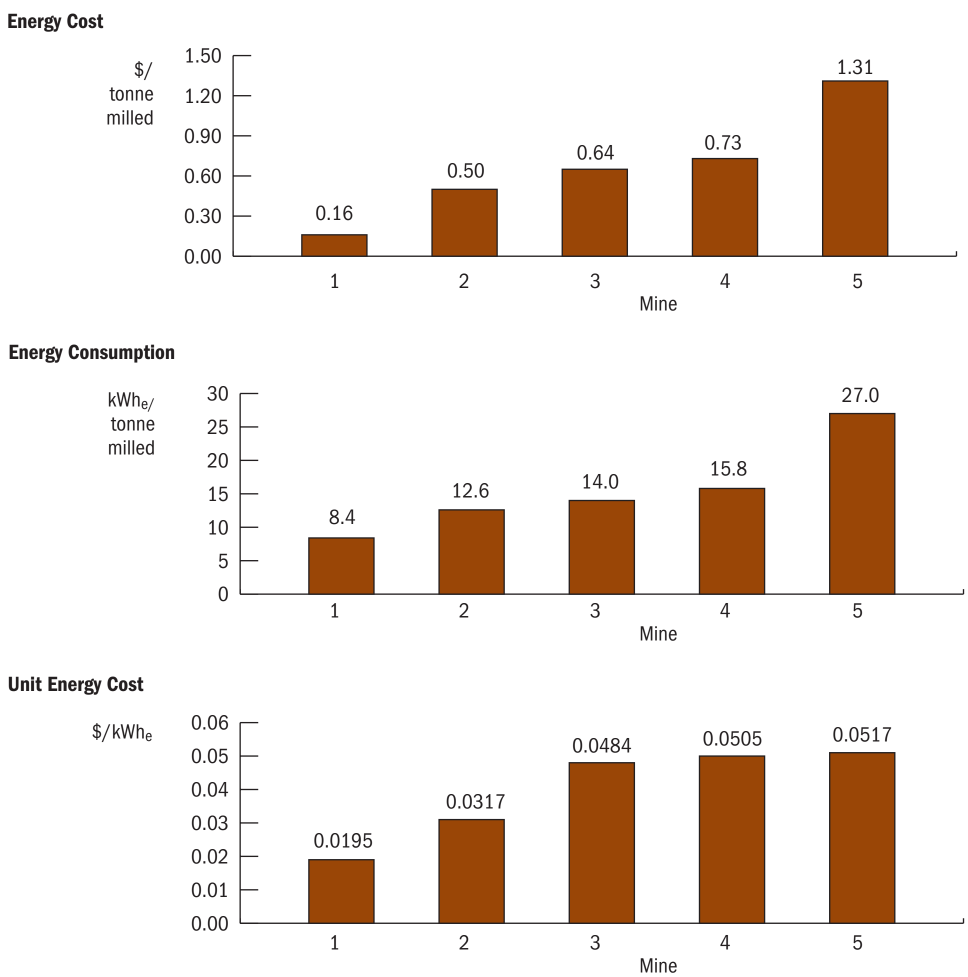


Grinding

The grinding energy costs varied from $0.16 per tonne of ore milled to $1.31 per tonne of ore milled, as illustrated in Figure 4.3.3. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	1.31 : 0.16	819
Energy Consumption (kWh_e/tonne milled)	27.0 : 8.4	321
Unit Energy Cost ($/$kWh_e$)	0.0517 : 0.0195	265

Figure 4.3.3 – Energy Costs: Grinding

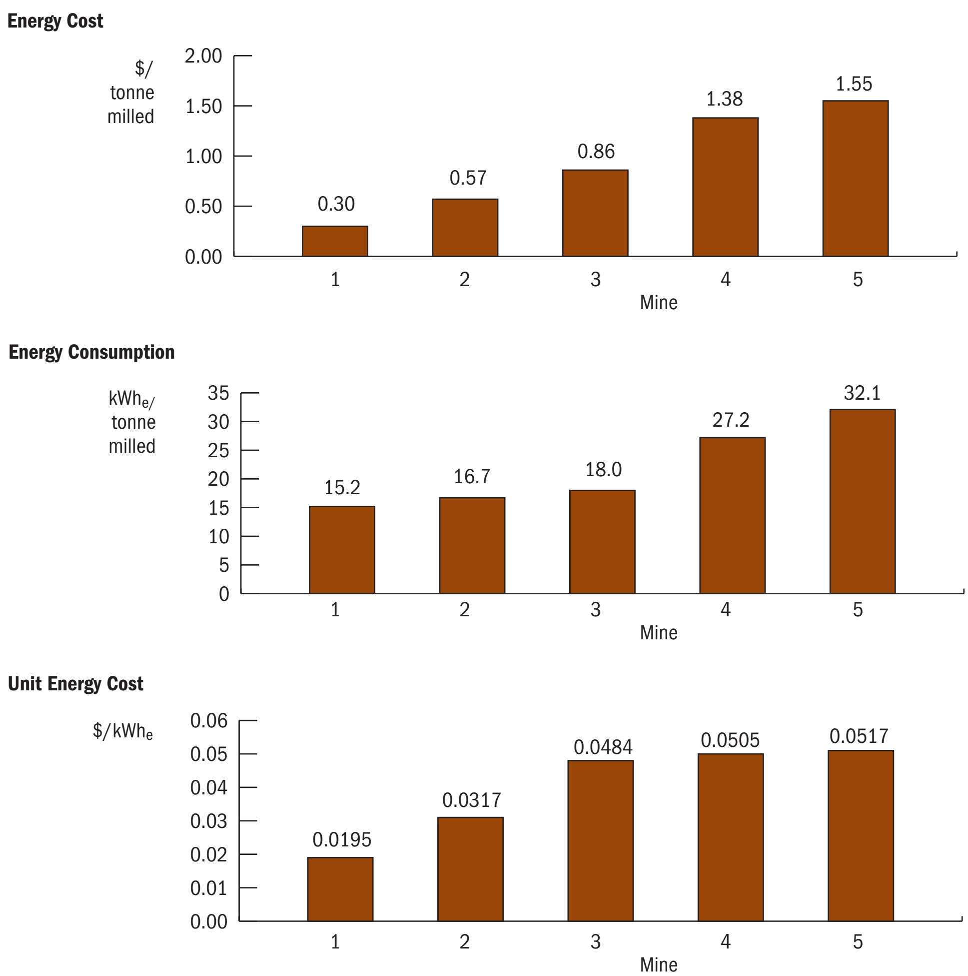


Crushing and Grinding Combined

The combined crushing and grinding energy costs varied from $0.30 per tonne of ore milled to $1.55 per tonne of ore milled, as illustrated in Figure 4.3.4. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	1.55 : 0.30	517
Energy Consumption (kWh_e/tonne milled)	32.1 : 15.2	211
Unit Energy Cost ($/$kWh_e$)	0.0517 : 0.0195	266

Figure 4.3.4 – Energy Costs: Crushing and Grinding

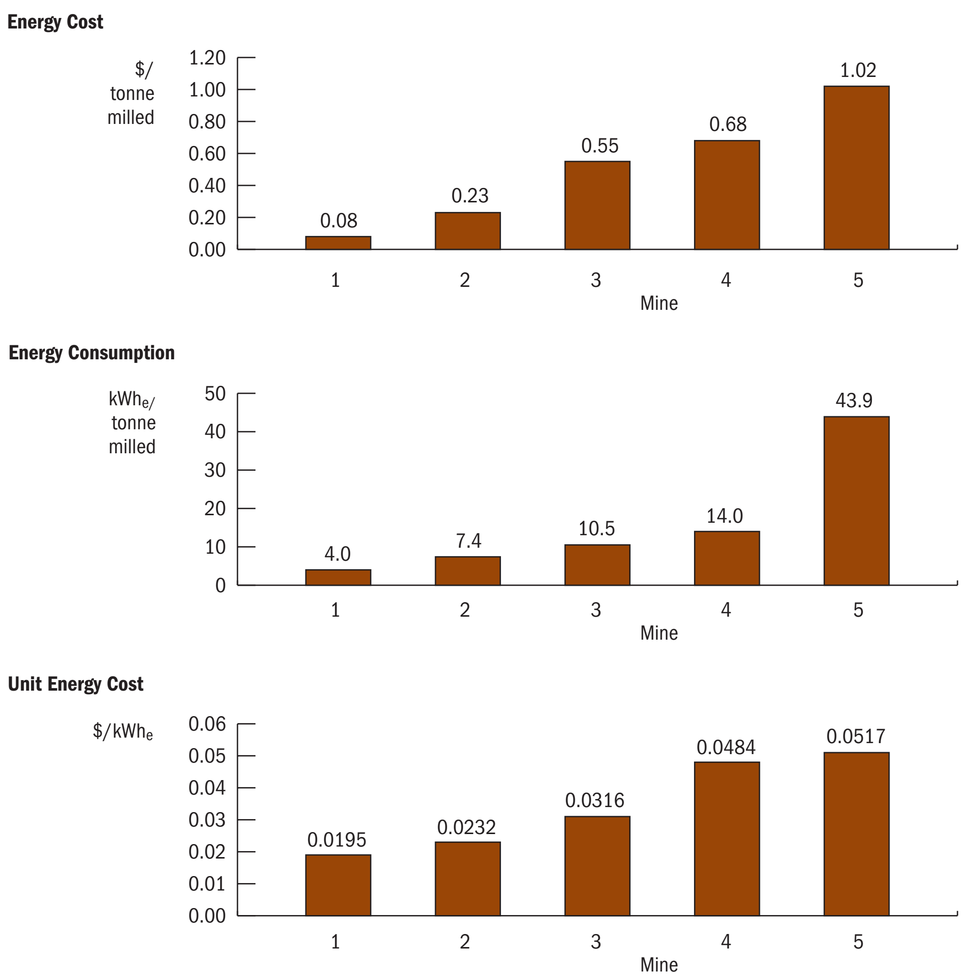


Separation/Floatation

The separation/floatation energy costs varied from $0.08 per tonne of ore milled to $1.02 per tonne of ore milled, as illustrated in Figure 4.3.5. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	1.02 : 0.08	1275
Energy Consumption (kWh_e/tonne milled)	43.90 : 3.98	1103
Unit Energy Cost ($/$kWh_e$)	0.0517 : 0.0195	265

Figure 4.3.5 – Energy Costs: Separation/Floatation

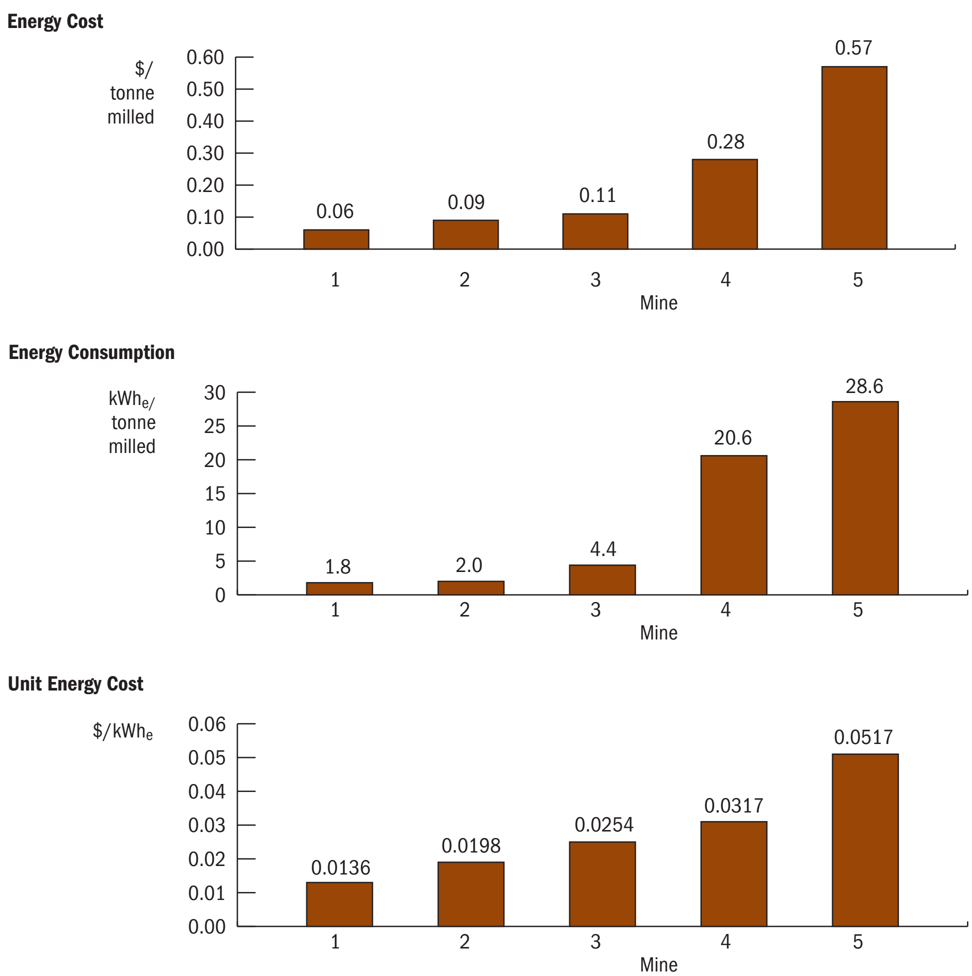


Thickening, Filtration and Drying

The thickening, filtration and drying energy costs varied from $0.06 per tonne of ore milled to $0.57 per tonne of ore milled, as illustrated in Figure 4.3.6. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.57 : 0.06	950
Energy Consumption (kWh_e/tonne milled)	28.56 : 1.77	1613
Unit Energy Cost ($/$kWh_e$)	0.0517 : 0.0132	392

Figure 4.3.6 – Energy Costs: Thickening, Filtration and Drying

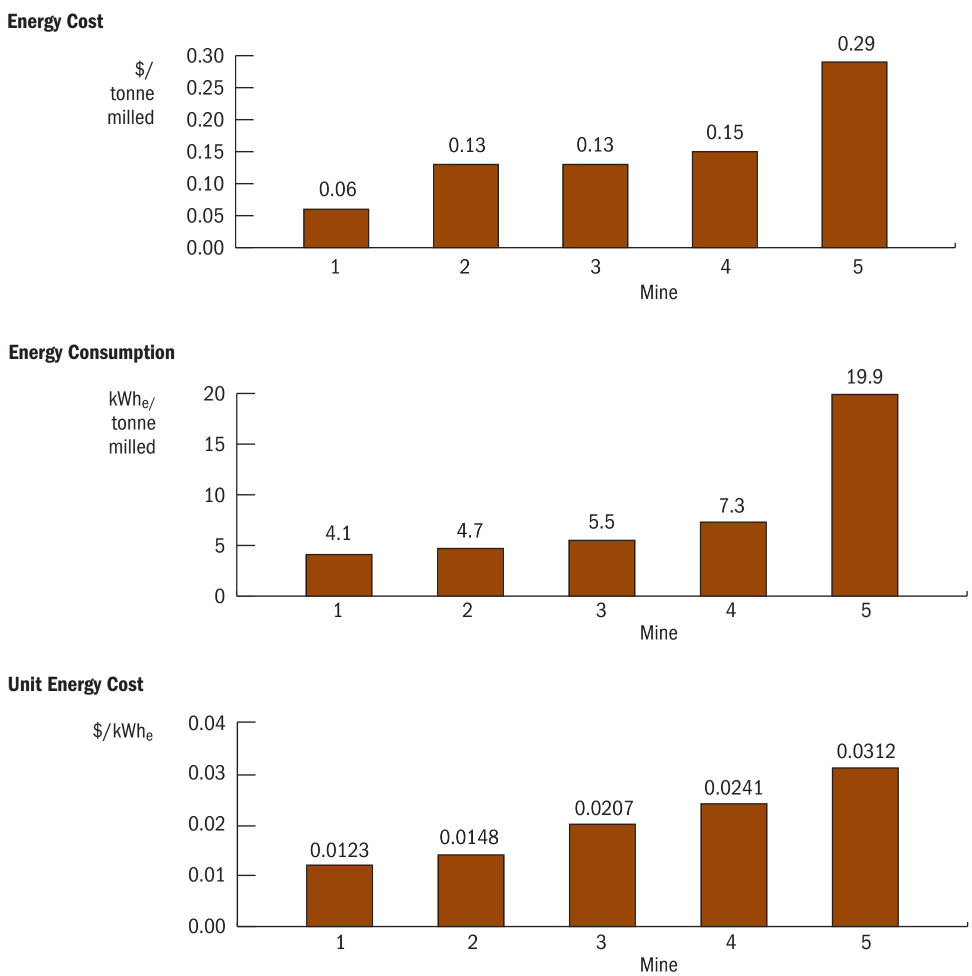


Mill Heating and Lighting

The mill heating and lighting energy costs varied from $0.06 per tonne of ore milled to $0.29 per tonne of ore milled, as illustrated in Figure 4.3.7. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.29 : 0.06	483
Energy Consumption (kWh_e/tonne milled)	19.86 : 4.12	482
Unit Energy Cost ($/$kWh_e$)	0.0312 : 0.0123	254

Figure 4.3.7 – Energy Costs: Mill Heating and Lighting

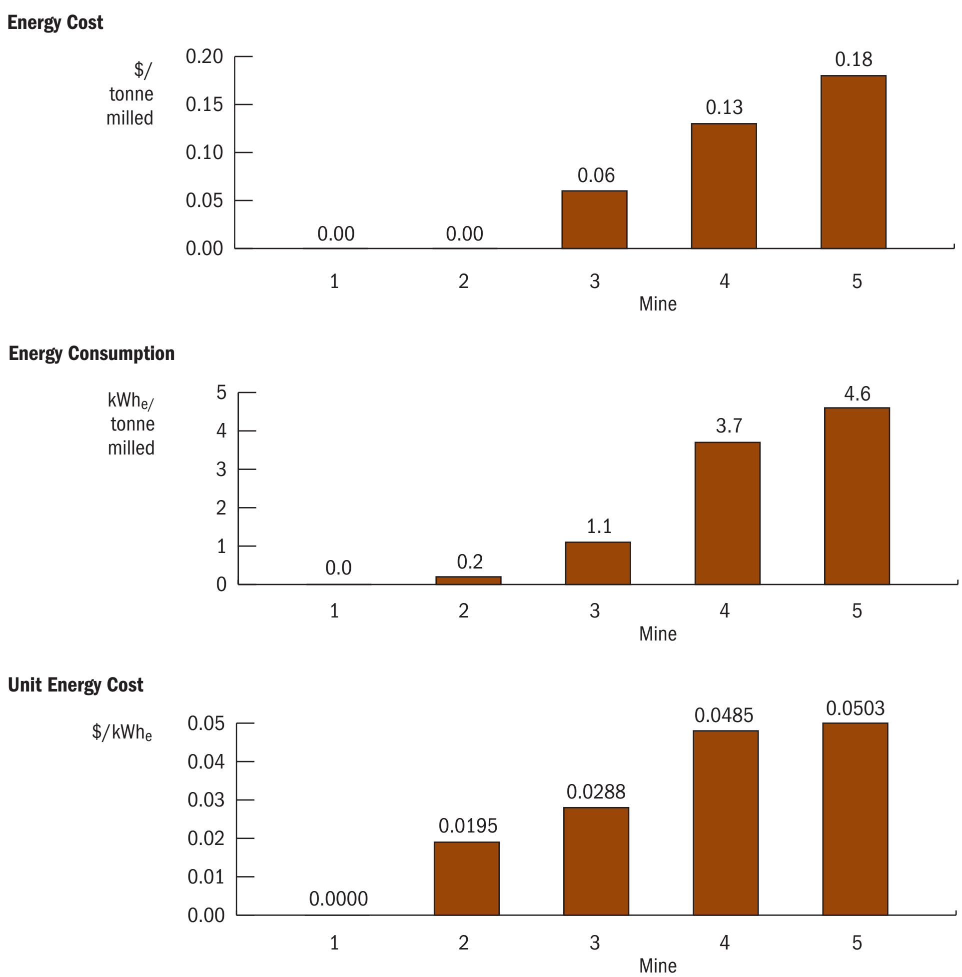


Mill Support

The mill support energy costs varied from $0.0 per tonne of ore milled to $0.18 per tonne of ore milled, as illustrated in Figure 4.3.8. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.18 : 0.00	n/a
Energy Consumption (kWh_e/tonne milled)	4.6 : 0.0	n/a
Unit Energy Cost ($/$kWh_e$)	0.0503 : 0.0000	n/a

Figure 4.3.8 – Energy Costs: Mill Support

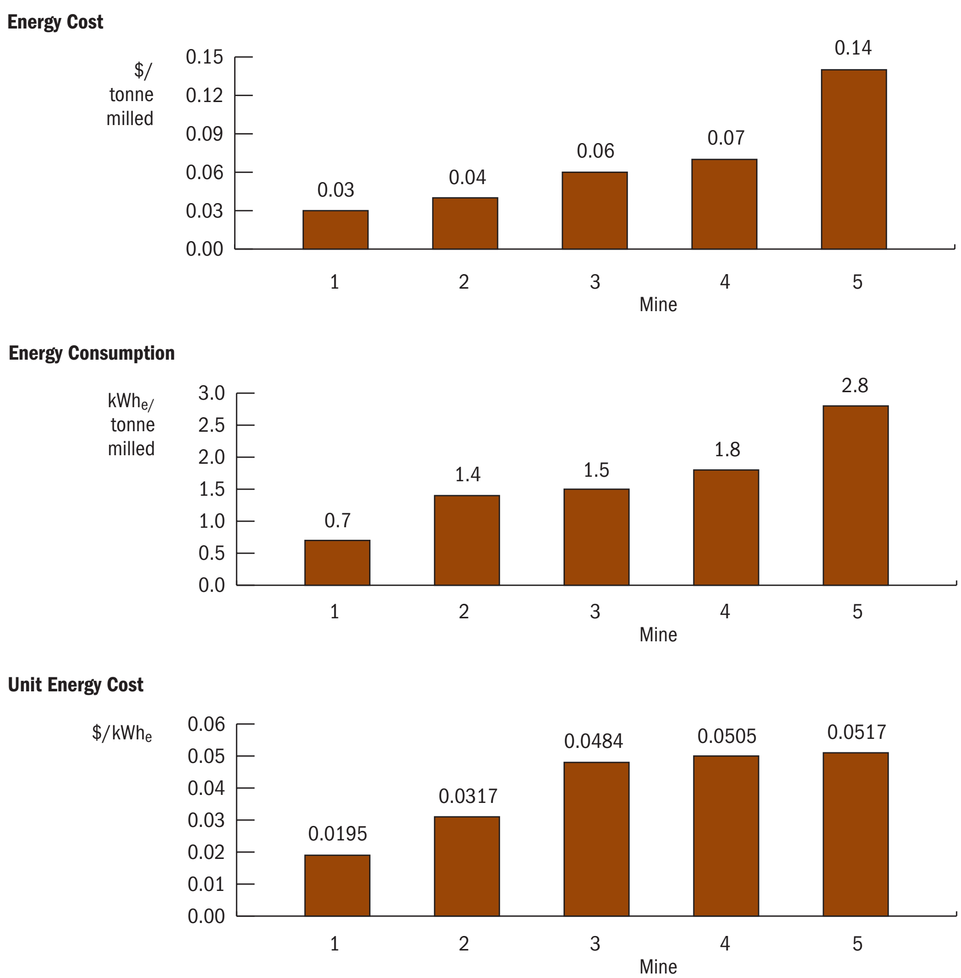


Tailings Disposal

The tailings disposal energy costs varied from $0.03 per tonne of ore milled to $0.14 per tonne of ore milled, as illustrated in Figure 4.3.9. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.14 : 0.03	467
Energy Consumption (kWh_e/tonne milled)	2.79 : 0.68	410
Unit Energy Cost ($/$kWh_e$)	0.0517 : 0.0195	265

Figure 4.3.9 – Energy Costs: Tailings Disposal



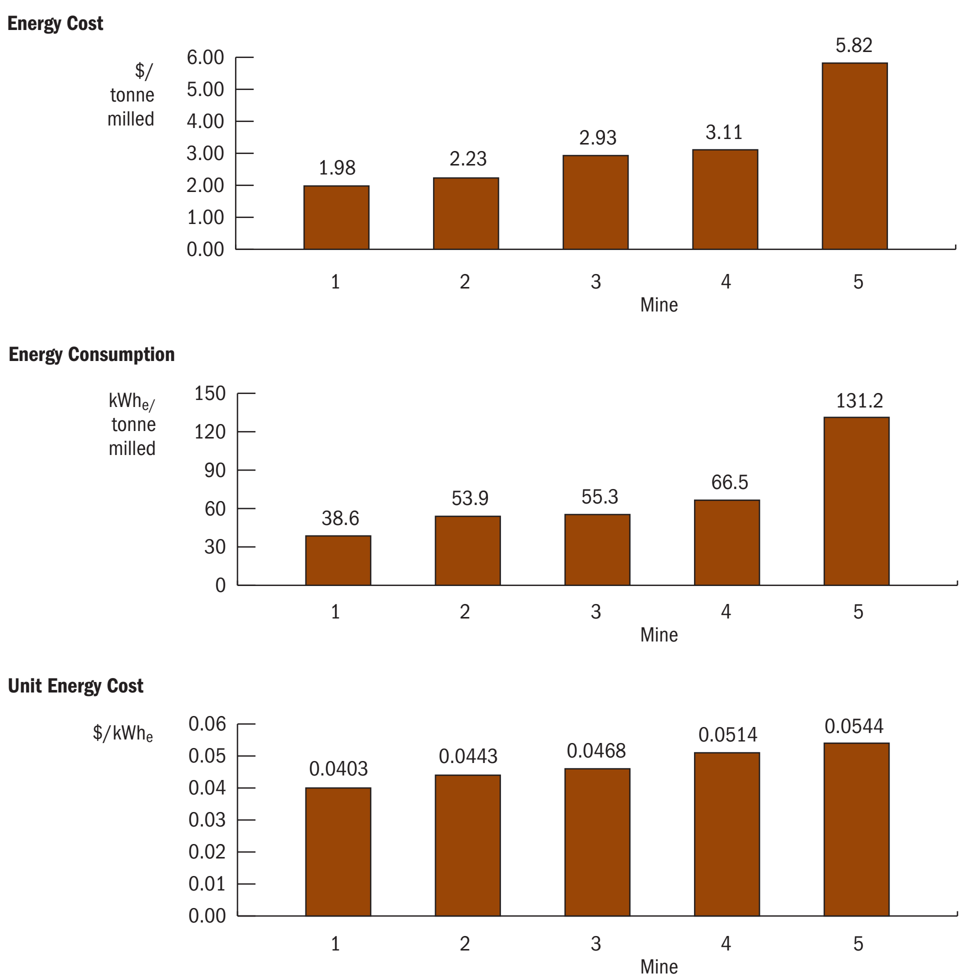
4.4 Gold Recovery Operations

4.4.1 Total Energy Costs: Gold Recovery

Five gold recovery operations were included in the sample. The energy costs were compared on the basis of tonnes of ore milled. As illustrated in Figure 4.4.1, the unit energy costs for the gold recovery operation varied from $1.98 to $5.82 per tonne milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	5.82 : 1.98	294
Energy Consumption (kWh_e/tonne milled)	131.16 : 38.61	340
Unit Energy Cost ($/$kWh_e$)	0.0544 : 0.0403	135

Figure 4.4.1 – Total Energy Costs: Gold Recovery



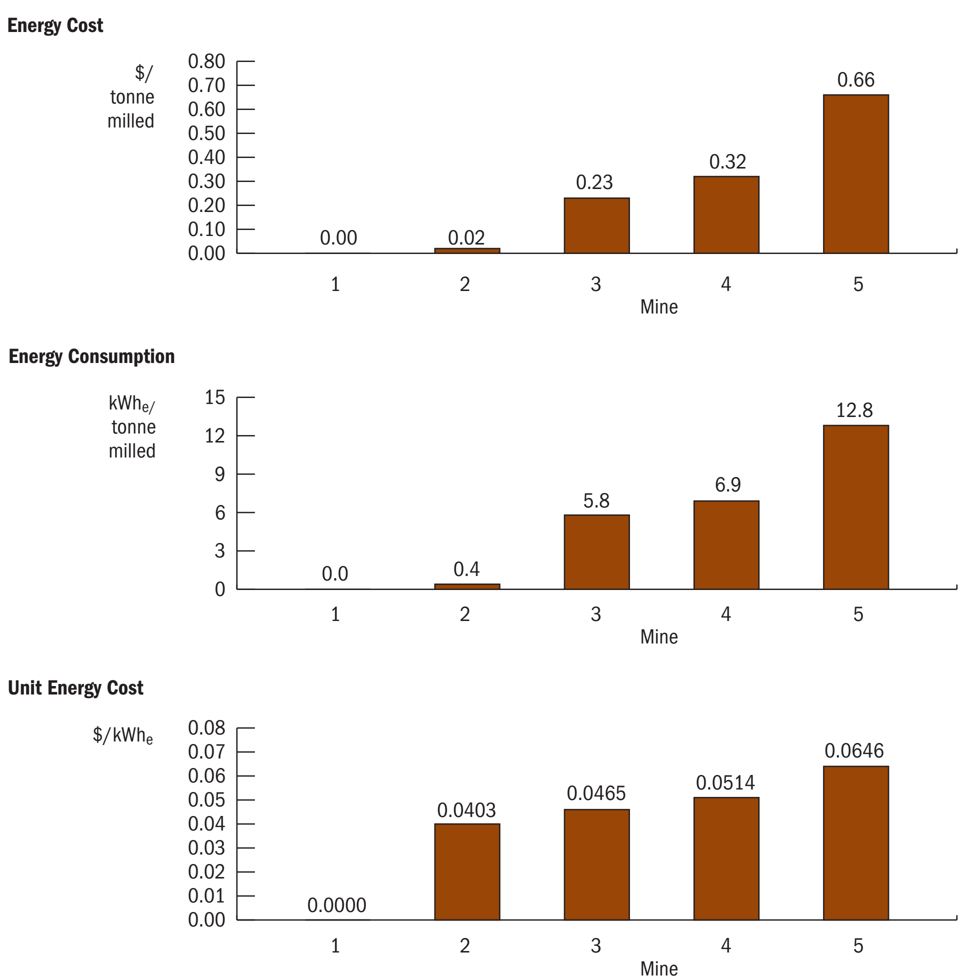
4.4.2 Energy Costs: Gold Recovery – Stage of Production

Crushing

The crushing energy costs varied from $0.00 per tonne milled to $0.66 per tonne milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.66 : 0.00	n/a
Energy Consumption (kWh_e/tonne milled)	12.8 : 0.0	n/a
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0403	n/a

Figure 4.4.2 – Total Energy Costs: Crushing

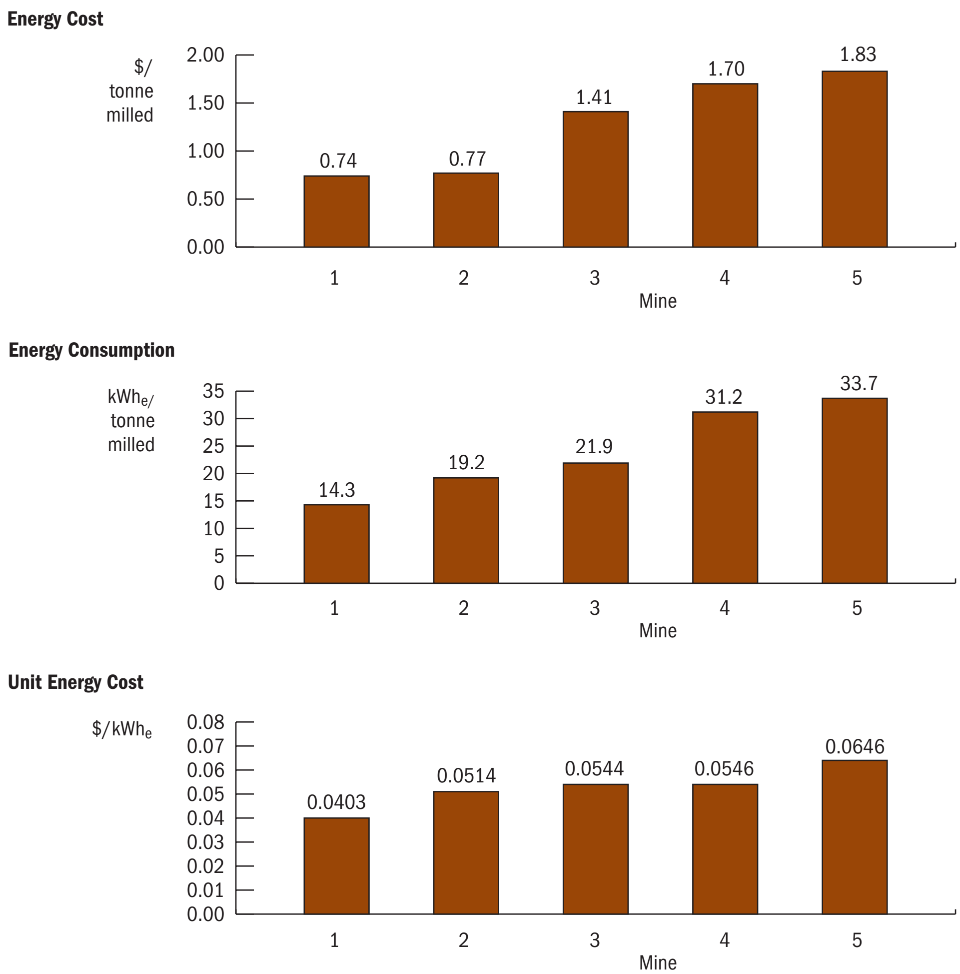


Grinding

The grinding energy costs varied from $0.74 per tonne milled to $1.83 per tonne milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	1.83 : 0.74	247
Energy Consumption (kWh_e/tonne milled)	33.7 : 14.3	236
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0403	160

Figure 4.4.3 – Total Energy Costs: Grinding

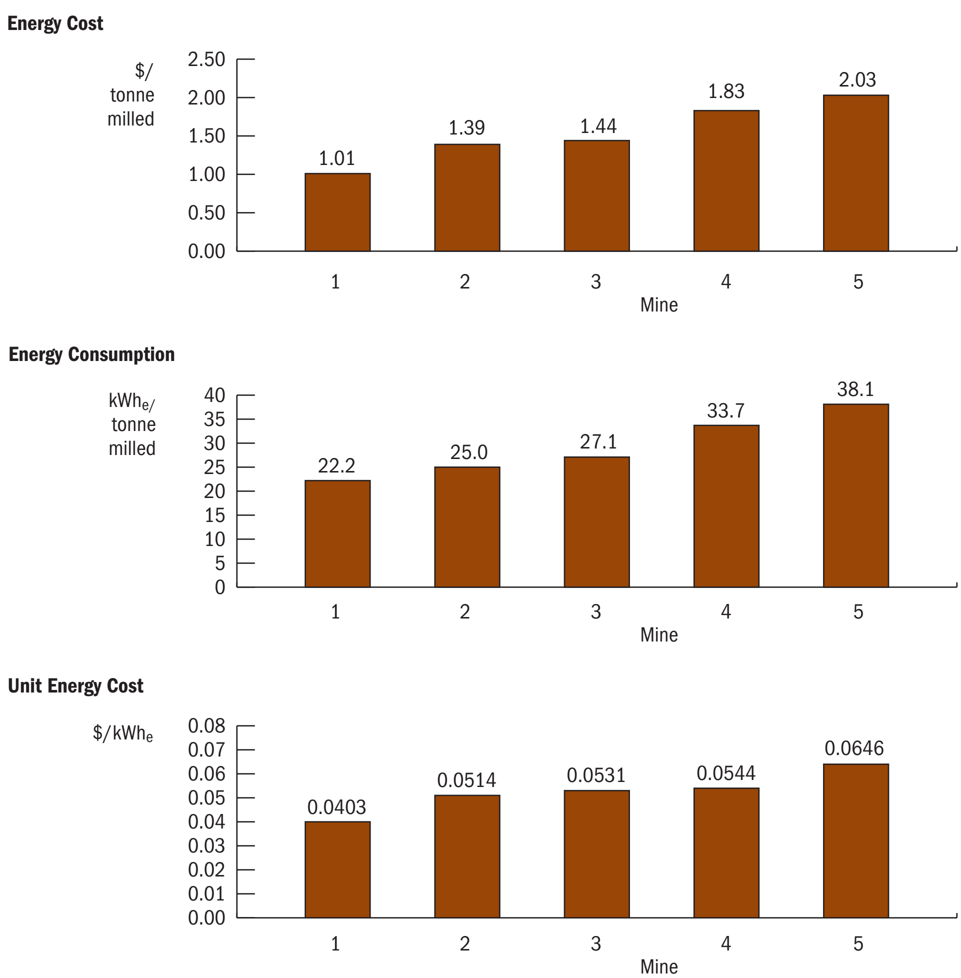


Crushing and Grinding Combined

The combined crushing and grinding energy costs varied from $1.01 per tonne milled to $2.03 per tonne milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	2.03 : 1.01	201
Energy Consumption (kWh_e/tonne milled)	38.1 : 22.2	172
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0403	160

Figure 4.4.4 – Total Energy Costs: Crushing and Grinding Combined

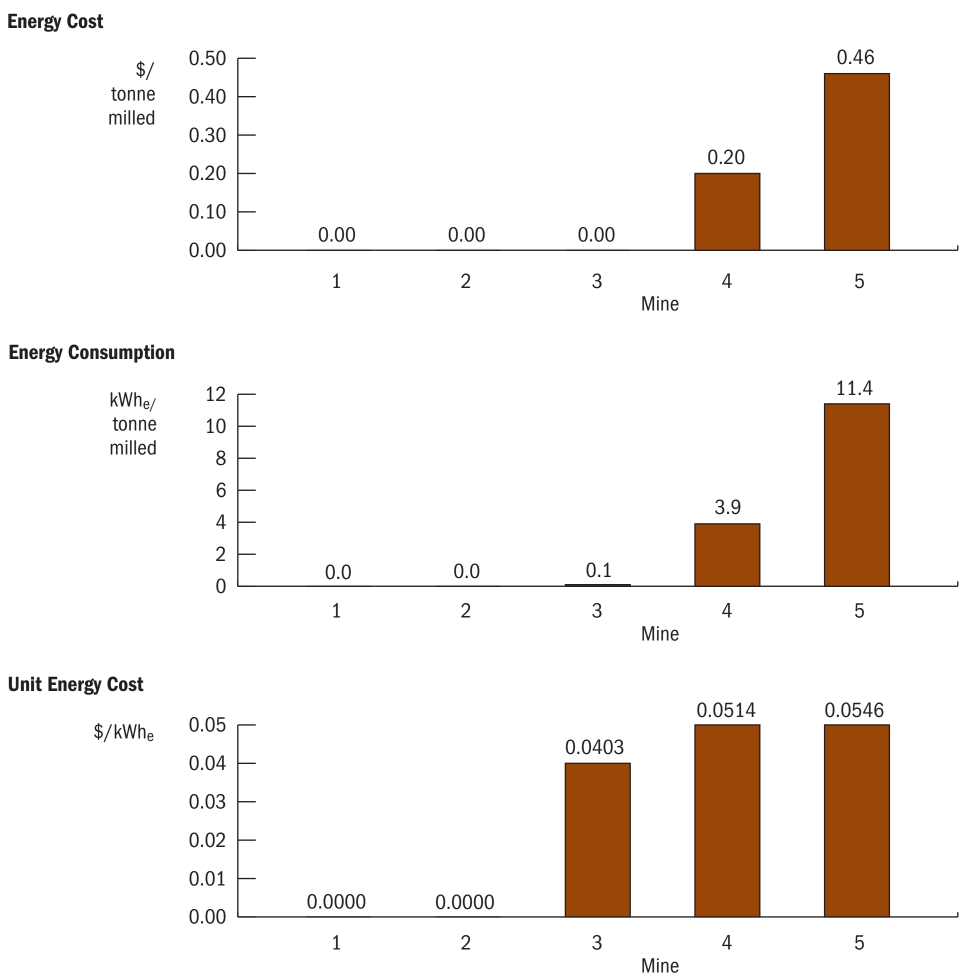


Gravity Separation

The gravity separation energy costs varied from $0.00 per tonne milled to $0.46 per tonne milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.46 : 0.00	n/a
Energy Consumption (kWh_e/tonne milled)	11.43 : 0.00	n/a
Unit Energy Cost ($/$kWh_e$)	0.0546 : 0.0000	n/a

Figure 4.4.5 – Total Energy Costs: Gravity Separation

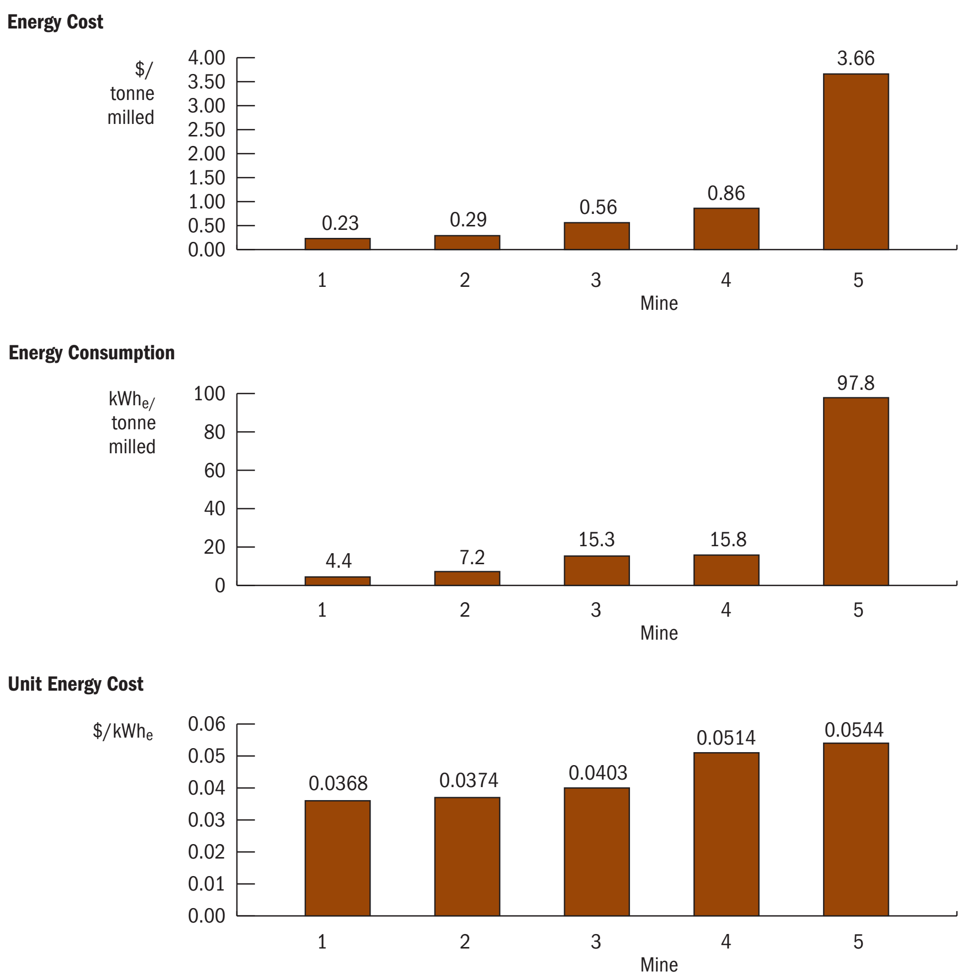


Extraction and Refining

The extraction and refining energy costs varied from $0.23 per tonne milled to $3.66 per tonne milled. The range of costs and efficiencies is as follows.

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	3.66 : 0.23	1591
Energy Consumption (kWh_e/tonne milled)	97.77 : 4.43	2207
Unit Energy Cost ($/$kWh_e$)	0.0544 : 0.0368	148

Figure 4.4.6 – Total Energy Costs: Extraction and Refining

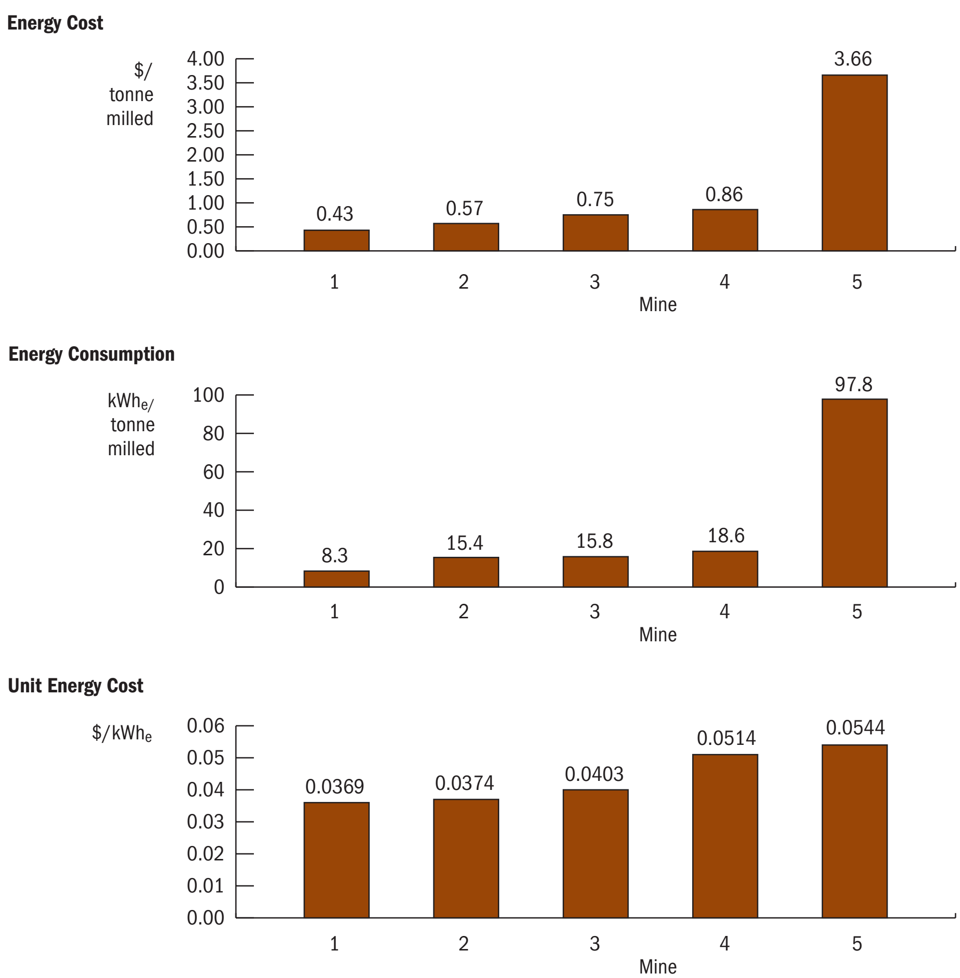


Separation, Extraction and Refining Combined

The unit energy costs varied from $0.43 per tonne milled to $3.66 per tonne milled. The range of unit costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	3.66 : 0.43	851
Energy Consumption (kWh_e/tonne milled)	97.77 : 8.28	1180
Unit Energy Cost ($/$kWh_e$)	0.0544 : 0.0369	147

Figure 4.4.7 – Total Energy Costs: Separation, Extraction and Refining Combined

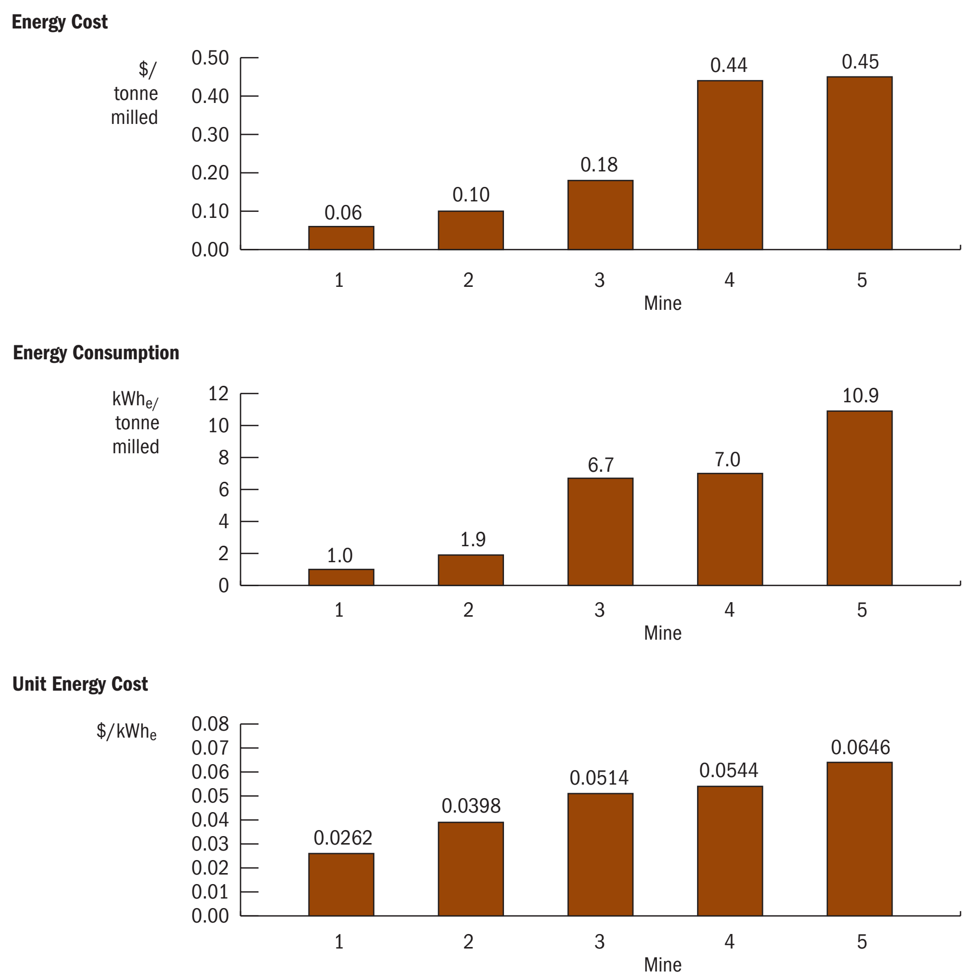


Mill Heat and Lighting

The unit energy costs varied from $0.06 per tonne milled to $0.45 per tonne milled. The range of unit costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.45 : 0.06	750
Energy Consumption (kWh_e/tonne milled)	10.93 : 1.05	1041
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0262	247

Figure 4.4.8 – Total Energy Costs: Mill Heat and Lighting

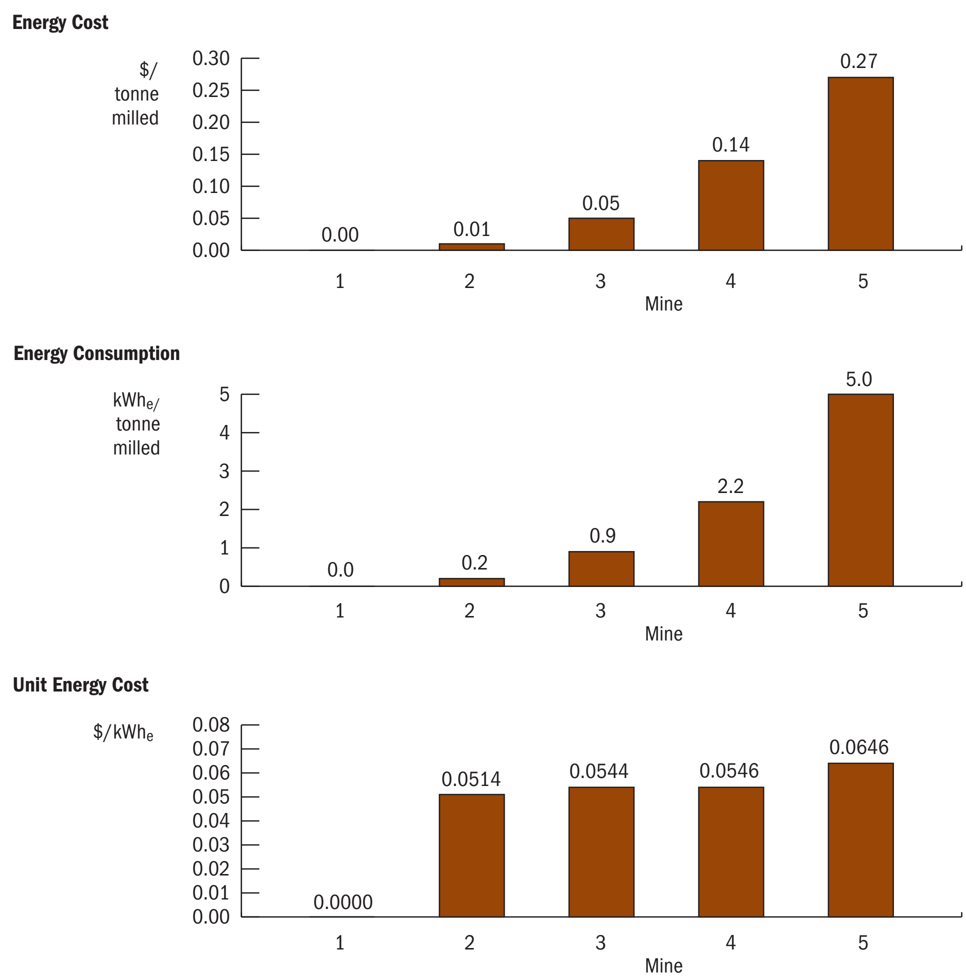


Tailings Disposal

The unit energy costs varied from $0.00 per tonne milled to $0.27 per tonne milled. The range of unit costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.27 : 0.00	n/a
Energy Consumption (kWh_e/tonne milled)	5.0 : 0.0	n/a
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0000	n/a

Figure 4.4.9 – Total Energy Costs: Tailings Disposal

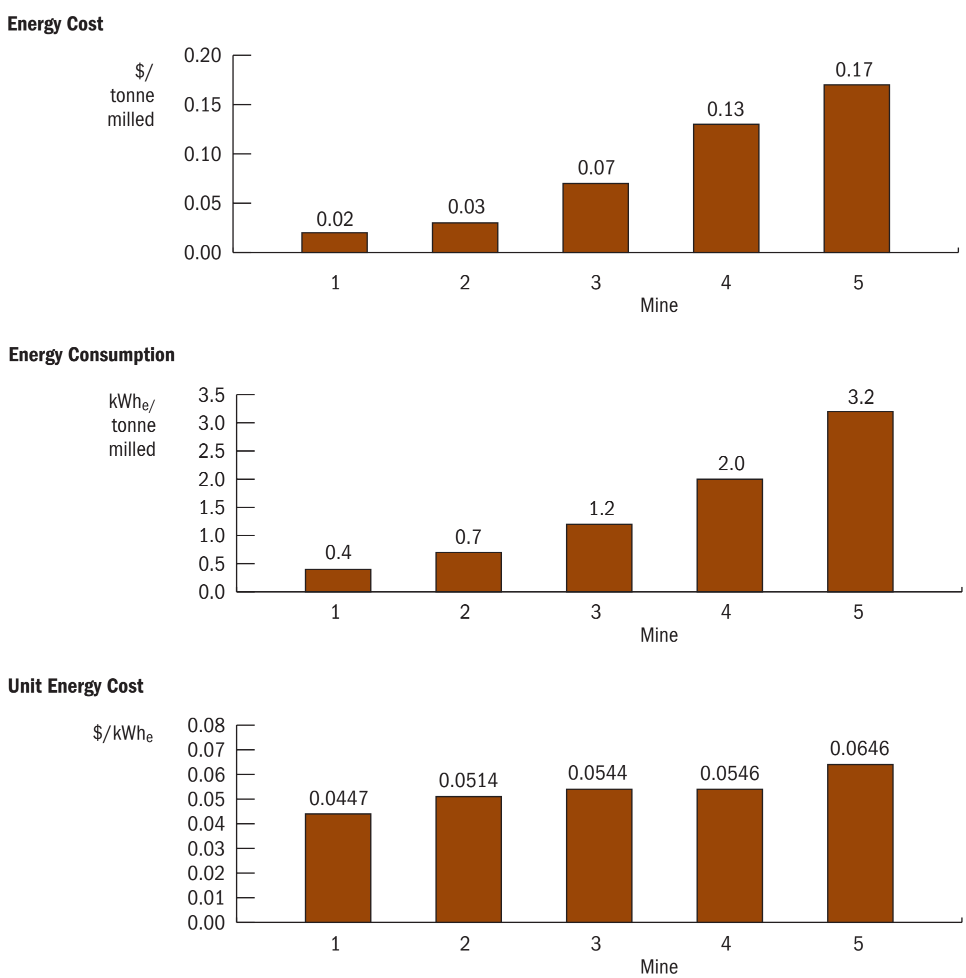


Mill Support Operations

The unit energy costs varied from $0.02 per tonne milled to $0.17 per tonne milled. The range of unit costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/tonne milled)	0.17 : 0.02	850
Energy Consumption (kWh_e/tonne milled)	3.17 : 0.37	857
Unit Energy Cost ($/$kWh_e$)	0.0646 : 0.0447	145

Figure 4.4.10 – Total Energy Costs: Mill Support Operations



5

POTENTIAL SAVINGS: ACHIEVING BENCHMARK STANDARDS

5.0 POTENTIAL SAVINGS: ACHIEVING BENCHMARK STANDARDS

5.1 Context

The comparisons in Chapter 4.0 relate the energy costs and efficiencies of participants to those of the lowest-cost and most efficient (i.e. lowest kWh_e/unit) operations. In this chapter, we present some general estimates of the potential savings to be generated by matching the performance of the lowest-cost, most efficient operations. Note, however, that these estimates could be low – even very low – for a number of reasons:

- First, there are opportunities for improvement in the lowest-cost, most efficient facilities. The fact that the leading firm varies from one stage of production to another provides even more evidence of the potential.
- Second, there could be operations outside the study sample that have lower-cost, more efficient operations.

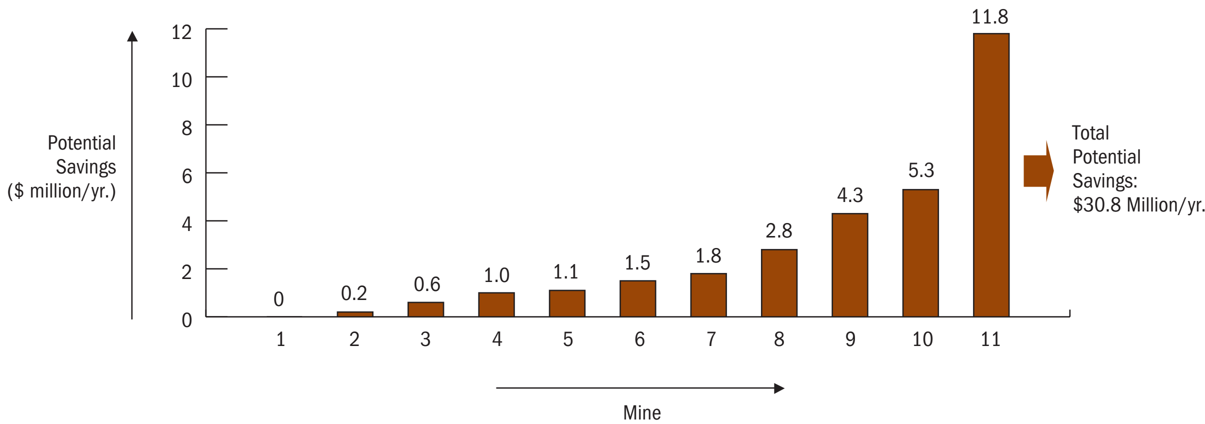
Below, we present the estimated potential savings for participants, based on a comparison of each participant's costs with those for the lowest-cost operation. The comparisons are made for mining (including both gold and base metals mines), concentration (base metals), and gold recovery. On the one hand, the estimates may be too low for the reasons stated above. On the other hand, the estimates may be too high in that the savings may be unattainable for practical reasons. For example, potential savings may differ significantly among the various gold recovery processes.

Irrespective of the above limitations, it is clear that the potential savings are very high. Below, we present a simplified estimate of potential savings from matching the energy costs of the lowest-cost operations.

5.2 Mining: Potential Energy Savings

The energy costs for mining vary from $3.25 per tonne hoisted to $7.61 per tonne hoisted. Assuming that all 11 operations could achieve the $3.25 per tonne cost, the potential total savings for each mine are as follows.

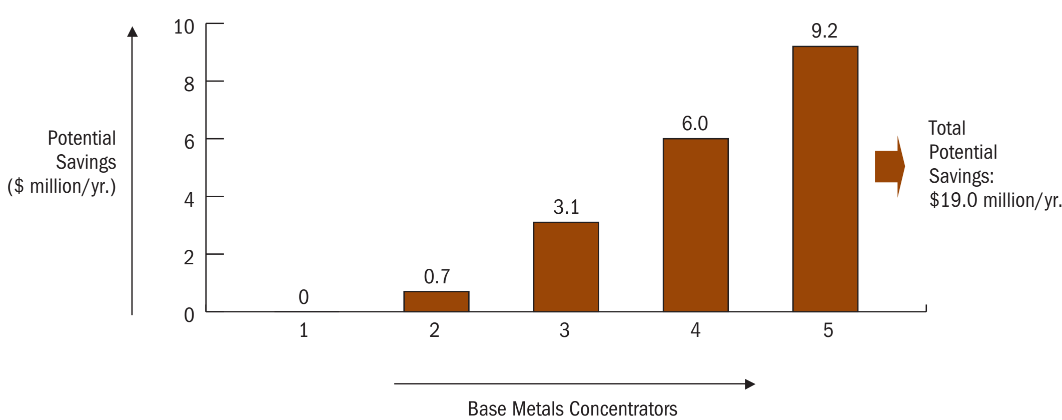
Figure 5.1 – Mining: Potential Savings – Benchmark ($ million/yr.)



5.3 Potential Savings: Concentration

The energy costs for the five mills in the study varied from $0.64 per tonne milled to $3.35 per tonne milled. The maximum savings are estimated to be $19.0 million per year. The distribution of savings among the participants is illustrated below.

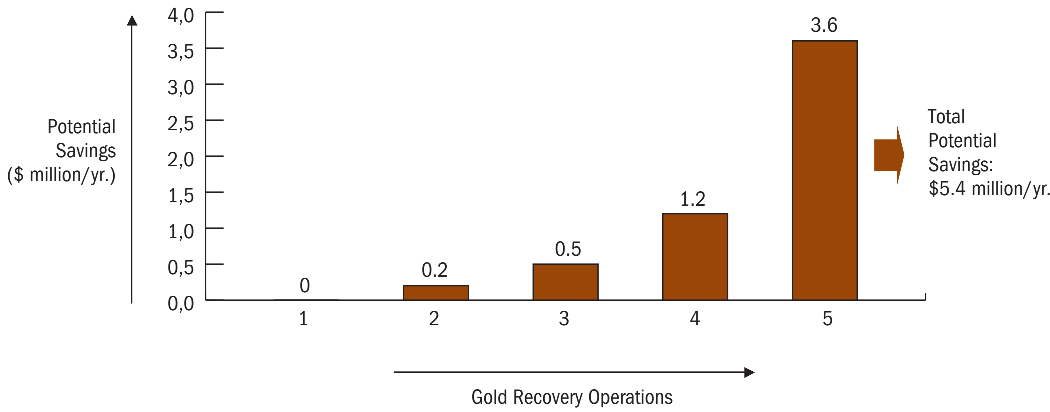
Figure 5.2 – Concentration: Potential Savings – Benchmark



5.4 Potential Savings: Gold Recovery

The energy costs for the five gold recovery operations in the sample varied from $2.00 per tonne ore milled to $5.81 per tonne ore milled. The total savings are approximately $5.4 million per year, as illustrated below.

Figure 5.3 – Gold Recovery: Potential Savings – Benchmark



We need to add a word of caution here. By their very nature, gold recovery processes differ appreciably in their energy requirements. For example, autoclaving and oxygenated roasting consume enormous amounts of power. If participants used these processes, the potential practical savings could be less than those illustrated above.

APPENDIX

APPENDIX 2-1 – UNDERGROUND MINES INCLUDED IN THE SAMPLE

GOLD

COUNTRY	MINE	CORPORATION
Australia	Agnew	WMC Limited
Australia	Beaconsfield	Allstate/Beaconsfield
Australia	Bronzewing	Great Central Mines
Australia	Henty	Gold Fields Ltd.
Australia	Kanowna Belle	Delta Gold Ltd.
Australia	Lawlers	Homestake Mining Company
Australia	Mount Charlotte	Homestake Mining Company
Australia	New Celebration	Newcrest Mining Limited
Australia	Pajingo	Battle Mountain/Normandy
Australia	Peak Gold	Rio Tinto
Australia	Wiluna	Great Central Mines
Canada	Bousquet Complex	Barrick Gold Corp.
Canada	Bousquet Complex	Barrick Gold Corp.
Canada	Campbell	Placer Dome Inc.
Canada	David Bell	Homestake Mining Company
Canada	Detour Lake	Placer Dome Inc.
Canada	Doyon	Cambior Inc.
Canada	Golden Giant	Battle Mountain Gold
Canada	Holloway	Battle Mountain Gold
Canada	Holt-McDermott	Barrick Gold Corp
Canada	Hoyle Pond	Kinross Gold Corporation
Canada	Joe Mann	Campbell Resources
Canada	LaRonde	Agnico-Eagle Mines Ltd.
Canada	Kiena	McWatters Mining Inc.
Canada	Musselwhite	Placer Dome Inc.
Canada	Williams	Homestake Mining Company/ Teck Corporation

GOLD (con't)

COUNTRY	MINE	CORPORATION
South Africa	Bambanani	Anglogold Ltd.
South Africa	Beatrix	Gold Fields Ltd.
South Africa	Blyvooruitzicht	Durban Roodepoort Deep Ltd.
South Africa	Buffelsfontein	Durban Roodepoort Deep Ltd.
South Africa	Deelkraal	Anglogold Ltd.
South Africa	Driefontein Consol.	Gold Fields Ltd.
South Africa	Elandsrand	Anglogold Ltd.
South Africa	ERPM	East Rand Proprietary Mines
South Africa	ET Consolidated	Avgold Limited
South Africa	Evander	Harmony Gold Mining Company Ltd.
South Africa	Great Noligwa	Anglogold Ltd.
South Africa	Harmony	Harmony Gold Mining Company Ltd.
South Africa	Hartebeestfontein	Durban Roodepoort Deep Ltd.
South Africa	Joel	Anglogold Ltd.
South Africa	Kloof Division	Gold Fields Ltd.
South Africa	Kopanang	Anglogold Ltd.
South Africa	Leeudoorn Division	Gold Fields Ltd.
South Africa	Libanon Division	Gold Fields Ltd.
South Africa	Matjhabeng	Anglogold Ltd.
South Africa	Mponeng	Anglogold Ltd.
South Africa	Oryx	Gold Fields Ltd.
South Africa	Savuko	Anglogold Ltd.
South Africa	St. Helena	Gold Fields Ltd.
South Africa	Tau Lekoa	Anglogold Ltd.
South Africa	Tau Tona	Anglogold Ltd.
South Africa	Tshepong	Anglogold Ltd.
South Africa	Western Areas	Placer Dome Inc.
U.S.	Getchell	Placer Dome Inc.
U.S.	Homestake	Homestake Mining
U.S.	Ken Snyder	Franco-Nevada Mining
U.S.	Kettle River	Echo Bay Mines Limited
U.S.	Meikle	Barrick Gold Corp.

COPPER

COUNTRY	MINE	CORPORATION
Australia	Mount Isa	MIM Holdings Ltd.
Australia	Mount Lyell	Sterlite Industries
Australia	Northparkes	North Ltd. / Sumitomo Corporation
Australia	Olympic Dam	WMC Ltd.
Australia	Osborne	Placer Dome Inc.
Canada	Hudson Bay Complex	Anglo American PLC
Canada	Kidd Creek	Falconbridge Limited
Canada	Louvicourt	Novicourt Inc./Aur Resources Inc./ Noranda Inc./Teck Corporation
Canada	Myra Falls	Boliden Ltd.
Canada	Sudbury	Falconbridge Limited
Chile	El Indio	Barrick Gold
Chile	El Teniente	CODELCO
Chile	Michilla	Luksic Group
Chile	Salvador	CODELCO

LEAD AND ZINC

COUNTRY	MINE	CORPORATION
Australia	Broken Hill	Pasminco Limited
Australia	Cadjebut	Western Metals Ltd.
Australia	Cannington	BHP Minerals (Broken Hill)
Australia	Golden Grove	Normandy Mining
Australia	Elura	Pasminco Limited
Australia	Hellyer	Aberfoyle Ltd.
Australia	McArthur River	MIM Holdings Ltd. (McArthur)
Australia	Mount Isa-Hilton	MIM Holdings Ltd. (Mount Isa)
Australia	Pillara	Western Metals Ltd.
Australia	Rosebery	Pasminco Limited
Australia	Woodcutters	Normandy Mining

LEAD AND ZINC (con't)

COUNTRY	MINE	CORPORATION
Canada	Bouchard-Hebert	Breakwater Resources Ltd.
Canada	Brunswick	Noranda Inc.
Canada	Heath Steele	Noranda Inc.
Canada	Hudson Bay Complex	Anglo American PLC
Canada	Kidd Creek	Falconbridge Limited
Canada	Langlois	Breakwater Resources Ltd.
Canada	Matagami Mines	Noranda Inc.
Canada	Myra Falls	Boliden Ltd.
Canada	Nanisivik	Breakwater Resources Ltd.
Canada	Polaris	Cominco
Canada	Sullivan	Cominco
Peru	Atacocha	Minera Atacocha
Peru	Cerro de Pasco	Centromin
Peru	Iscaycruz	Glencore International AG/Minero
Peru	Milpo/El Porvenir	Minera Milpo
Peru	Quiruvilca	Minera Nor Peru
Peru	San Vicente	Minera San Ignacio de Morococha
U.S.	Brushy Creek/Buick/ Fletcher/Viburnum	Doe Run Co./ The Renco Group
U.S.	Gordonsville	Pasminco Limited
U.S.	Greens Creek	Rio Tinto/Hecla Mining Co.
U.S.	Lucky Friday	Hecla Mining Co.
U.S.	Sweetwater	Doe Run Co./ The Renco Group
U.S.	Tennessee Mines	ASARCO
U.S.	West Fork	Doe Run Co./ The Renco Group