CIPEC

BENCHMARKING THE ENERGY CONSUMPTION OF

CANADIAN OPEN-PIT MINES

PREPARED FOR MINING ASSOCIATION OF CANADA
AND NATURAL RESOURCES CANADA

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Canada

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FOREWORD

On behalf of the Mining Sector Task Force of the Canadian Industry Program for Energy Conservation (CIPEC), the Mining Association of Canada (MAC) retained Corporate Renaissance Group to work with mining companies to establish energy benchmarks for open-pit mines. Companies that participated 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, and is a partnership of industrial associations and the Government of Canada, represented by Natural Resources Canada's Office of Energy Efficiency. The Mining Sector Task Force comprises members of MAC's Energy Committee. 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 energy conservation and the reduction of 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.

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1. INTRODUCTION

1.1 Background

Energy costs represent a significant component of the total costs of operations for Canada's mining sector. Directly and indirectly, the energy use in the mining sector is also a significant contributor to Canada's greenhouse gas emissions. Improving energy efficiency reduces greenhouse gas emissions that contribute to climate changes. 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 open-pit 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 open-pit mines of MAC members. Nine mining/milling operations participated in the project, and the sample specifically included the operations of gold, oil sands and iron ore establishments.

The project involved a detailed inter-facility comparison of the energy consumed in mining (drilling – transport) and concentration (crushing – tailings disposal). Approximately 25 categories of energy cost and usage information were examined.

Given the significantly different nature of the milling/concentrator operations for gold and iron ore operations, energy comparisons for these aspects of the operations have been aggregated into larger groupings where feasible. The oil sands operations are compared only with regard to their mining activities.

1.3 Layout of Report

We begin by outlining our methodology in **Section 2.** We describe our approach for developing energy cost comparisons ($/kilotonne mined; $/kilotonne milled) to analyse the operations of the study participants.

Section 3 presents the results of the detailed benchmarking of energy costs and usage for the nine participating establishments. Inter-establishment comparisons are presented at the mine and mill levels, as well as at the various stages of production.

Section 4 presents results on the potential savings generated by achieving benchmark standards. Comparing the costs for each participant with those for the lowest-cost operations produces the estimated potential savings.

2 METHODOLOGY

6

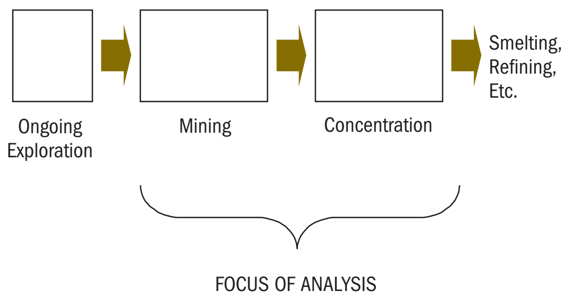
2. METHODOLOGY

2.1 Boundaries of the Analysis

The focus of the analysis of comparative energy costs and usage was as follows:

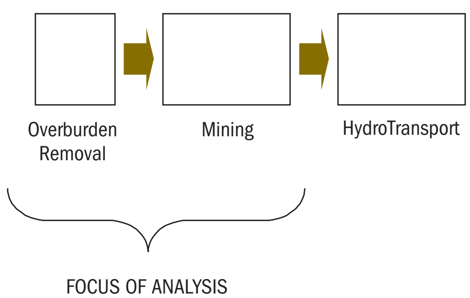
2.1.1 Gold and Iron Ore

The gold and iron ore energy analysis focused on mining and milling/concentration operations.



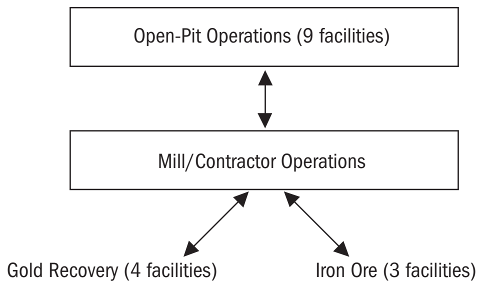
2.1.2 Oil Sands

The oil sands energy analysis focused on the mining operations.



2.2 The Mining Association of Canada (MAC) Sample

A total of nine establishments participated in this project. Each case study included an open-pit mining facility. For seven of the nine mines, energy information was provided for milling/concentrator operations. These included four gold recovery operations producing gold bars and three iron ore operations producing concentrates.



2.2.1 Analysis: Overview

The objective of the analysis is to provide a detailed inter-facility comparison of the cost per kilotonne mined and processed, split into costs per unit of energy and energy consumed per kilotonne for the following:

Open-Pit Mining

Nine mining operations will be compared – all operations, including the transport of ore to the crusher.

Milling/Concentrator Operations (Gold Recovery and Iron Ore Concentration)

The analysis will reflect comparisons of energy consumption and costs for the four gold recovery facilities and three iron ore facilities and will include crushing, grinding and the aggregate of all production stages beyond grinding to loadout, plus process water, tailings disposal and support services.

A more detailed process comparison would not be meaningful due to the radically different processes followed by the companies. However, a more detailed analysis of each company's milling/concentrator processes was presented to the individual companies involved in the study.

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. These conversions are derived from energy content factors reported in *Canada's Energy Outlook 1996–2000,* Natural Resources Canada, April 1997, page D-3.

Table 2.1 – 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 Oil	L	11.59

The inter-facility comparisons are based on the following unit costs and disaggregation into components for open-pit mining and milling/concentrator facilities.

Open-Pit Mining (Gold, Iron Ore and Oil Sands)

$$\left[\frac{\$}{\text{kilotonne ore mined}}\right] = \left[\frac{\$}{kWh_e}\right] \times \left[\frac{kWh_e}{\text{kilotonne ore mined}}\right]$$

Milling/Concentrator (Gold and Iron Ore)

$$\left[\frac{\$}{\text{kilotonne ore milled}}\right] = \left[\frac{\$}{kWh_e}\right] \times \left[\frac{kWh_e}{\text{kilotonne ore milled}}\right]$$

NOTE: ONE KILOTONNE = 2.204623 MILLION POUNDS

Total Complex

For the total complexes, the unit energy costs and consumption will be based on a roll-up of the above. Given that some milling/concentrator operations process ore from more than one open pit and that certain operations use different processes for different qualities/types of ore, the data for the total complex is based on:

a. the average mining energy costs and usage for the facility in the study; and

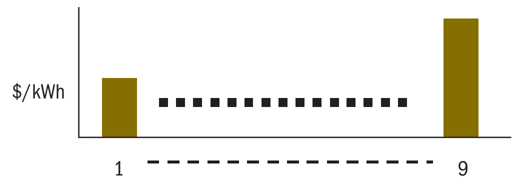
b. actual costs and usage for the energy used in milling/concentrator operations.

Given the above assumptions, the total energy costs can be subdivided to calculate the cost per kilotonne milled for both gold and iron ore.

2.2.2 Comparative Energy Costs

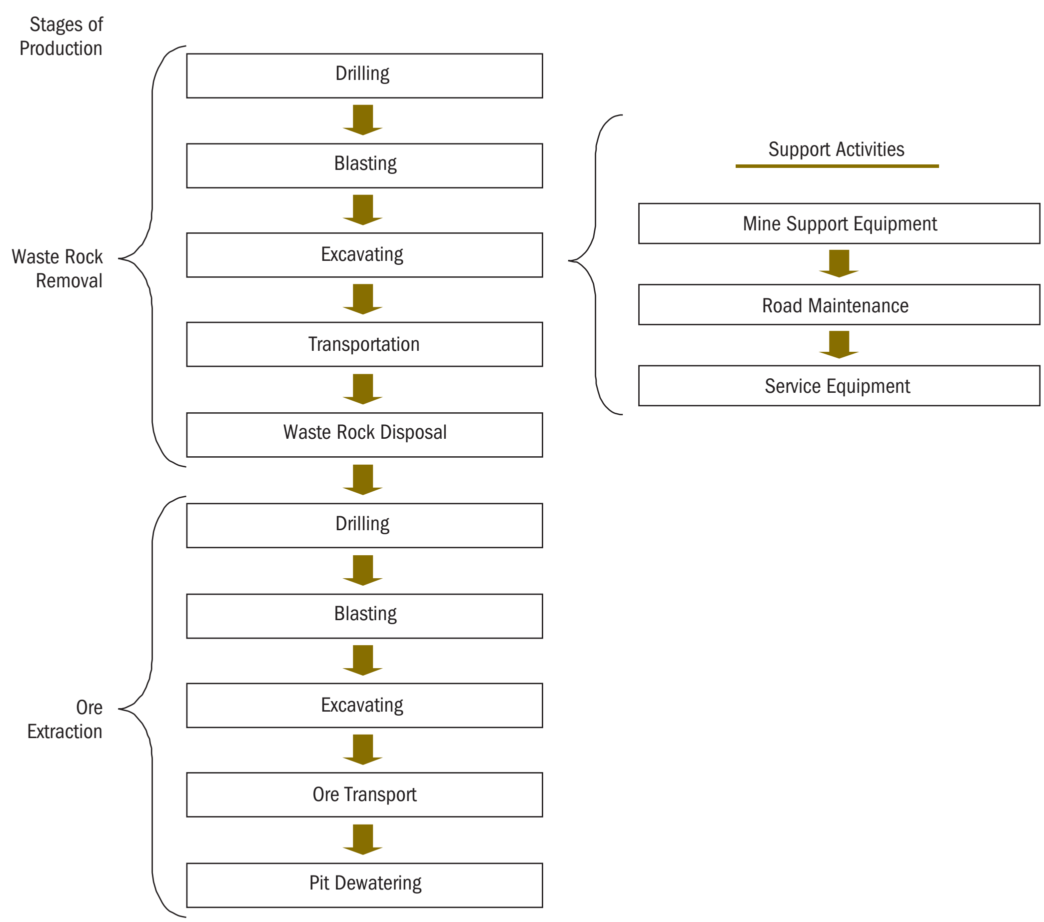
Not surprisingly, average energy unit costs by source vary among the nine open-pit mines.

Energy source (e.g. electricity)

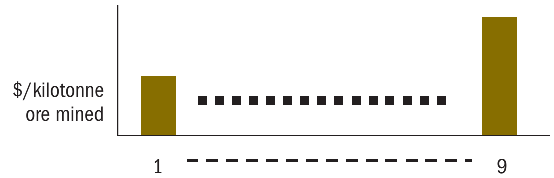


2.2.3 Analysis: Open-Pit Mining Operations

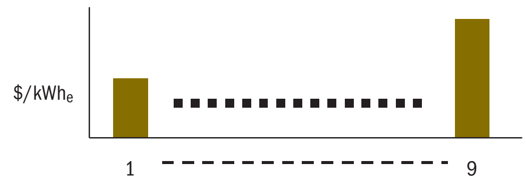
The open-pit mining operations were subdivided into 10 stages of production and three support activities. These categories are illustrated below.

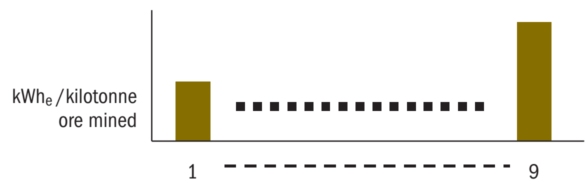


The total energy costs for open-pit mining operations for the nine operations were compared.



These energy costs were, in turn, subdivided into two components: $/kWh$_e$ and kWh$_e$/kilotonne of ore mined.

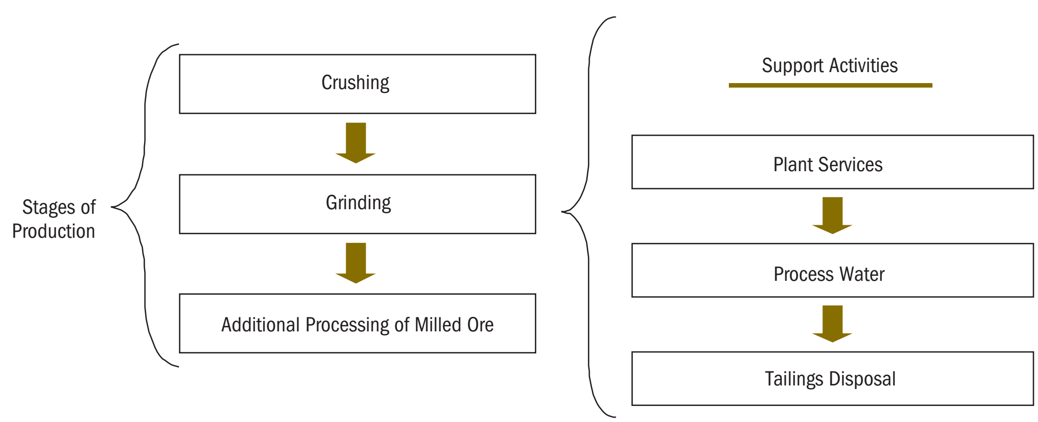




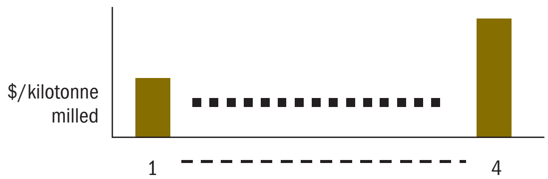
Similarly, energy costs and consumption were compared for each of the nine operations by stage of production.

2.2.4 Analysis: Milling Operations – Gold Recovery

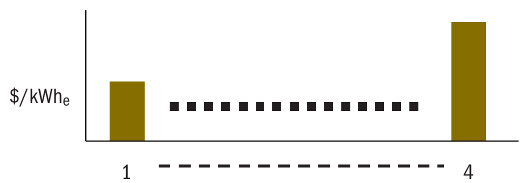
The gold recovery milling operations were subdivided into the following stages of production and support activities.

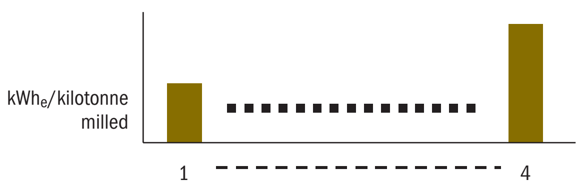


The total energy costs for the milling process in the four gold recovery operations were compared.



These energy costs were, in turn, subdivided into two components: $\$/kWh_e$ and kWh_e/kilotonne ore milled.

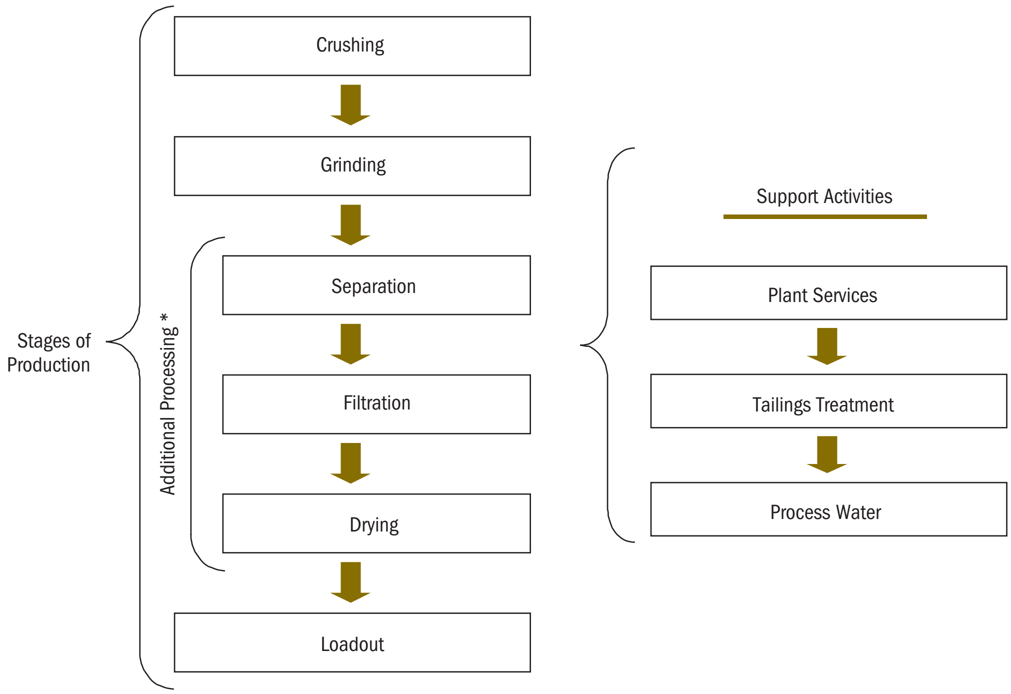




The total energy costs were compared for **each** of the milling gold recovery production stages (crushing, grinding and additional processing through to tailings treatment and disposal). In each case, the total energy costs/kilotonne milled, $\$/kWh_e$ and kWh_e/kilotonne milled were compared as illustrated above for the mining operations.

2.2.5 Analysis: Concentrator Operations – Iron Ore

The iron ore concentration facilities were subdivided into the following stages of production and support facilities.



* NOTE: STUDY PARTICIPANTS FOLLOWED MATERIALLY DIFFERENT PROCESSES FOR PRODUCTION STAGES RELATED TO SEPARATION, FILTRATION AND DRYING. TO ACHIEVE MEANINGFUL COMPARISONS OF ENERGY CONSUMPTION FOR THESE STAGES, IT WAS NECESSARY TO AGGREGATE THE DATA UNDER THE HEADING "ADDITIONAL PROCESSING" EVEN THOUGH ENERGY CONSUMPTION FOR THESE STAGES WAS REPORTED TO THE INDIVIDUAL COMPANIES.

As in the case of the gold operations, the total energy costs per kilotonne for the three concentrator operations were compared. These energy costs were, in turn, divided into their two subcomponents: $\$/kWh_e$ and kWh_e/tonne processed.

The above comparisons were made for each stage of production in the concentration process: crushing, grinding and separation through to tailings treatment and disposal.

2.2.6 General and Administrative

The costs for general and administrative activities were compared separately for both gold and iron ore mining. As in the case of the mining and milling/concentrator analysis, the total energy cost for general and administrative activities per kilotonne mined was determined. This number, in turn, was broken down into its cost per kilowatt hour equivalent and the kilowatt hour equivalent per kilotonne mined.

3

RESULTS: BENCHMARKING PARTICIPATING MINES

3. RESULTS: BENCHMARKING PARTICIPATING MINES

As mentioned above, the nine participants in the study included three iron ore mines, four gold mines and two oil sands operations (for which only mining energy data were collected). In all cases, the mine operations reported their energy consumption and costs for the full calendar year 2000.

For the nine mines, total energy expenditures of $228 million were incurred for the calendar year 2000. The most heavily used fuels were diesel (235 million litres) and electricity (2265 gigawatt hours). Together, these two energy sources accounted for more than 75 percent of the total energy (kWh_e) consumed at the mines.

The mines in the sample collectively produced over 260 million tonnes of ore during 2000 and removed a comparable amount of waste rock. The volume of ore mined during the year varied from less than 4 million tonnes to over 60 million tonnes at the largest mine. Total material removed (ore plus waste rock) ranged from just under 20 million tonnes to over 120 million tonnes. Stripping ratios (waste rock : ore tonnage) varied considerably, from 0.04 to 6.05. This variation has a significant influence on the costs and energy consumption *per tonne of ore mined* that is reported in Sections 3.2 and 3.3 of this study. In Section 3.4, however, we compare the mining operations on the basis of total tonnage removed (ore plus waste), a comparison that removes the influence of the stripping ratios on the comparisons.

The energy benchmarking results will be presented as we compare:

1. the costs across the participants for the individual energy sources;
2. the mining operations for the nine establishments; and
3. the results for the concentration operations of seven facilities.

3.1 Comparative Unit Costs for Energy

There are very significant differences between the lowest and highest unit costs reported for the sources of energy used at the mining operations in the study sample. As illustrated below, the range of unit costs for each energy category is very wide (from 118 to 3 849 percent). The unit energy costs are compared in the figures below.

Figure 3.1 – Range of Unit Energy Costs

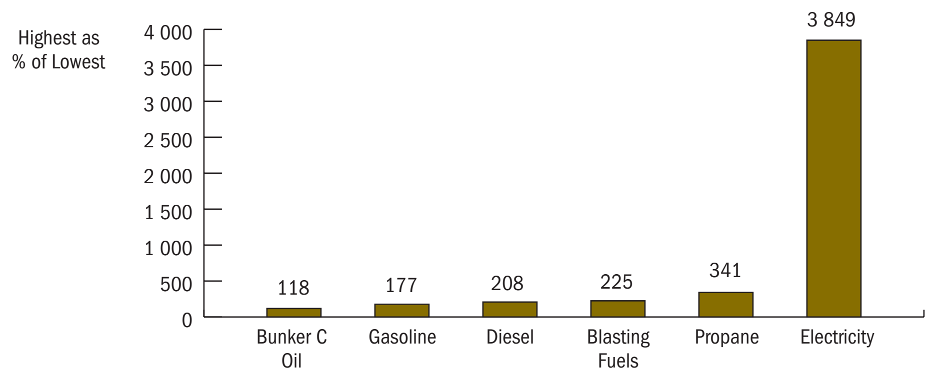
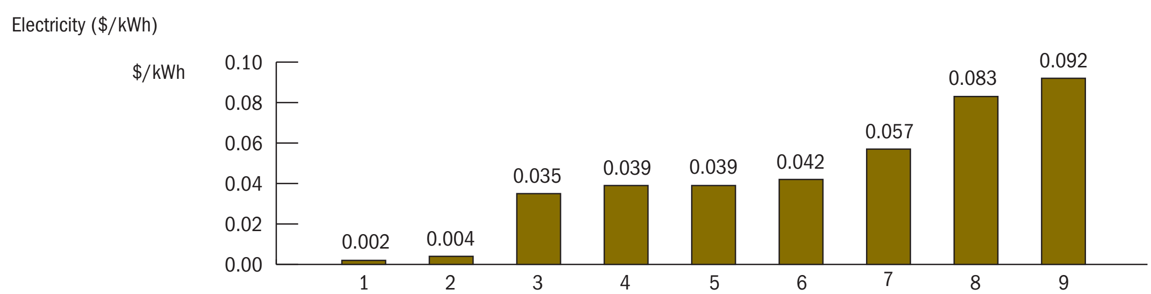


Figure 3.2 – Comparative Unit Energy Costs (CAN$)



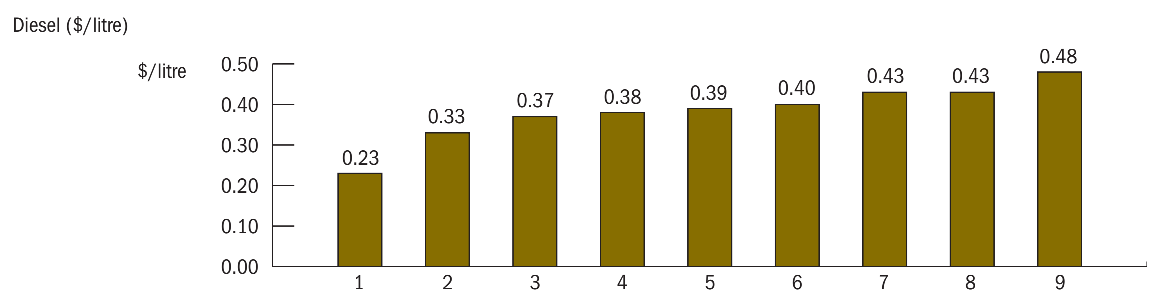
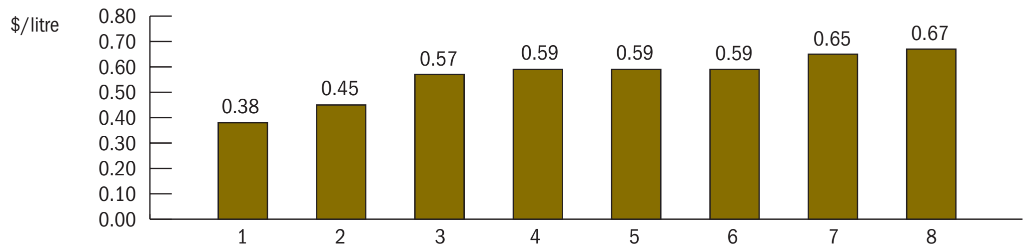
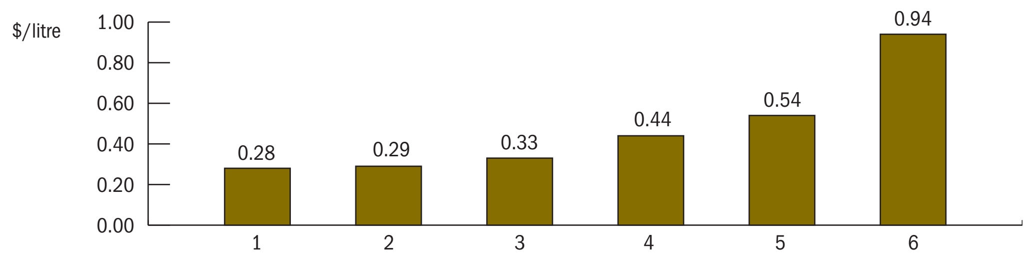


Figure 3.2 (cont.) – Comparative Unit Energy Costs (CAN$)

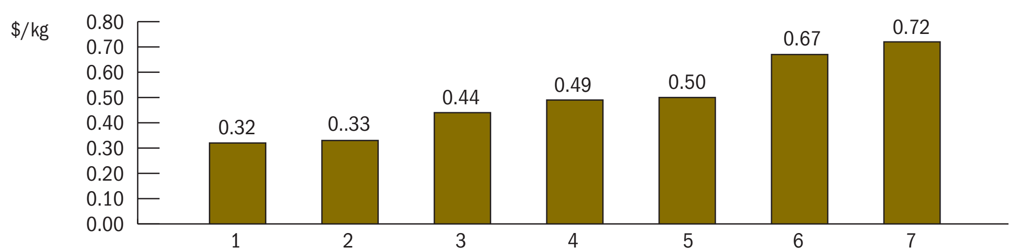
Gasoline ($/litre)



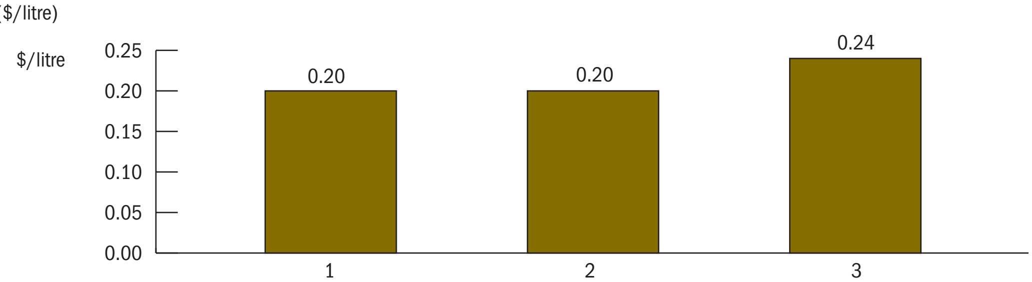
Propane ($/litre)



Blasting Fuels ($/kg of explosive)



Bunker C Oil ($/litre)



3.2 Inter-Mine Comparative Energy Costs – Total Operations

Sufficient information was received from seven open-pit mining operations to make comparisons at the "total operations" level (mining and milling/concentrating costs and energy consumption per kilotonne of ore mined or processed) and for each of the stages of production (drilling, blasting, loading/excavating, hauling, crushing, grinding, etc.). For the two oil sands projects in the sample, only mining data was collected. For heap leach gold mines in the sample, costs were separated for ore destined for the milling process versus ore treated on leach pads, and the "mill ore" costs are reported here.

In all cases, the energy costs were compared based on Canadian dollars per kilotonne (million kilograms[1]) of ore mined. These unit costs, in turn, were subdivided into an energy cost component (dollars per kWh equivalent) and a usage component (kWh equivalent per kilotonne of ore mined). The energy costs for total operations represent the average cost per kilotonne of ore mined plus the average cost per kilotonne of ore milled/concentrated. This concept is captured using the phrase "$ per kilotonne of ore processed" (i.e. processed in the mining and the concentrating operations). The figure below summarizes the total energy costs per kilotonne of ore mined and ore milled/concentrated for the seven mines that reported all data for this study.

1 One tonne (1 000 kilograms) equals 2 204.6 lbs.

Figure 3.3 – Energy Costs: Total Operations

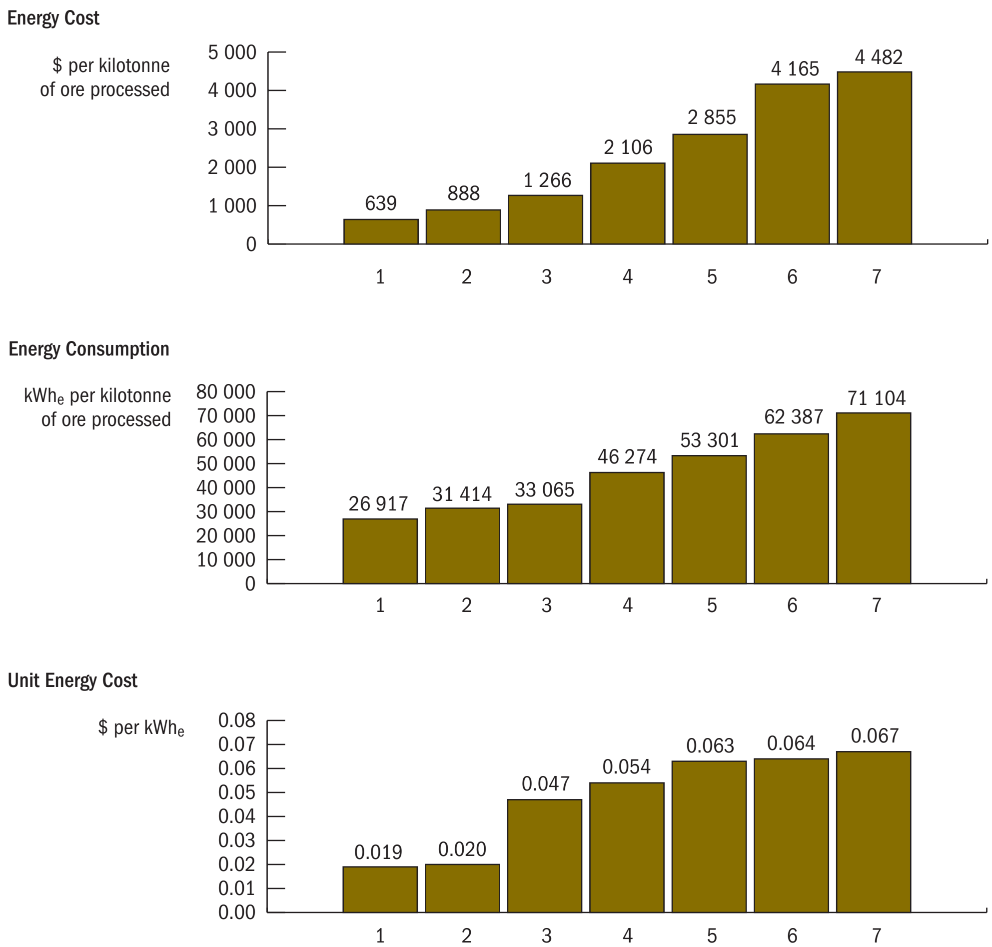


Figure 3.4 – Average Costs by Stage of Production

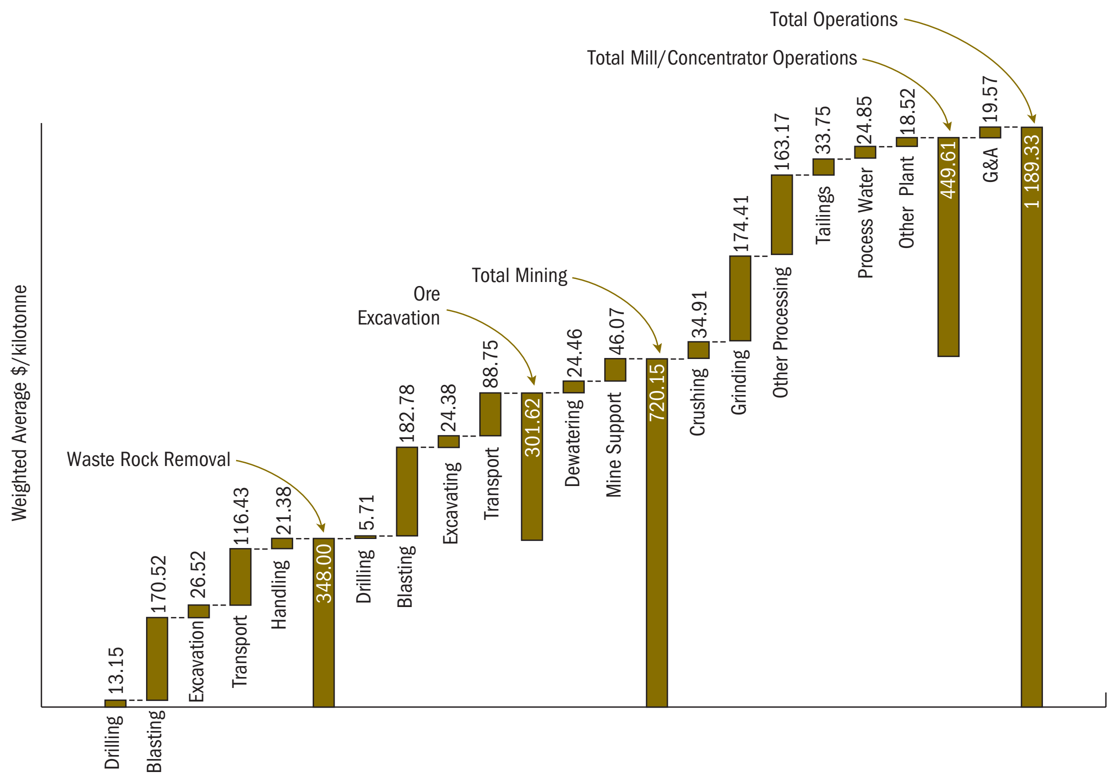
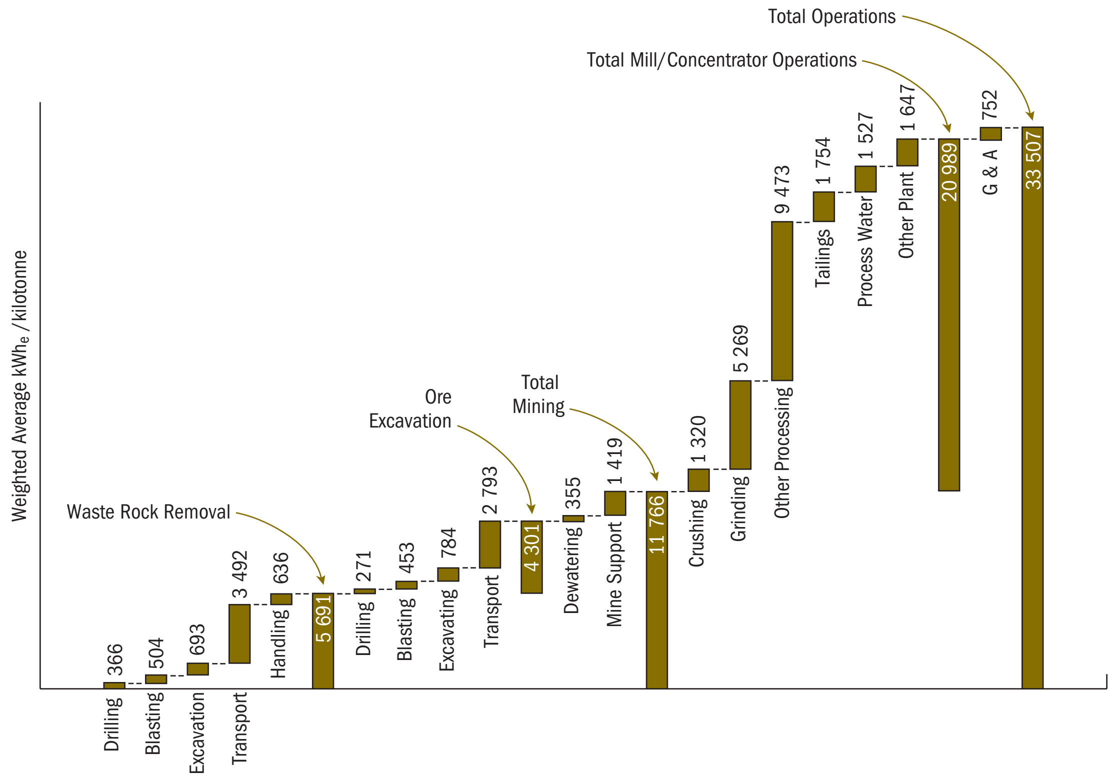


Figure 3.5 – Average Energy Consumption by Stage of Production



3.3 Inter-Mine Comparative Energy Costs – Mining Operations

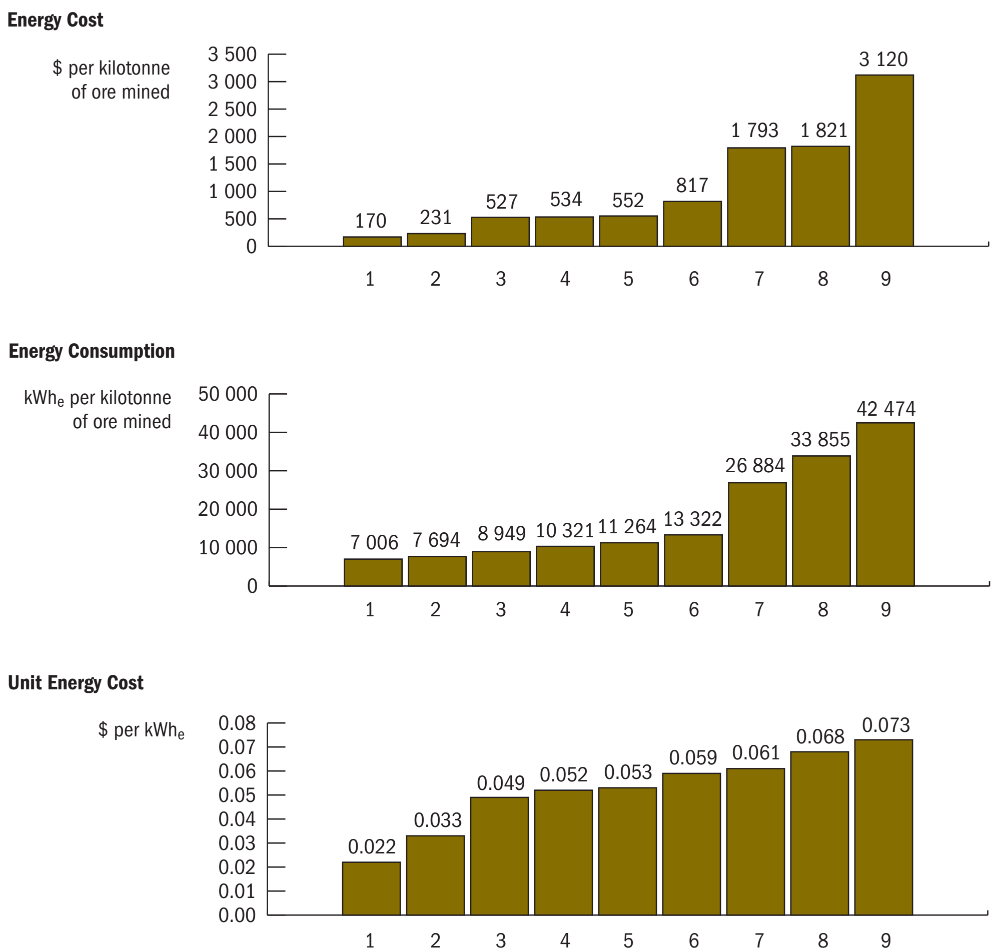
3.3.1 Total Mining Operations

The total energy costs for open-pit mining for the nine operations are shown below. As illustrated, the energy costs vary from $170 per kilotonne of ore mined to $3,120 per kilotonne. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	3 120 : 170	1 830
Energy Consumption (kWh_e/kilotonne of ore mined)	42 474 : 7 006	606
Unit Energy Cost ($/$kWh_e$)	0.073 : 0.022	331

The total costs shown here cover drilling, blasting, excavating, hauling, pit dewatering, and mine support equipment, road maintenance and service equipment. Any in-pit crushing or rehandling of ore from stockpiles is excluded.

Figure 3.6 – Total Energy Costs: Mining Operations



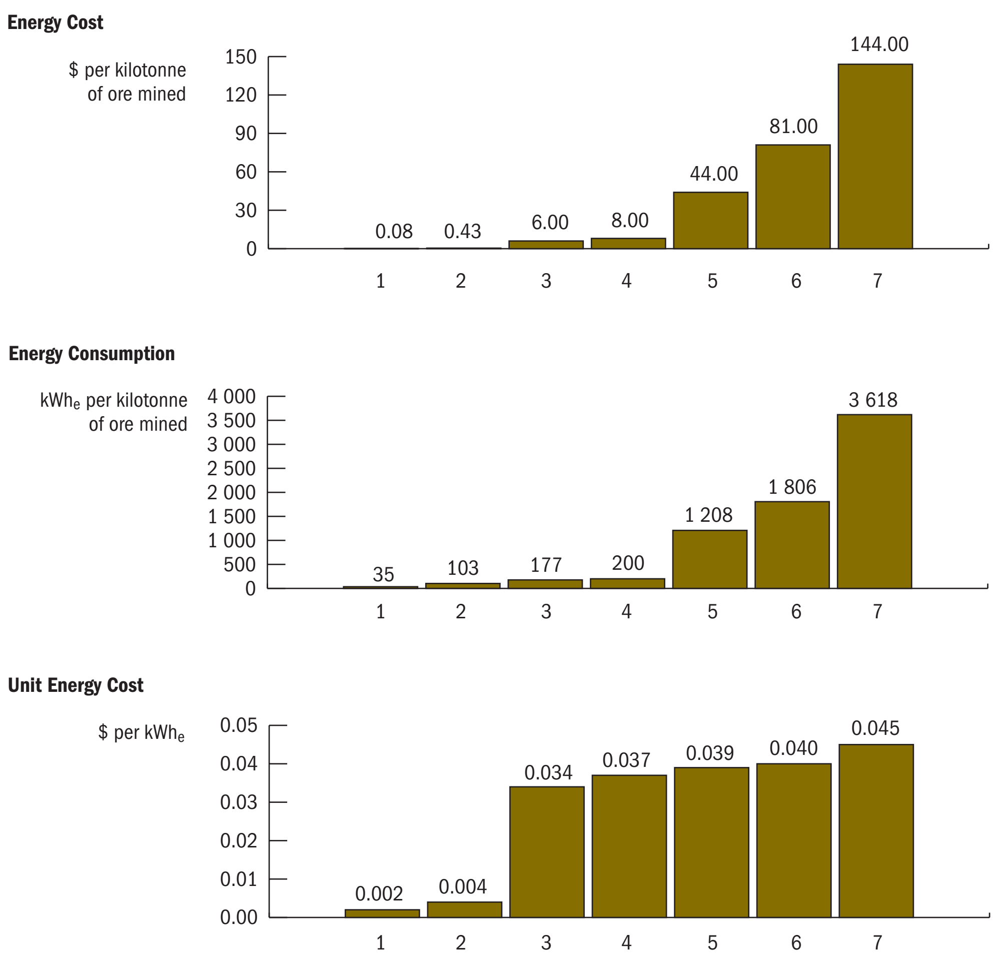
3.3.2 Waste Rock Operations – Stages of Production

Drilling (Waste Rock)

The cost for waste rock drilling energy varied from $0.08 to $144.00 per kilotonne of ore mined for seven drilling operations. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	144.00 : 0.08	179 800
Energy Consumption (kWh_e/kilotonne of ore mined)	3 618 : 35	10 439
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.002	1 858

Figure 3.7 – Drilling (Waste Rock) Energy Costs

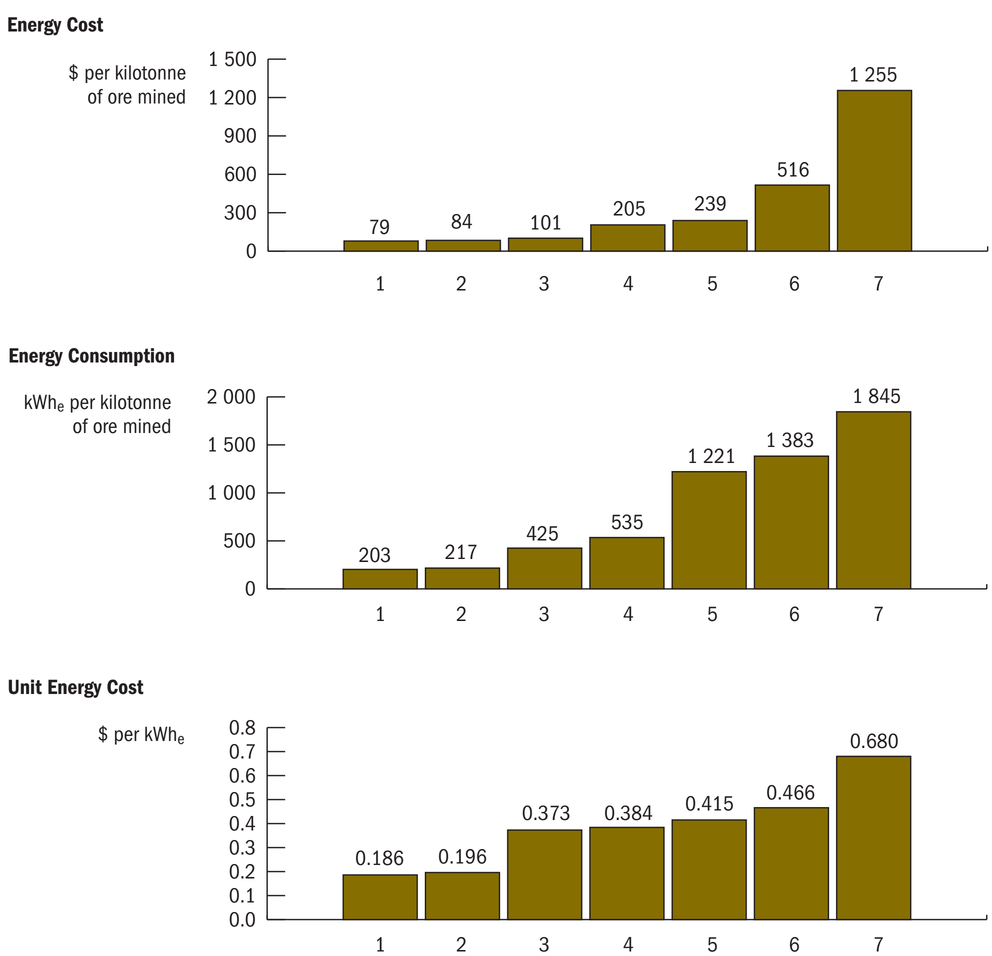


Blasting (Waste Rock)

The blasting energy costs for waste rock varied from $79 to $1,255 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	1 255 : 79	1 588
Energy Consumption (kWh_e/kilotonne of ore mined)	1 845 : 203	909
Unit Energy Cost ($/$kWh_e$)	0.680 : 0.186	366

Figure 3.8 – Blasting (Waste Rock) Energy Costs

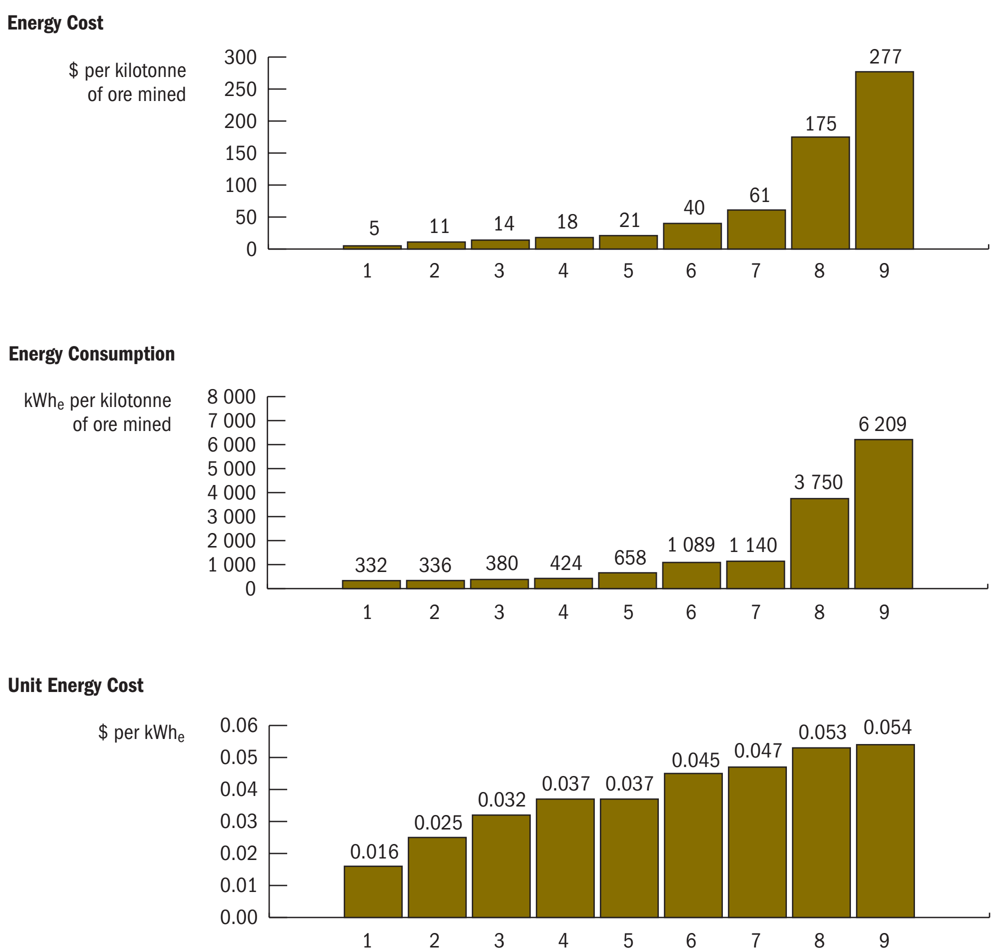


Loading/Excavating (Waste Rock)

The energy costs for loading/excavating waste rock varied from $5 to $277 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	277 : 5	5 213
Energy Consumption (kWh_e/kilotonne of ore mined)	6 209 : 332	1 868
Unit Energy Cost ($/$kWh_e$)	0.054 : 0.016	341

Figure 3.9 – Excavating (Waste Rock) Energy Costs

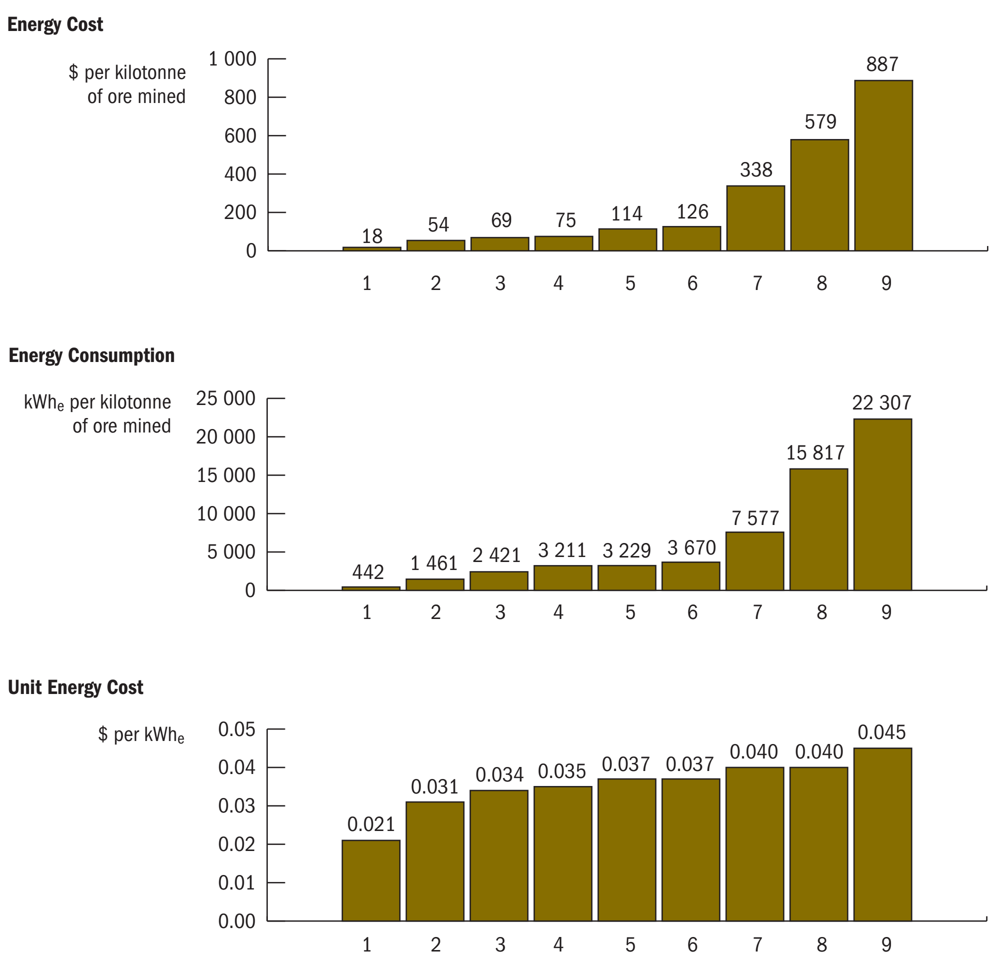


Waste Rock Transport

The energy costs for hauling waste rock varied from $18 to $887 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	887 : 18	4 986
Energy Consumption (kWh_e/kilotonne of ore mined)	22 307 : 442	5 052
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.021	208

Figure 3.10 – Waste Rock Transport Energy Costs

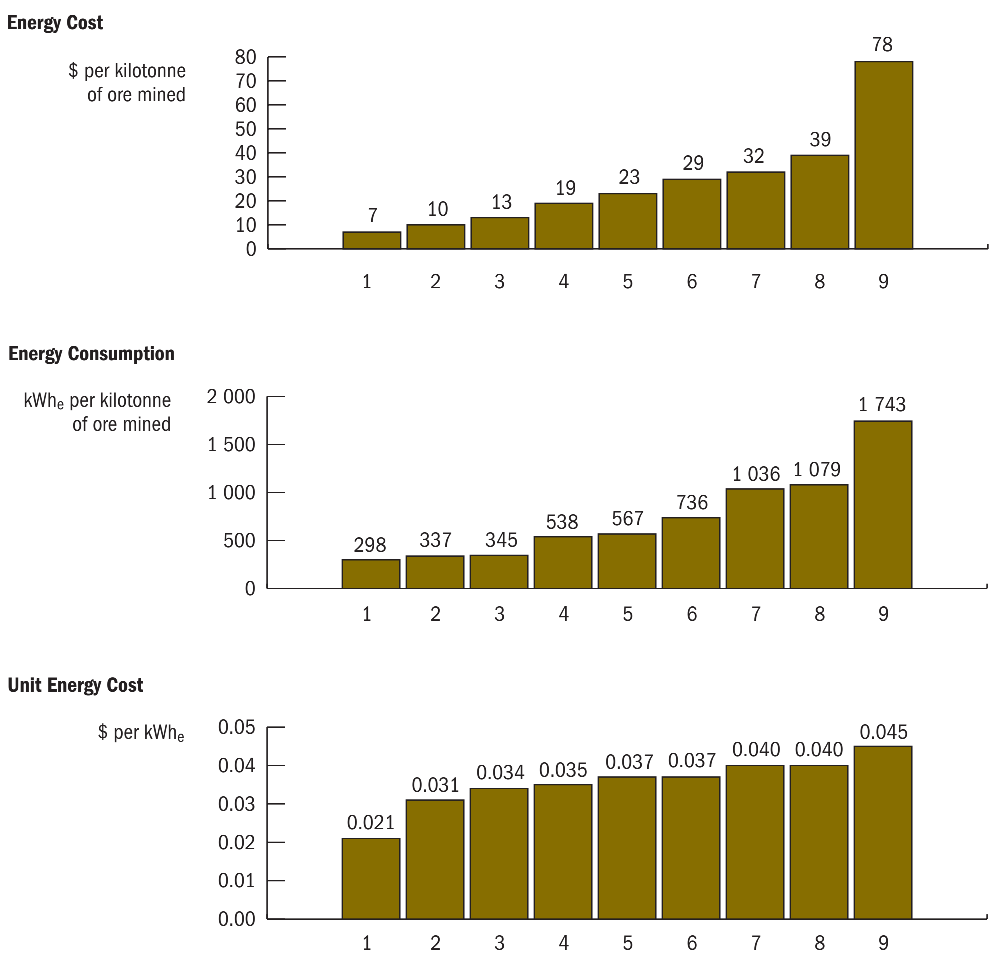


Waste Rock Handling

The energy costs for handling waste rock after transport varied from $7 to $78 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	78 : 7	1 076
Energy Consumption (kWh_e/kilotonne of ore mined)	1 743 : 298	586
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.021	208

Figure 3.11 – Waste Rock Handling Energy Costs



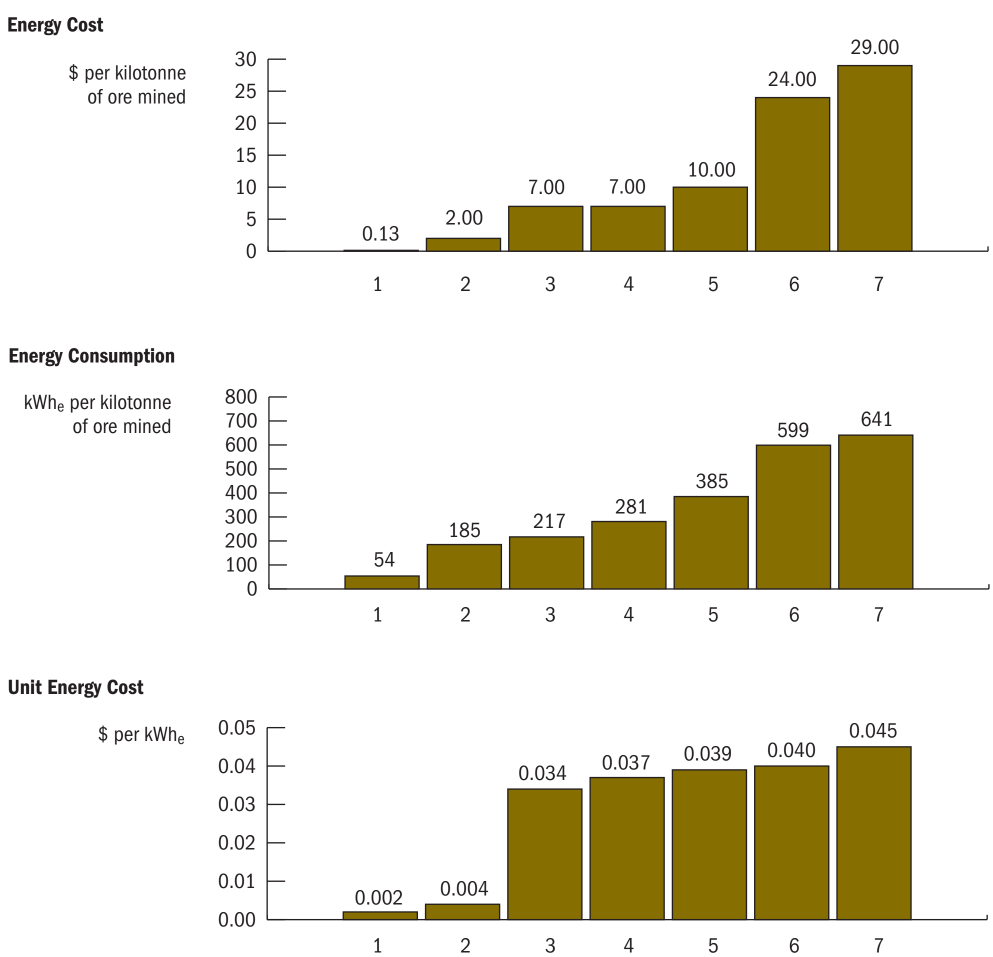
3.3.3 Ore Mining Operations – Stages of Production

Drilling (Ore)

The drilling energy costs varied from $0.13 to $29.00 per kilotonne of ore mined for seven drilling operations. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	29.00 : 0.13	21 969
Energy Consumption (kWh_e/kilotonne of ore mined)	641 : 54	1 191
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.002	1 858

Figure 3.12 – Drilling (Ore) Energy Costs

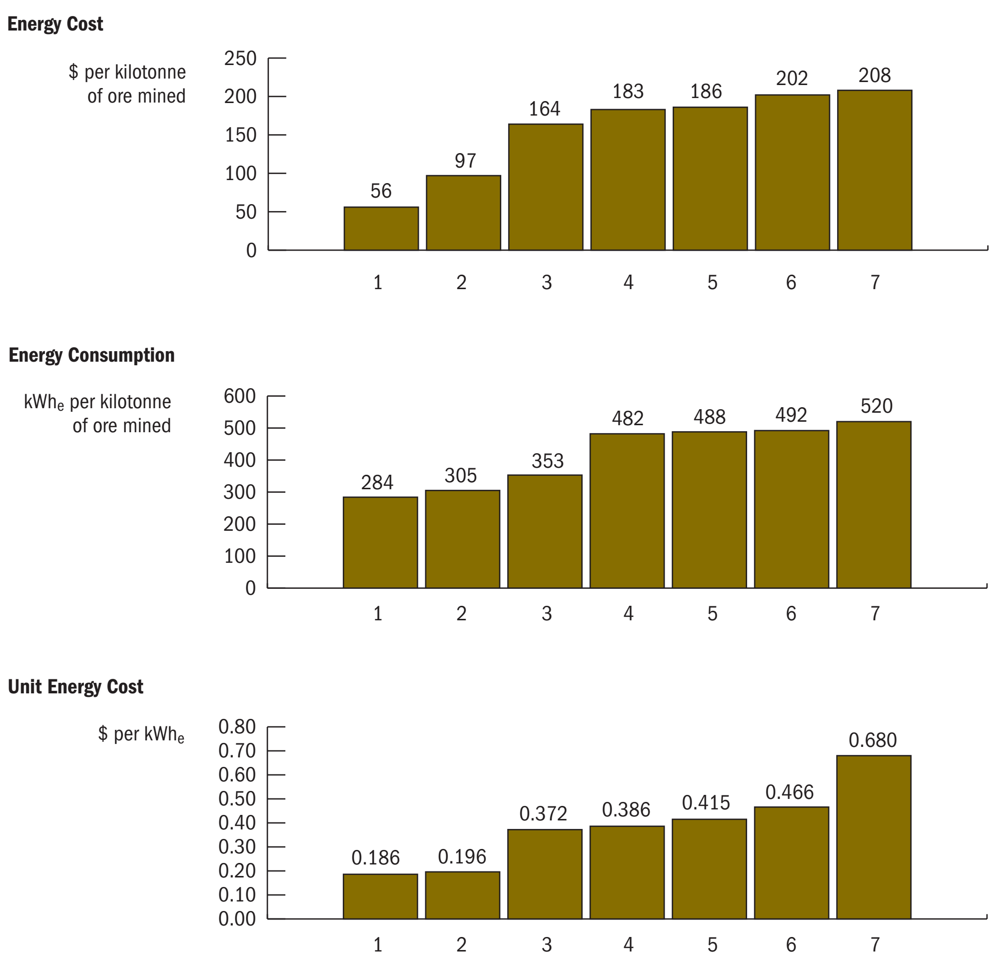


Blasting (Ore)

The energy costs for blasting ore varied from $56 to $208 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	208 : 56	374
Energy Consumption (kWh_e/kilotonne of ore mined)	520 : 284	183
Unit Energy Cost ($/$kWh_e$)	0.680 : 0.186	366

Figure 3.13 – Blasting (Ore) Energy Costs

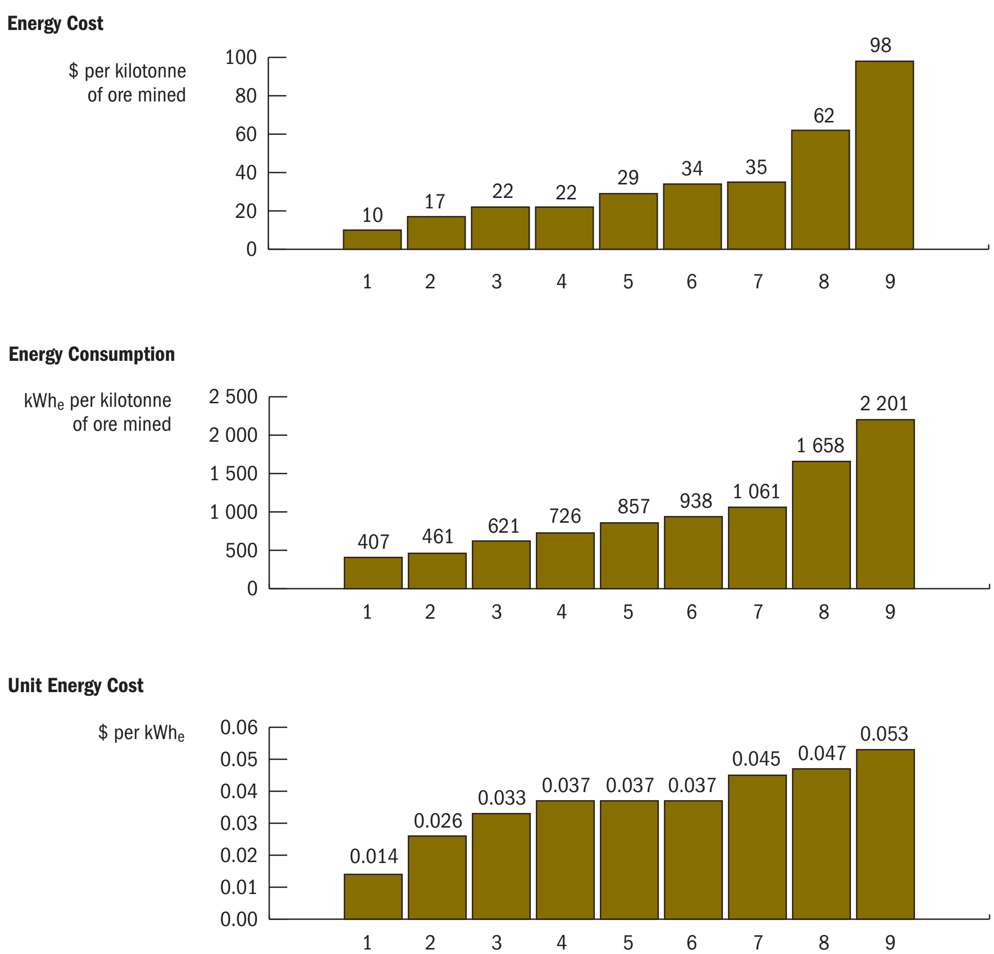


Loading/Excavating Ore

The energy costs for loading/excavating ore varied from $10 to $98 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	98 : 10	954
Energy Consumption (kWh_e/kilotonne of ore mined)	2 201 : 407	541
Unit Energy Cost ($/$kWh_e$)	0.053 : 0.014	378

Figure 3.14 – Excavating (Ore) Energy Costs

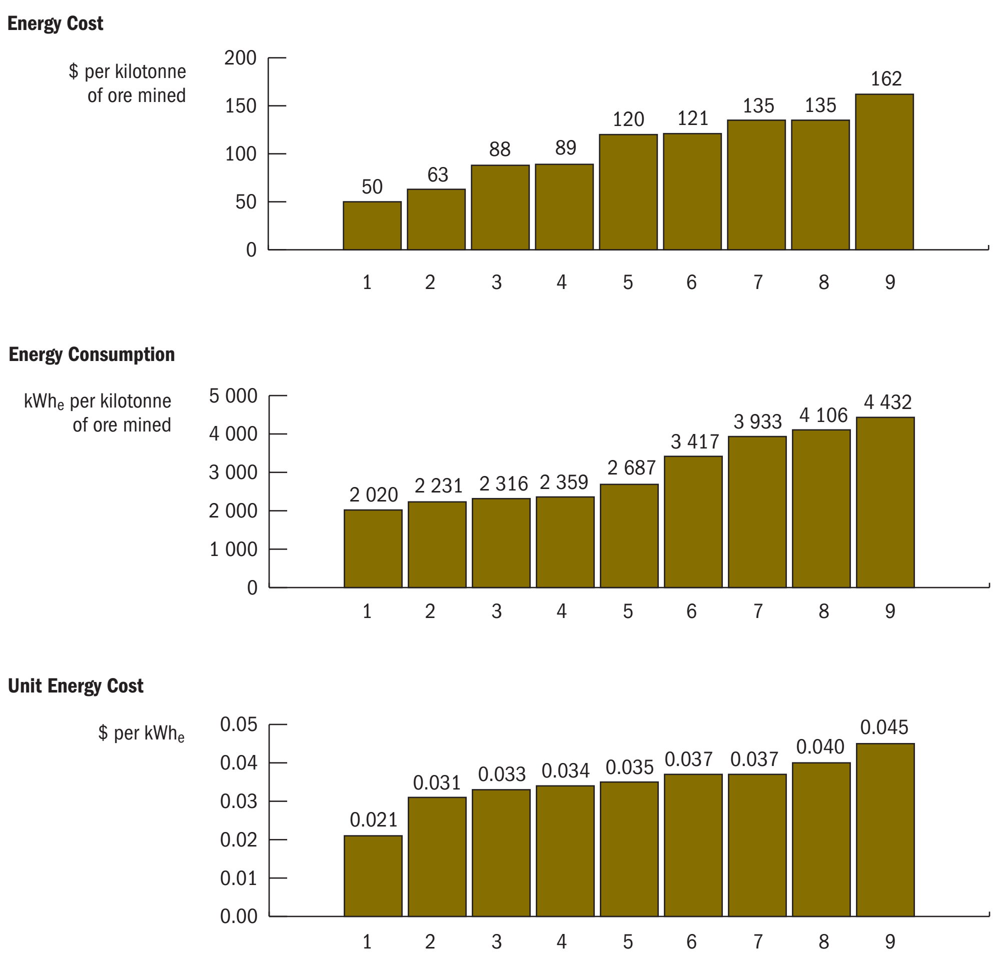


Ore Transport

The energy costs for hauling ore to the crusher or stockpile varied from $50 to $162 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	162 : 50	327
Energy Consumption (kWh_e/kilotonne of ore mined)	4 432 : 2 020	219
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.021	208

Figure 3.15 – Ore Transport Energy Costs

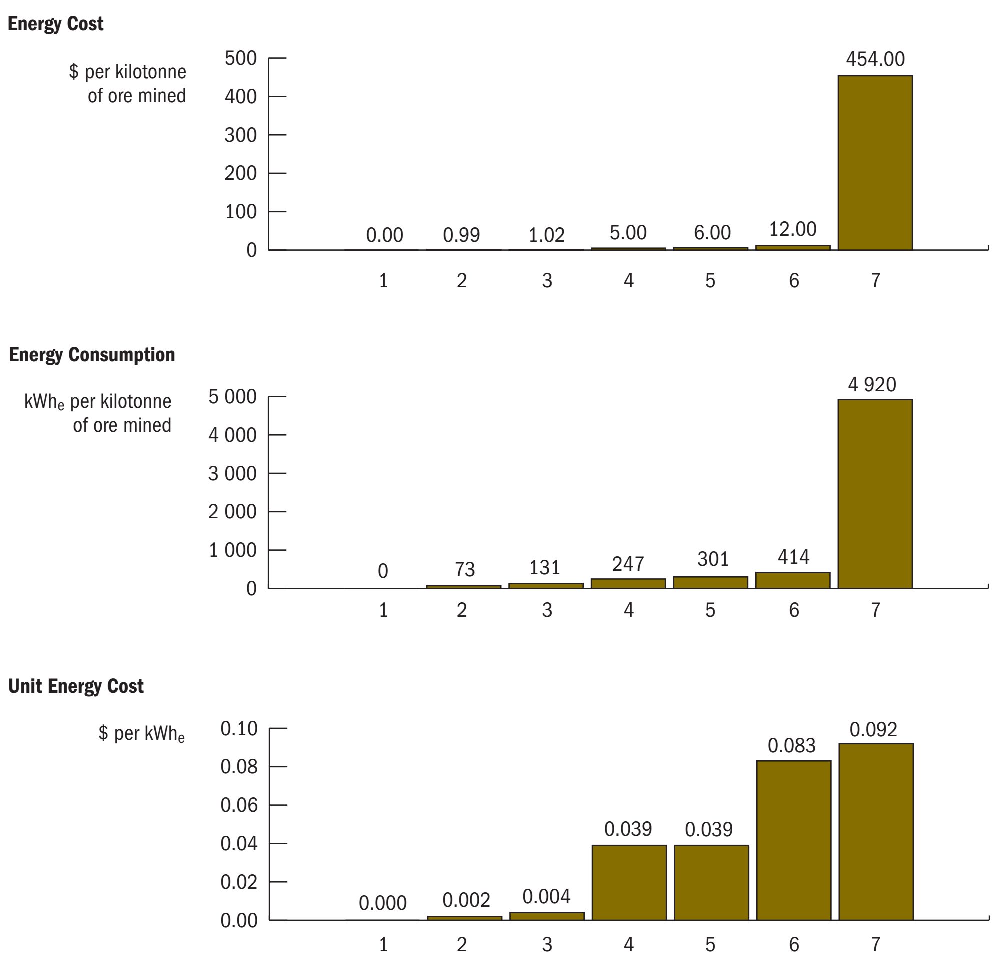


Mine Dewatering

The energy costs for mine dewatering varied from $0.00 to $454.00 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	454.00 : 0.00	n/a
Energy Consumption (kWh_e/kilotonne of ore mined)	4 920 : 0	n/a
Unit Energy Cost ($/$kWh_e$)	0.092 : 0.000	n/a

Figure 3.16 – Mine Dewatering Energy Costs

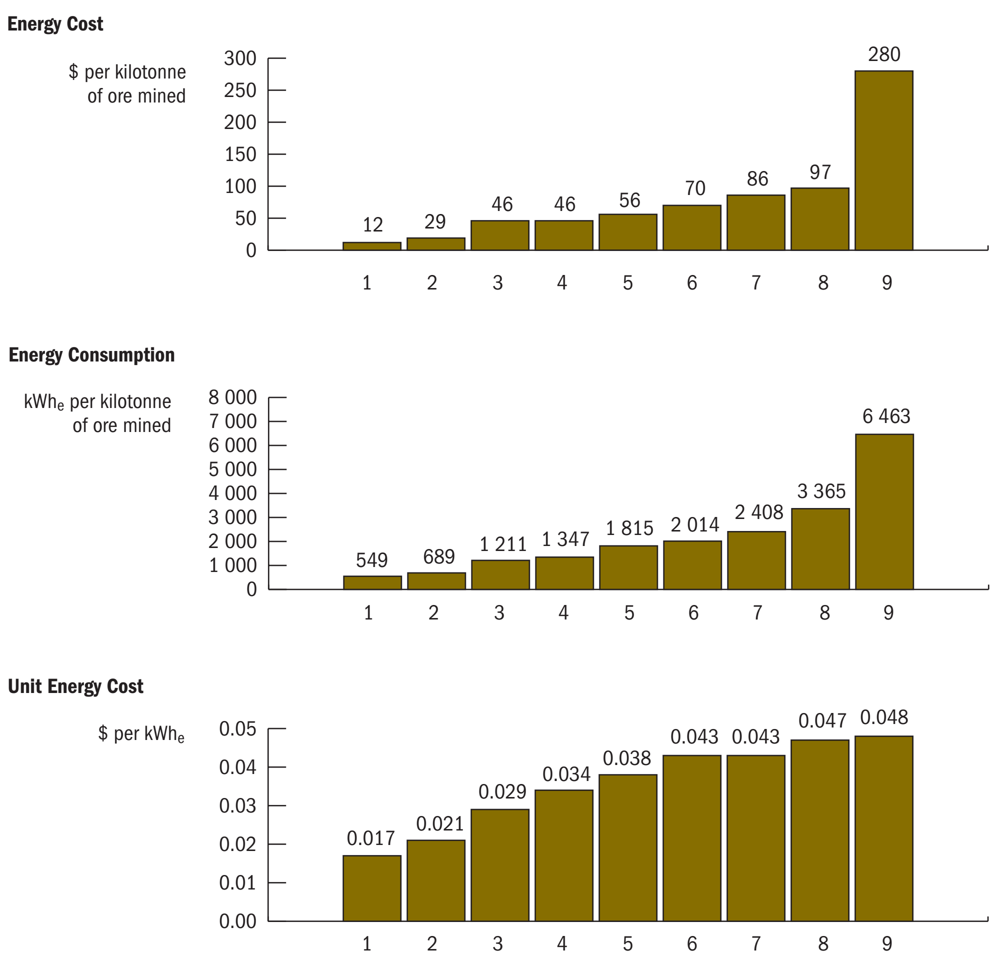


Mine Support Equipment and Services

This category includes energy consumption reported by participants for mine support equipment, road maintenance and service equipment and facilities. The energy costs for various mine support equipment and services ranged from $12 to $280 per kilotonne of ore mined. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	280 : 12	2 376
Energy Consumption (kWh_e/kilotonne of ore mined)	6 463 : 549	1 177
Unit Energy Cost ($/$kWh_e$)	0.048 : 0.017	288

Figure 3.17 – Mine Support Equipment and Services Energy Costs



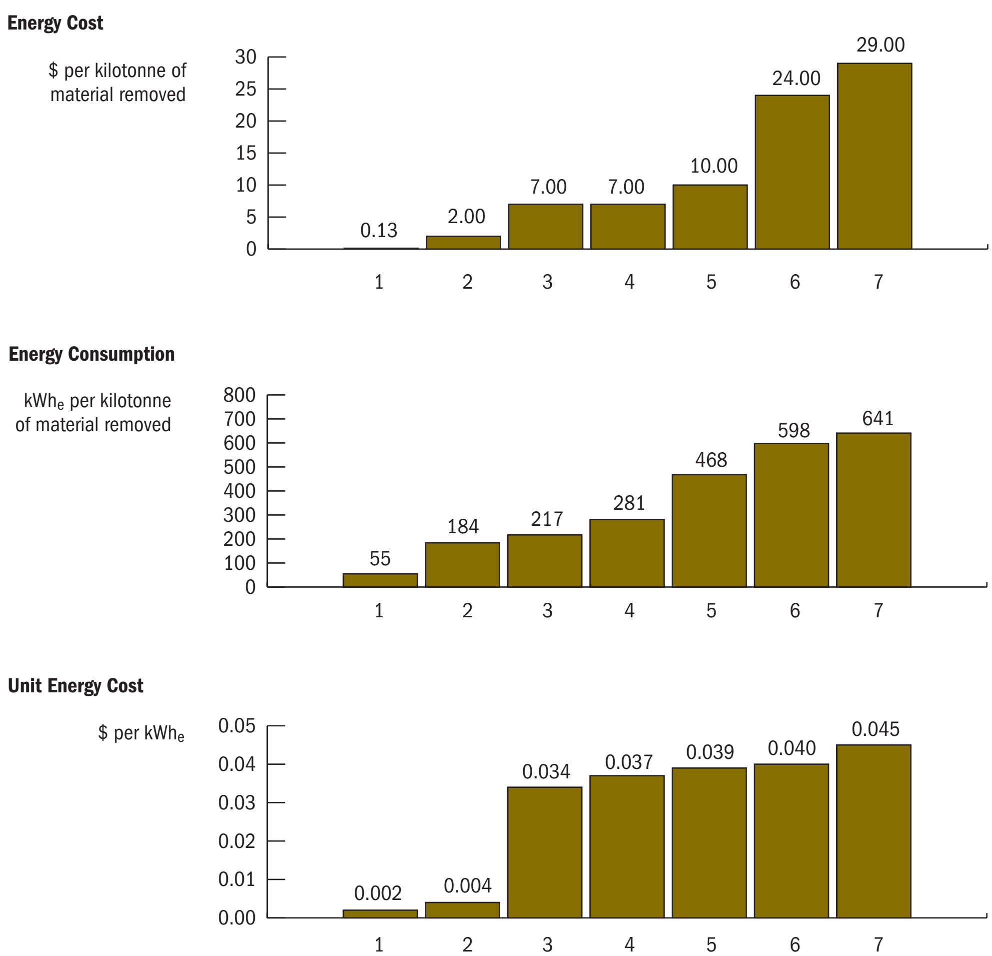
3.3.4 Comparisons Based on Total Material Removed

Drilling

The drilling energy costs varied from $0.13 to $29.00 per kilotonne of material removed (ore plus waste rock) for seven drilling operations, as illustrated below. The range of costs and efficiencies is as follows:

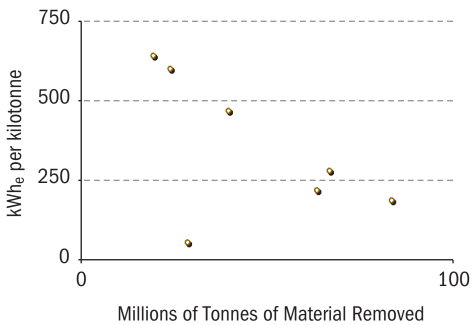
	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	29.00 : 0.13	21 969
Energy Consumption (kWh_e/kilotonne of material removed)	641 : 55	1 173
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.002	1 858

Figure 3.18 – Drilling Energy Costs



The influence of the size of the mining operation on energy consumption in drilling activities is explored in the figure below. There appears to be a very strong relationship between the drilling energy per kilotonne of material removed (i.e. rock broken) and the total volume of material removed at the mine. The largest operations consume less than one half of the energy per kilotonne in drilling operations that is reported by the smaller mines in the study sample.

Figure 3.19 – Scale Economies: Drilling

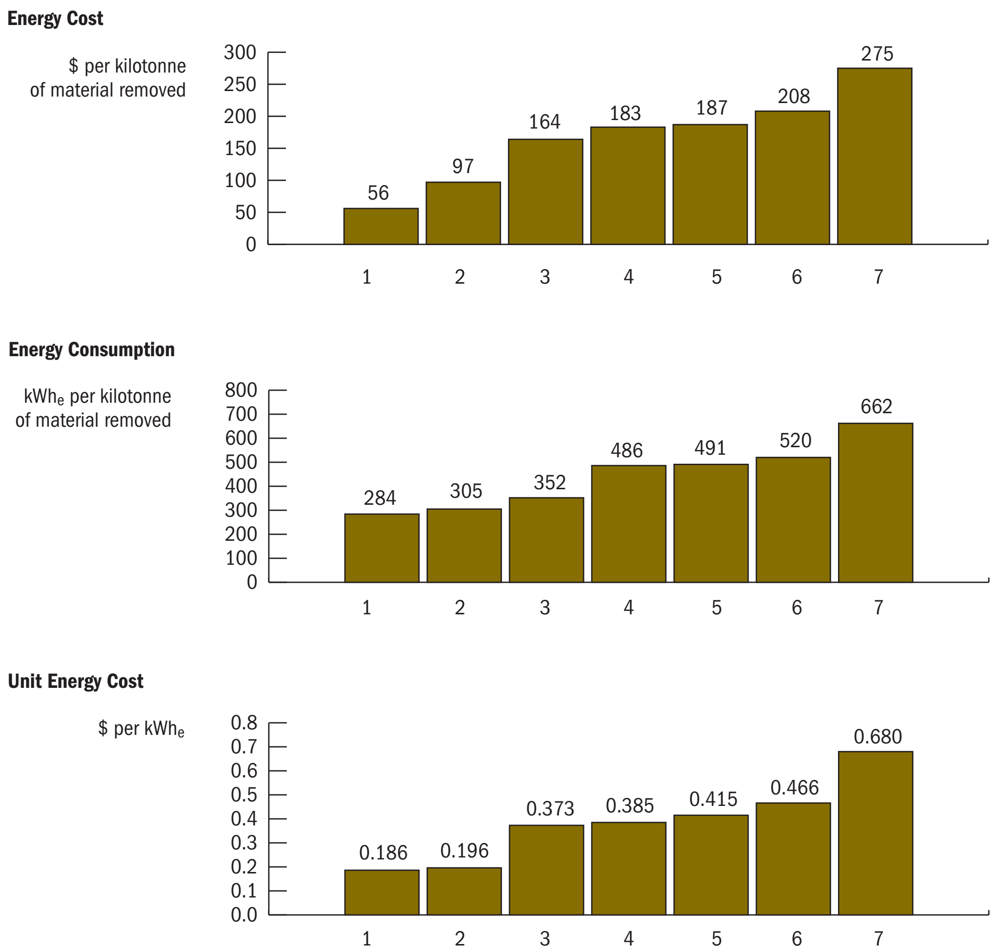


Blasting

The energy costs for blasting varied from $56 to $275 per kilotonne of material removed (ore plus waste rock). The range of costs and efficiencies is as follows:

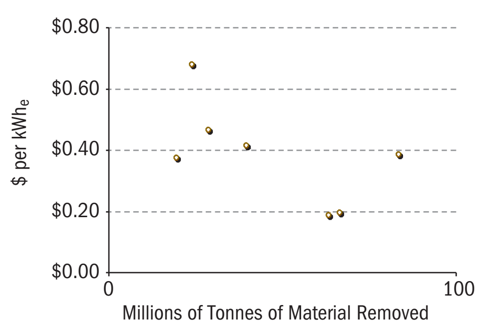
	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	275 : 56	494
Energy Consumption (kWh$_e$/kilotonne of material removed)	662 : 284	233
Unit Energy Cost ($/kWh$_e$)	0.680 : 0.186	366

Figure 3.20 – Blasting Energy Costs



We examined the relationship between the size of the open-pit mining operations and the price paid for blasting fuels. As indicated in the figure below, the larger operations tend to be able to leverage their substantial requirements for blasting fuels into lower prices from suppliers.

Figure 3.21 – Economies of Scale: Purchase Price of Blasting Fuels

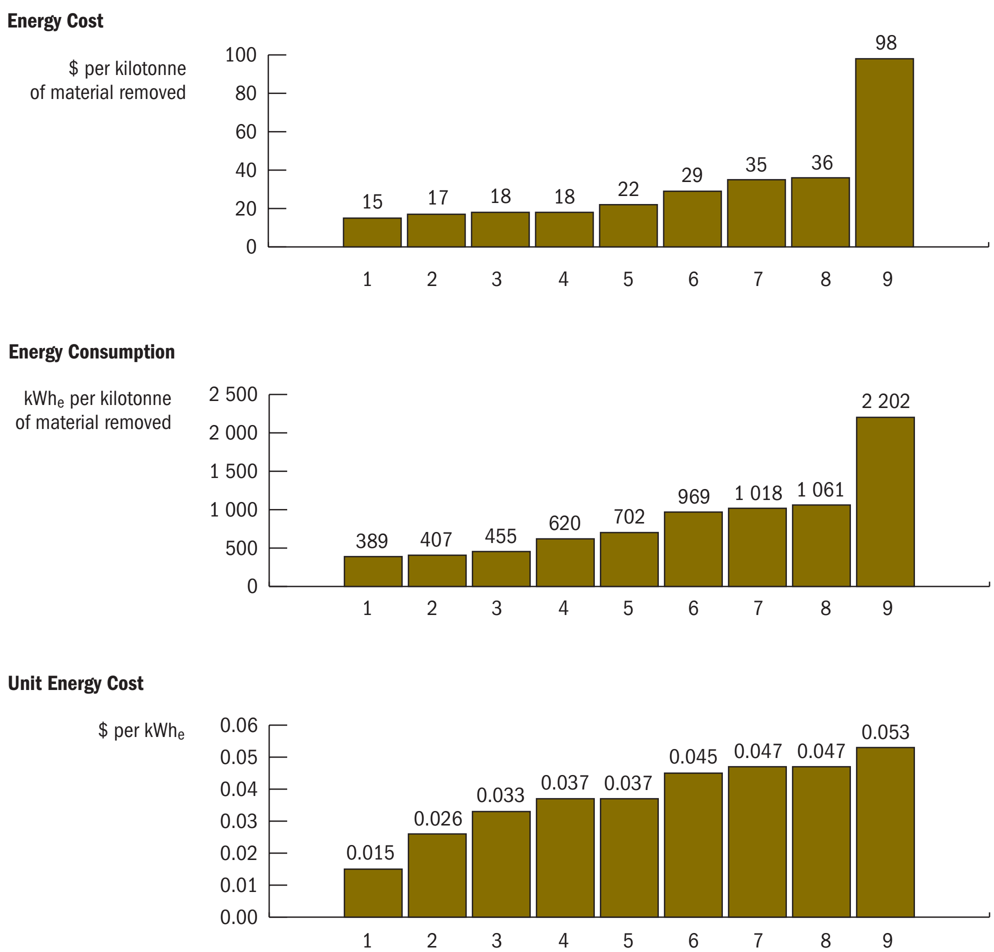


Material Loading/Excavating

The energy costs for loading/excavating ore and waste rock varied from $15 to $98 per kilotonne of material removed. The range of costs and efficiencies is as follows:

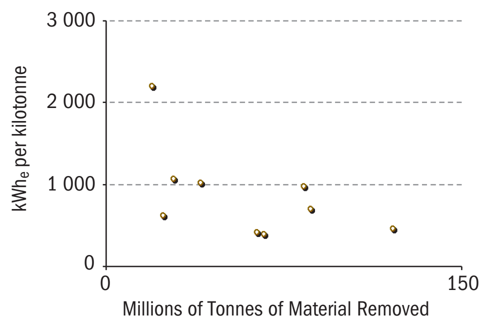
	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	98 : 15	657
Energy Consumption (kWh_e/kilotonne of material removed)	2 202 : 389	566
Unit Energy Cost ($/$kWh_e$)	0.053 : 0.015	364

Figure 3.22 – Excavating Energy Costs



The excavating/loading operations at open-pit mines would appear to generate significant economies of scale. Larger mines are able to deploy extremely large and expensive (electric) shovels that would not be cost-efficient in smaller mining operations. The figure below examines the economies of scale reported in loading operations at the nine mines in the study. Perhaps surprisingly, the energy consumption (kWh_e per kilotonne of material removed) reported for excavating operations is not much higher at the smaller mines participating in this study.

Figure 3.23 – Economies of Scale: Excavating

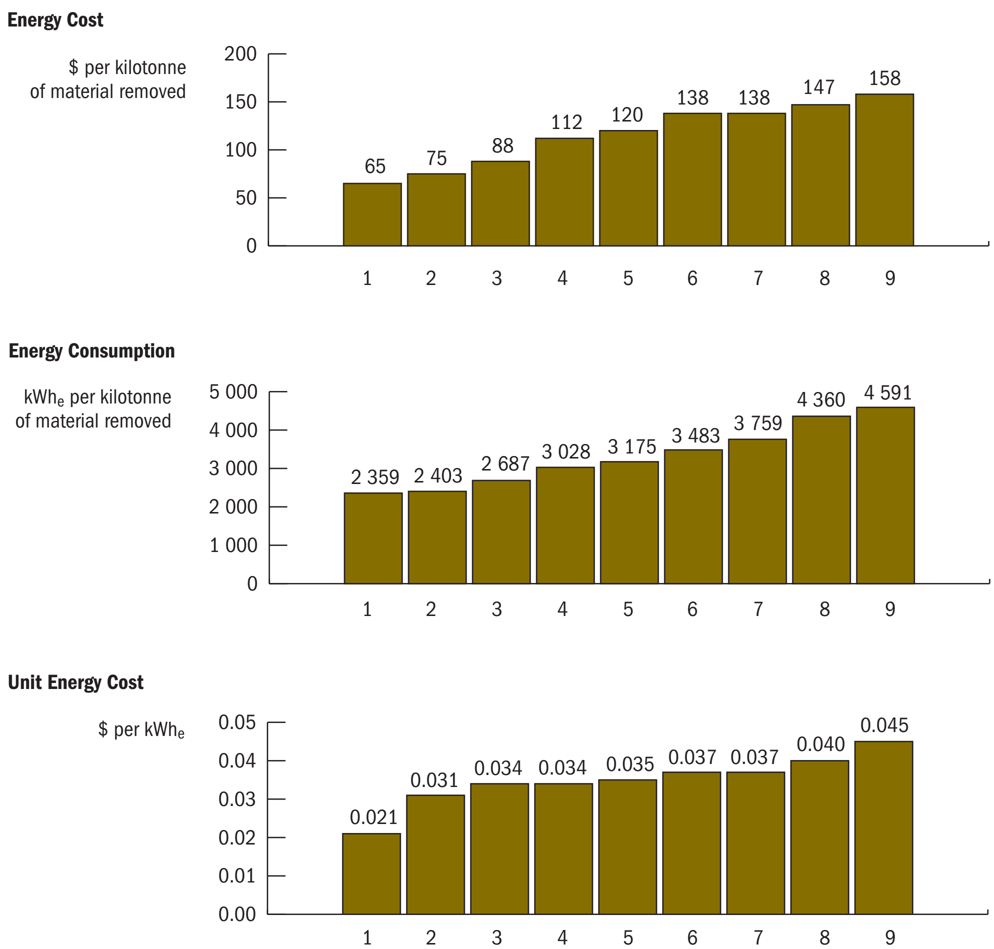


Hauling

The energy costs for hauling material from the pit to the crusher, stockpile or dump varied from $65 to $158 per kilotonne of material removed (ore plus waste rock). The range of costs and efficiencies is as follows:

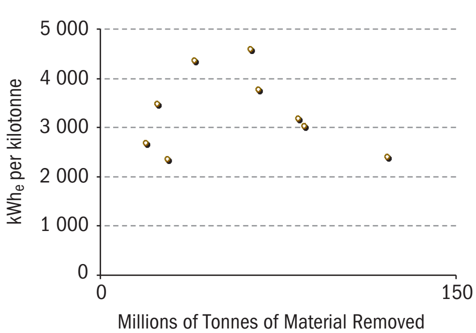
	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	158 : 65	243
Energy Consumption (kWh_e/kilotonne of material removed)	4 591 : 2 359	195
Unit Energy Cost ($/$kWh_e$)	0.045 : 0.021	208

Figure 3.24 – Transport/Hauling Energy Costs



Hauling is another mining operation that can generate economies of scale since the largest mines are more able to use very large trucks (over 200 tons). On the basis of the data illustrated in the figure below, however, the larger mines do not appear to be realizing any savings in energy consumption per kilotonne of material removed compared with the smaller open-pit mines in the study.

Figure 3.25 – Economies of Scale: Hauling

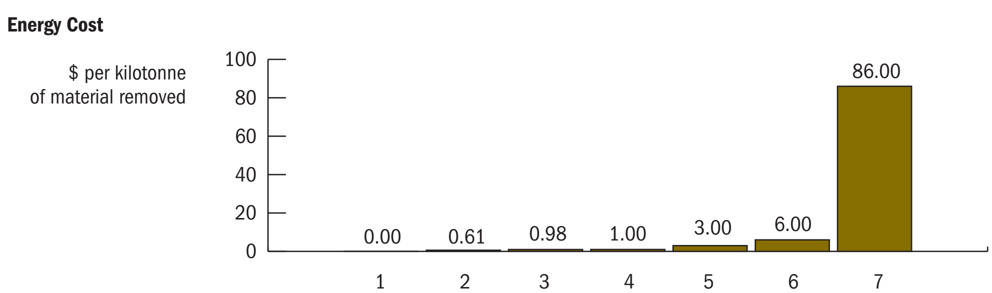


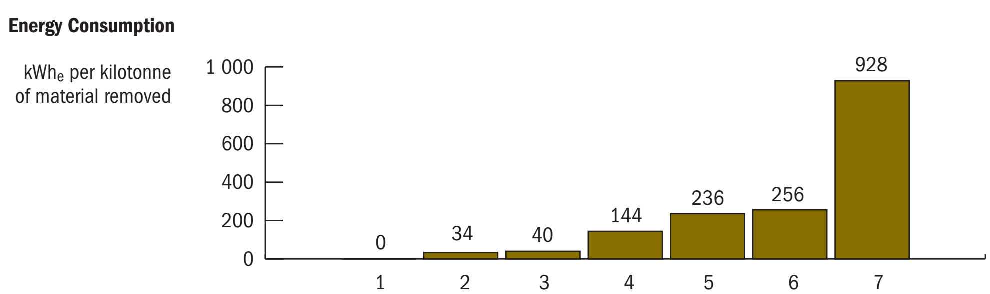
Mine Dewatering

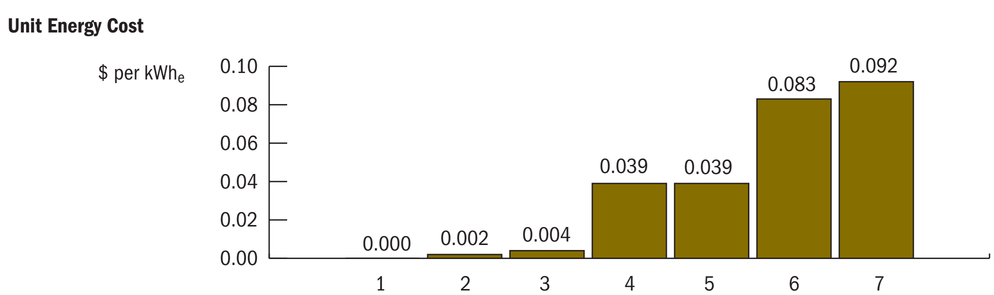
The energy costs for mine dewatering varied from $0.00 to $86.00 per kilotonne of material removed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	86.00 : 0.00	n/a
Energy Consumption (kWh_e/kilotonne of material removed)	928 : 0	n/a
Unit Energy Cost ($/$kWh_e$)	0.002 : 0.000	n/a

Figure 3.26 – Mine Dewatering Energy Costs





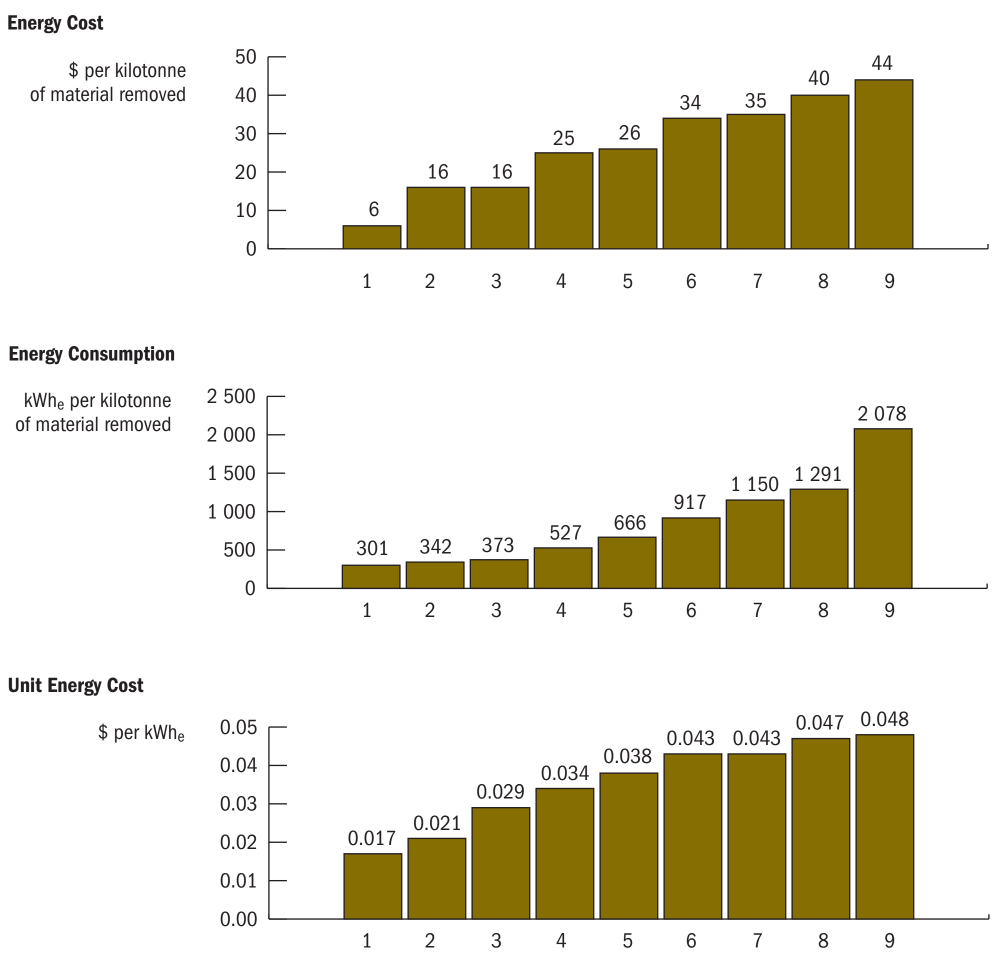


Mine Support Equipment and Services[2]

The energy costs for various mine support equipment and services ranged from $6 to $44 per kilotonne of material removed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	44 : 6	684
Energy Consumption (kWh_e/kilotonne of material removed)	2 078 : 301	691
Unit Energy Cost ($/$kWh_e$)	0.048 : 0.017	288

Figure 3.27 – Mine Support Equipment and Services Energy Costs



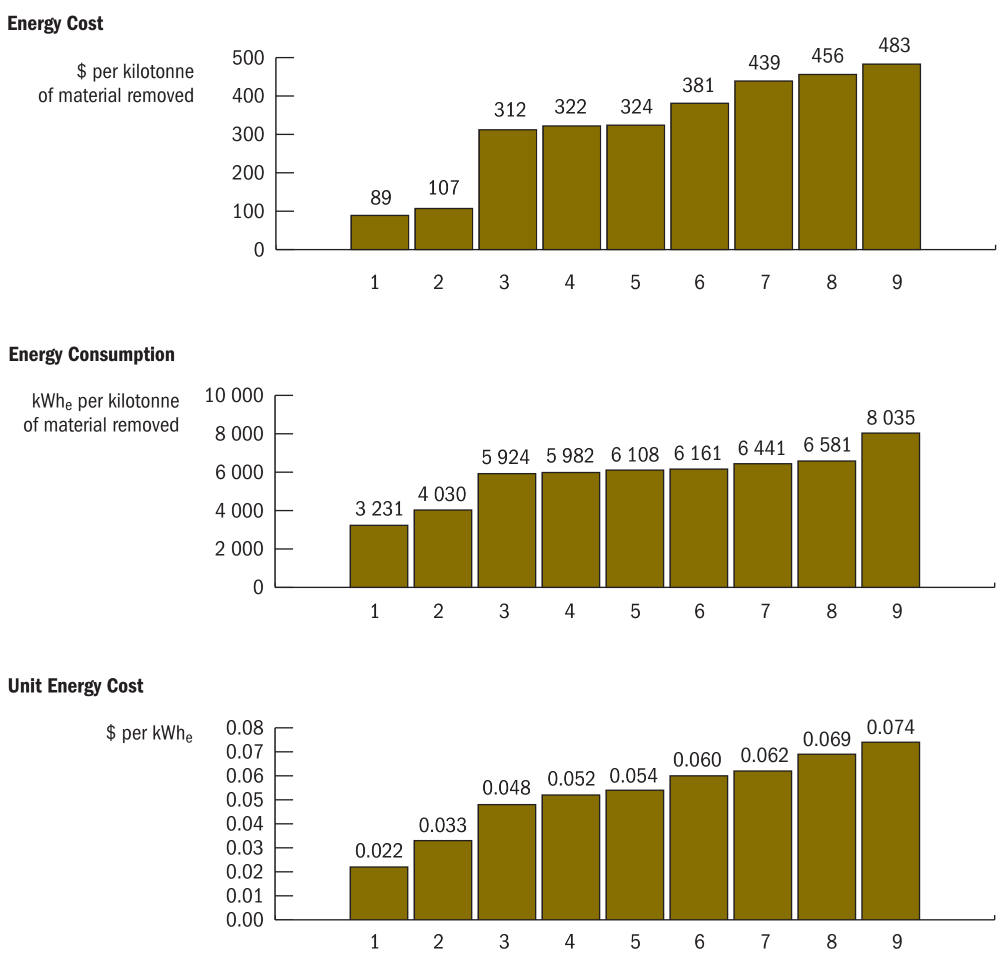
2 This category includes energy consumption reported by participants for Mine Support Equipment, Road Maintenance and Service Equipment and Facilities.

Total Mining Costs per Kilotonne Removed

The total energy costs for mining operations ranged from $89 to $483 per kilotonne of material removed. The range of costs and efficiencies is as follows:

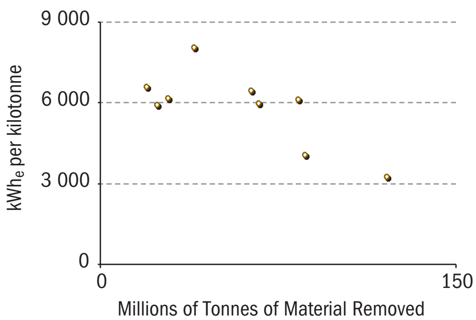
	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of material removed)	483 : 89	510
Energy Consumption (kWh_e/kilotonne of material removed)	8 035 : 3 231	249
Unit Energy Cost ($/$kWh_e$)	0.074 : 0.022	334

Figure 3.28 – Total Mining Costs



The effect of economies of scale on the energy consumption in total mining operations within the nine mines in the study is shown in the figure below. The two largest operations, the oil sands operations, which have no drilling or blasting operations, recorded the lowest energy consumption per kilotonne of material removed. There was, however, little evidence of any economies of scale for energy consumption among the seven "hard rock" open-pit mines in the study.

Figure 3.29 – Economies of Scale: Total Mining Energy



3.4 Inter-Mine Comparative Energy Costs – Mill/Concentrator Operations

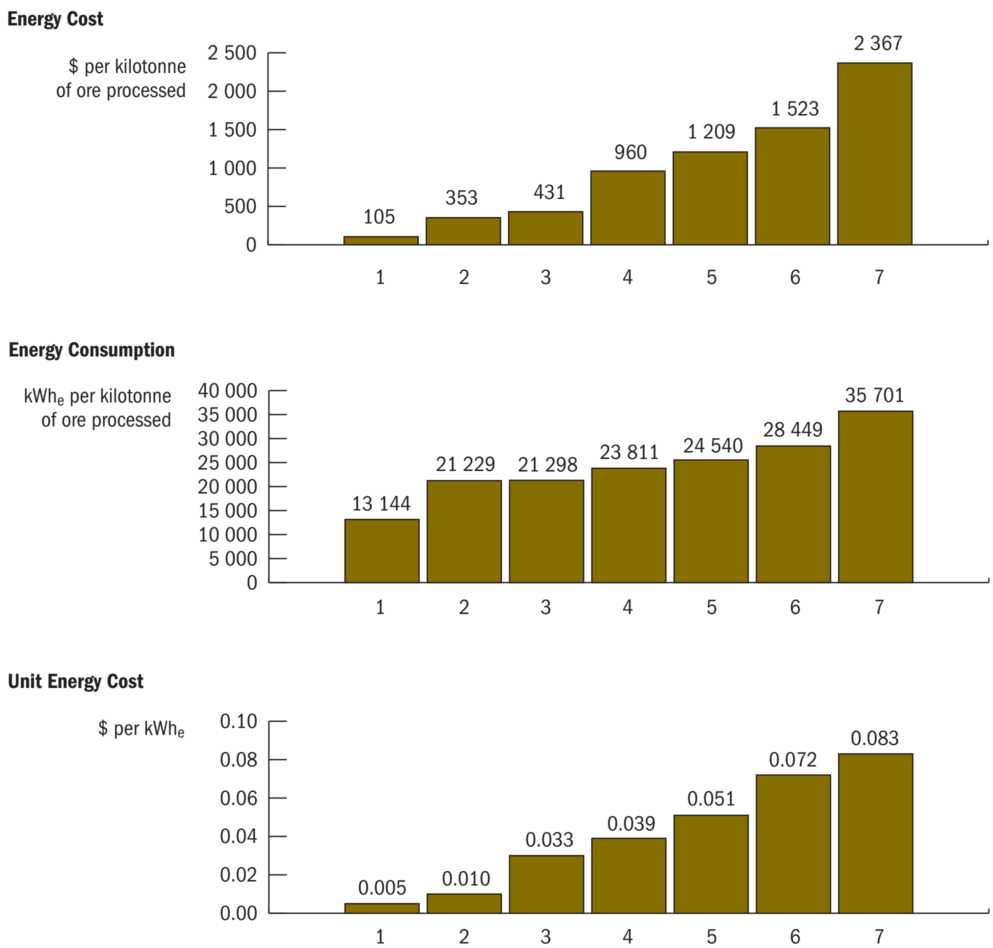
3.4.1 Total Mill/Concentrator Operations

The total energy costs for open-pit mining for seven operations are shown below. As illustrated, the energy costs vary from $105 per kilotonne of ore processed to $2,367 per kilotonne. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	2 367 : 105	2 254
Energy Consumption (kWh$_e$/kilotonne of ore processed)	35 701 : 13 144	272
Unit Energy Cost ($/kWh$_e$)	0.083 : 0.005	1 681

The total costs shown here cover crushing, grinding, all other concentration, extraction and recovery operations, tailings treatment, process water supply, and other plant energy. Any in-pit crushing has been included with the primary crushing operations at the mill.

Figure 3.30 – Total Energy Costs: Mill/Concentrator Operations



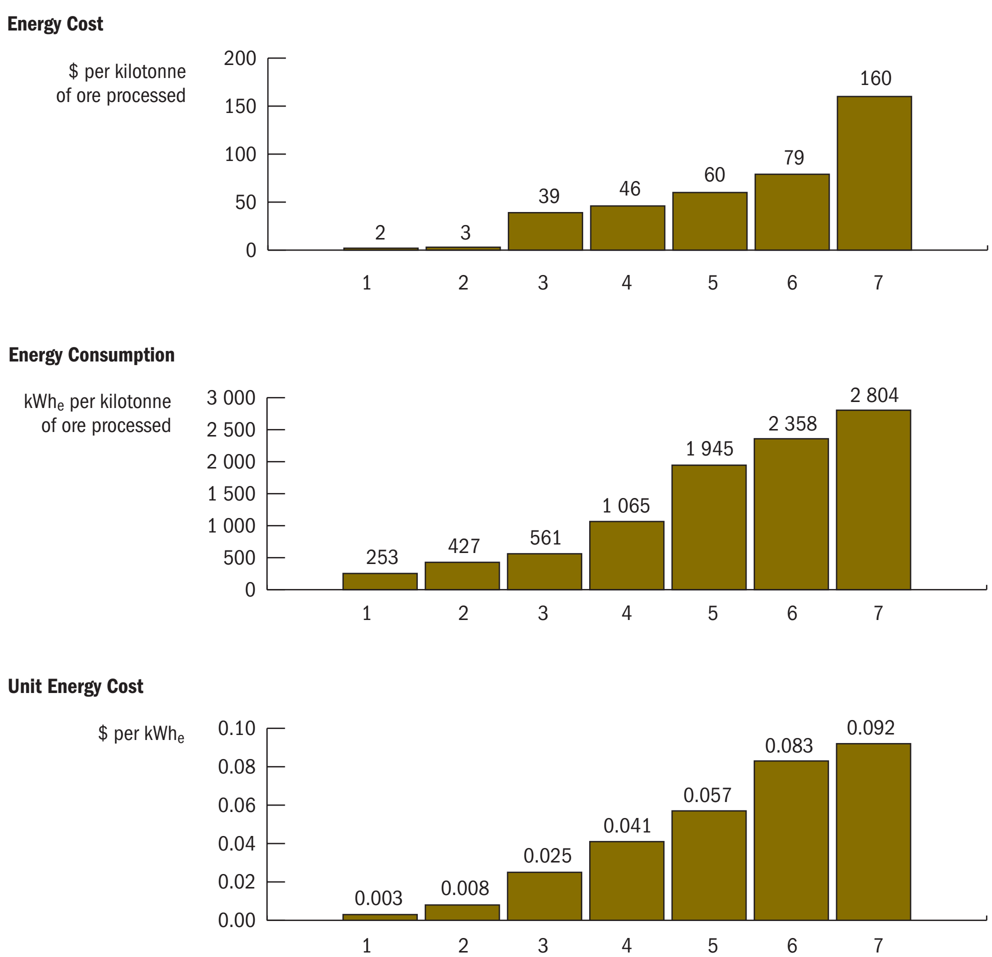
3.4.2 Mill/Concentrator Operations – Stages of Production

Crushing

Energy costs for crushing ore varied from $2 to $160 per kilotonne of ore processed for seven operations. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	160 : 2	8 126
Energy Consumption (kWh_e/kilotonne of ore processed)	2 804 : 253	1 110
Unit Energy Cost ($/$kWh_e$)	0.092 : 0.003	2 957

Figure 3.31 – Crushing Energy Costs

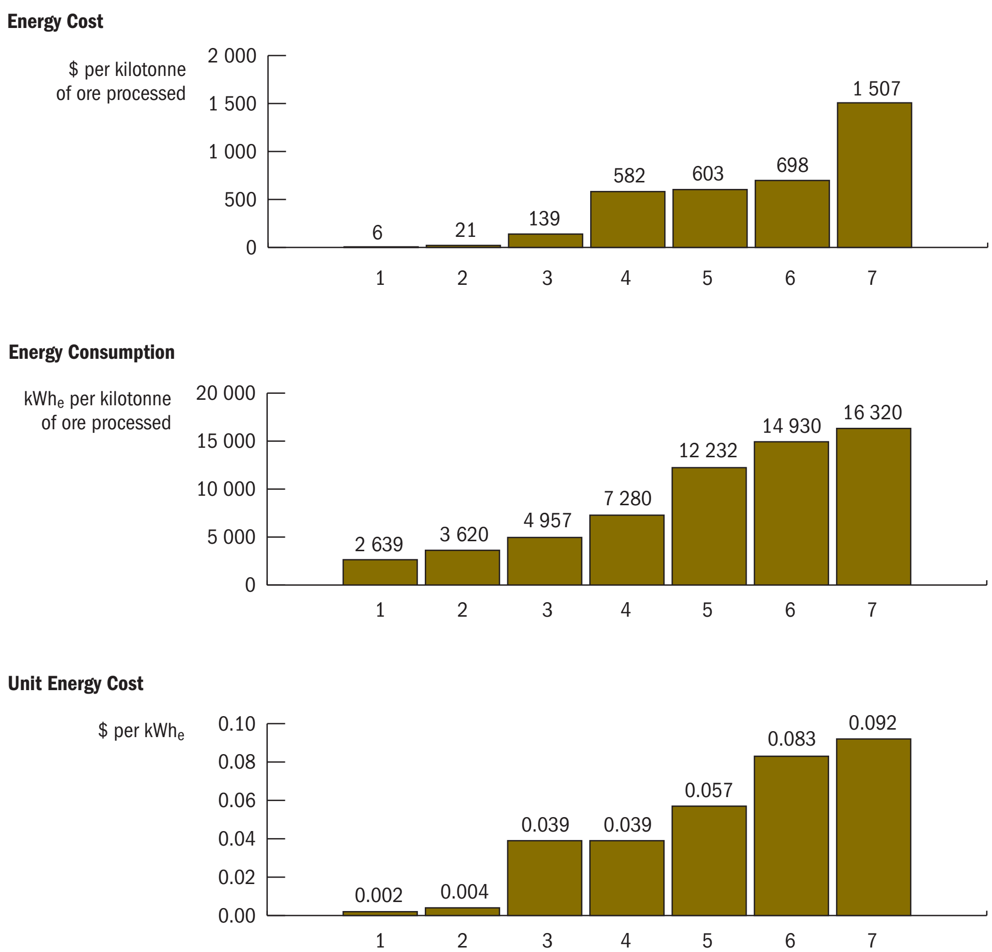


Grinding

Energy costs for grinding ore varied from $6 to $1,507 per kilotonne of ore processed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	1 507 : 6	23 815
Energy Consumption (kWh_e/kilotonne of ore processed)	16 320 : 2 639	619
Unit Energy Cost ($/$kWh_e$)	0.092 : 0.002	3 849

Figure 3.32 – Grinding Energy Costs

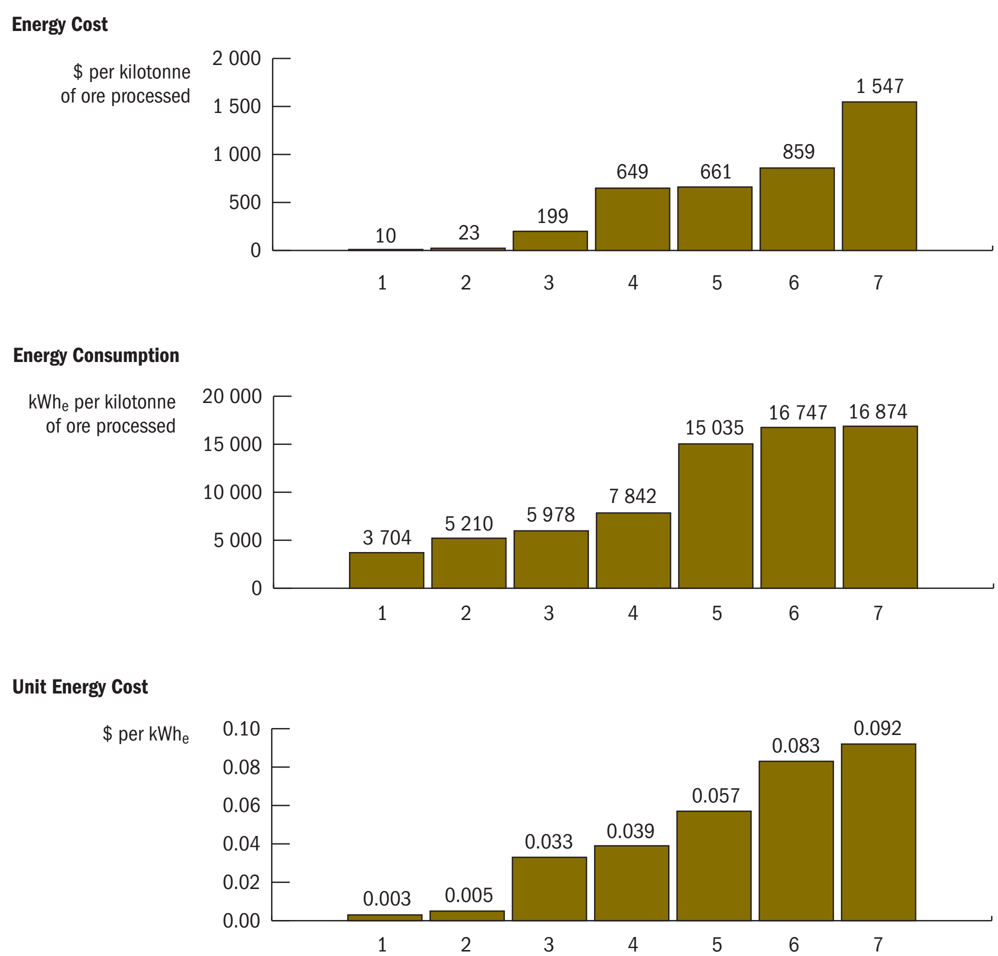


Crushing and Grinding Combined

Energy costs for crushing and grinding combined varied from $10 to $1,547 per kilotonne of ore processed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	1 547 : 10	16 014
Energy Consumption (kWh_e/kilotonne of ore processed)	16 874 : 3 704	456
Unit Energy Cost ($/$kWh_e$)	0.092 : 0.003	3 539

Figure 3.33 – Crushing and Grinding Energy Costs

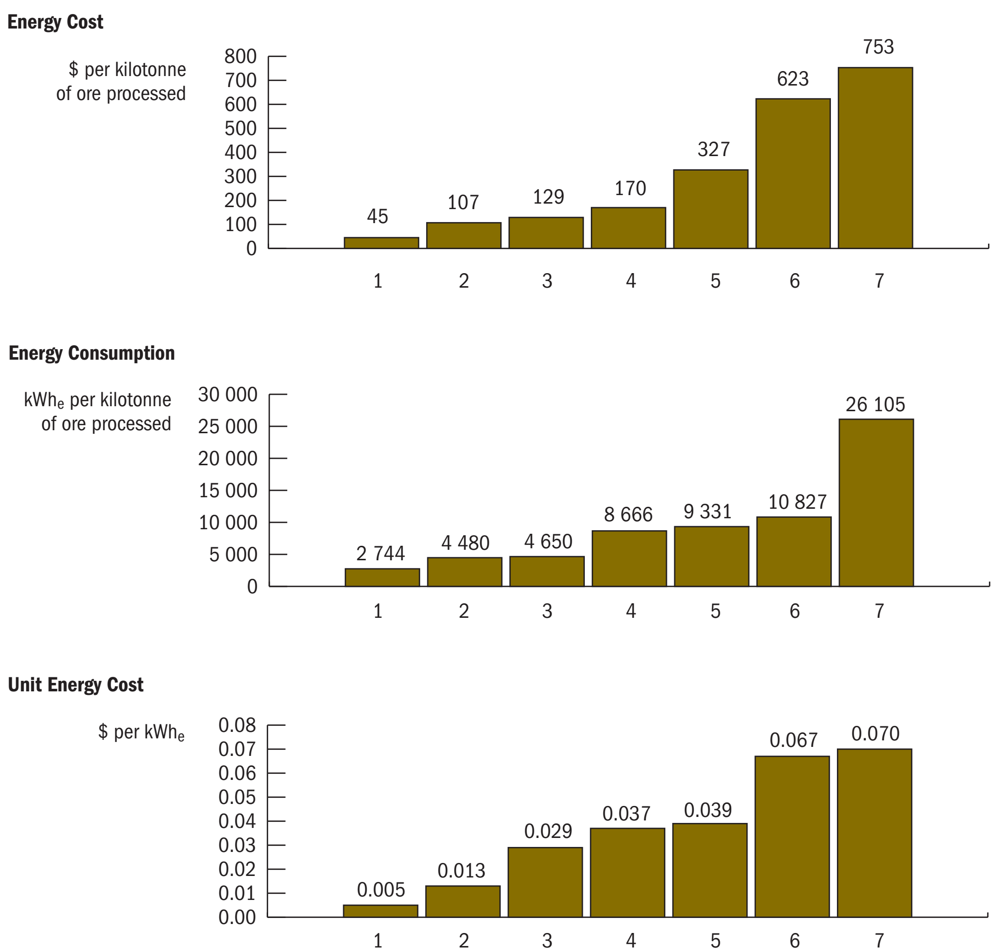


All Other Mill/Concentrator

This category of mill/concentrator costs aggregates energy consumed in the separation, filtering and drying processes for iron ore mines, and included in the separation are carbon-in-leach (CIL) and carbon-in-column (CIC) circuits, stripping, electrowinning and refining operations at gold mines. These costs varied from $45 to $753 per kilotonne of ore processed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	753 : 45	1 668
Energy Consumption (kWh_e/kilotonne of ore processed)	26 105 : 2 744	951
Unit Energy Cost ($/$kWh_e$)	0.070 : 0.005	1 334

Figure 3.34 – Energy Costs: All Other Processing

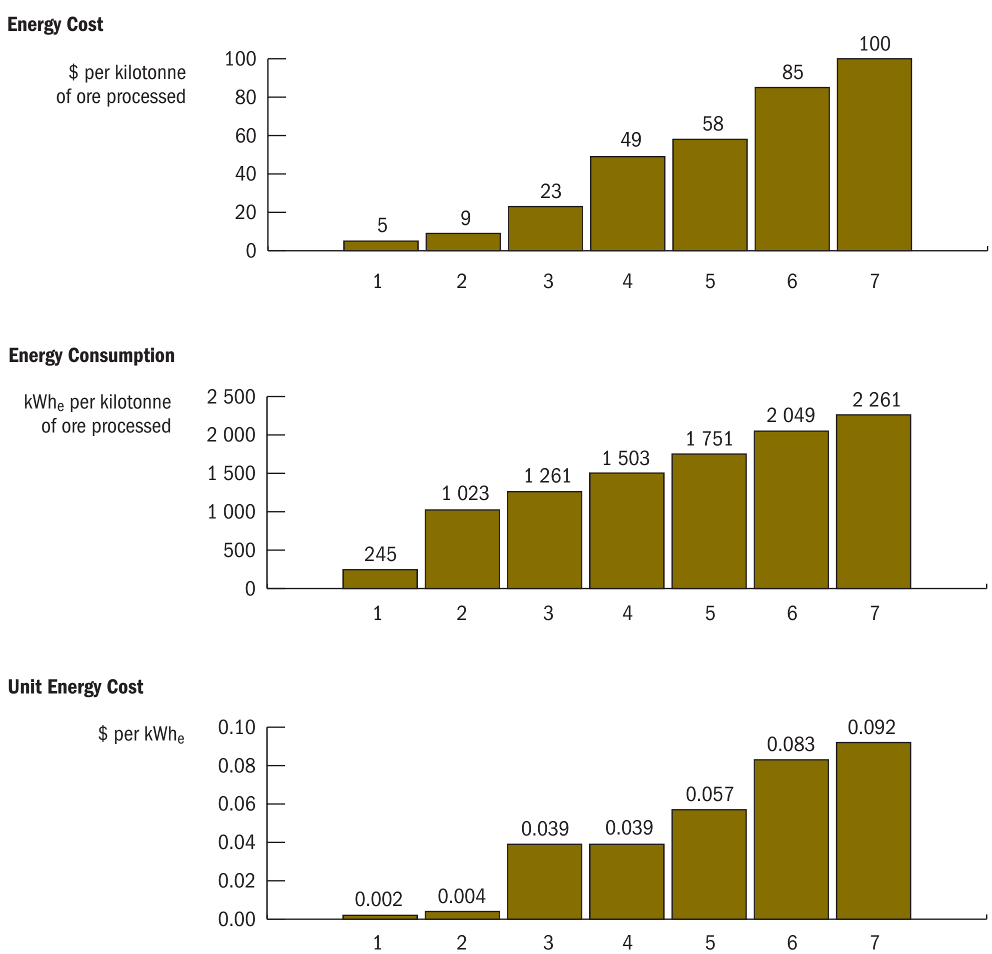


Tailings Treatment

Energy costs for tailings treatment varied from $5 to $100 per kilotonne of ore processed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	100 : 5	1 844
Energy Consumption (kWh_e/kilotonne of ore processed)	2 261 : 245	924
Unit Energy Cost ($/$kWh_e$)	0.092 : 0.002	3 849

Figure 3.35 – Energy Costs: Tailings Treatment

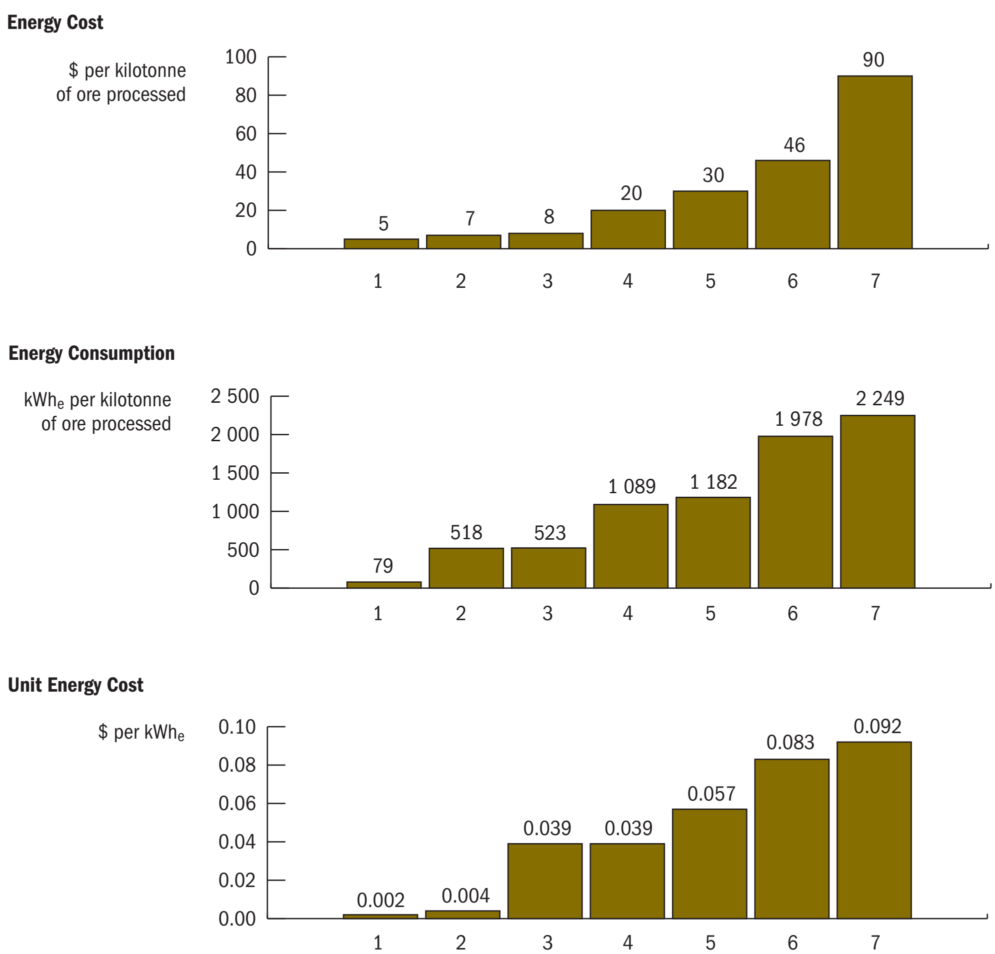


Process Water Supply

Energy costs for process water supply varied from \$5 to \$90 per kilotonne of ore processed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost (\$/kilotonne of ore processed)	90 : 5	1 671
Energy Consumption (kWh_e/kilotonne of ore processed)	2 249 : 79	2 864
Unit Energy Cost (\$/kWh_e)	0.092 : 0.002	3 849

Figure 3.36 – Process Water Supply Energy Costs

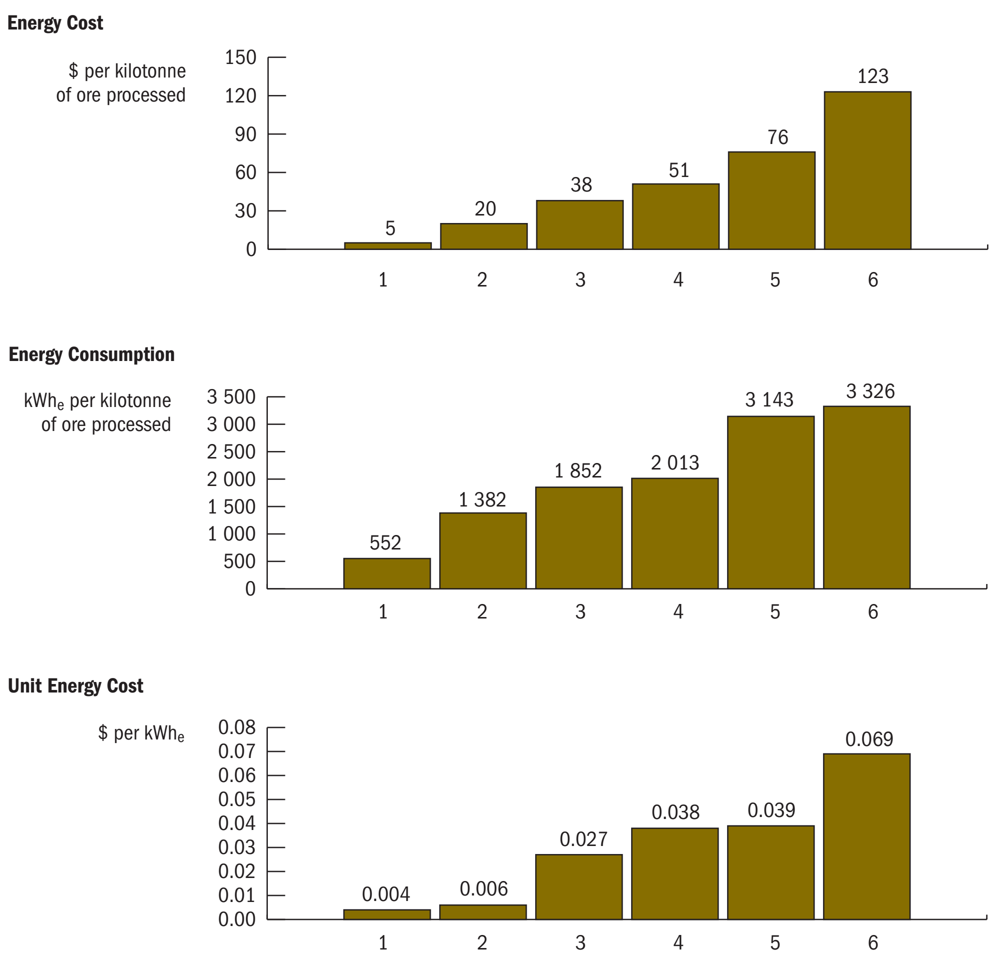


Other Plant Energy

Other plant energy costs varied from $5 to $123 per kilotonne of ore processed. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore processed)	123 : 5	2 254
Energy Consumption (kWh$_e$/kilotonne of ore processed)	3 326 : 552	603
Unit Energy Cost ($/kWh$_e$)	0.069 : 0.004	1 745

Figure 3.37 – Other Plant Energy Costs



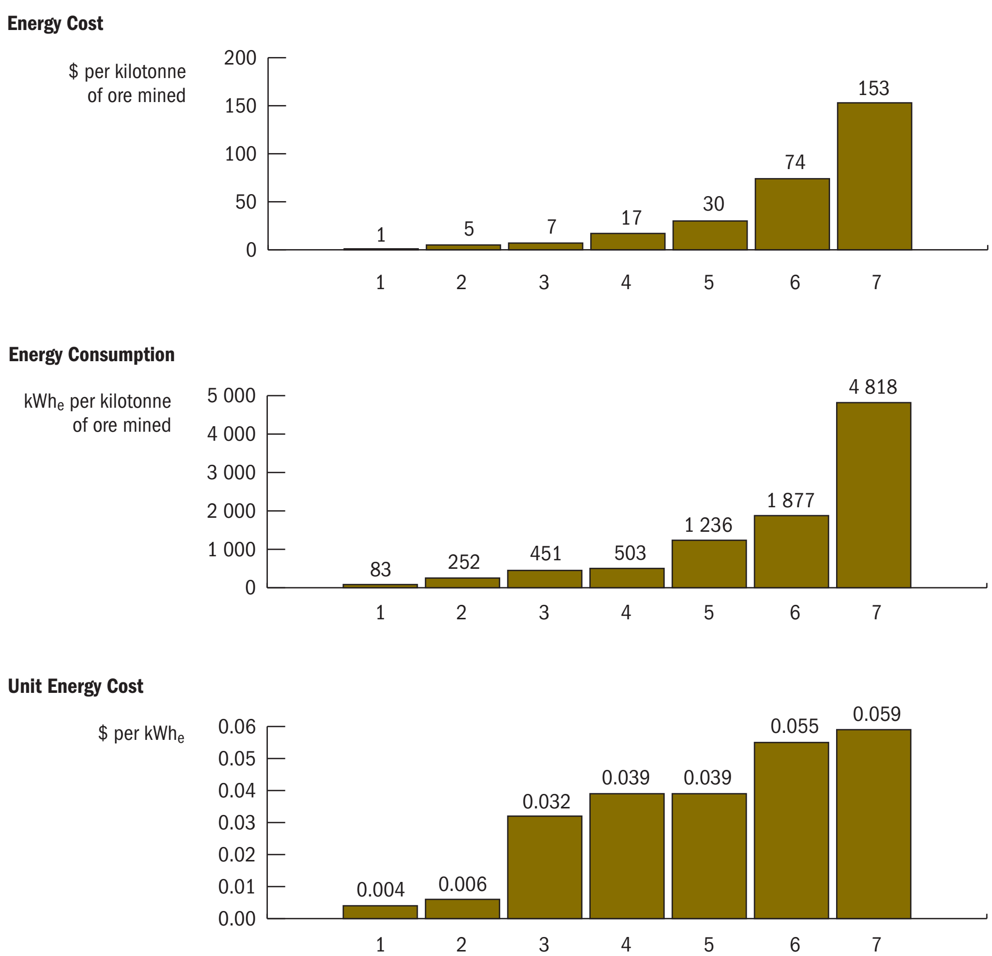
3.5 General and Administrative

The total energy costs for general and administrative operations for seven operations are shown below. As illustrated, the reported energy costs vary from $1 per kilotonne of ore mined to $153 per kilotonne. The range of costs and efficiencies is as follows:

	Range High : Low	High : Low Percent
Energy Cost ($/kilotonne of ore mined)	153 : 1	15 504
Energy Consumption (kWh_e/kilotonne of ore mined)	4 818 : 83	5 819
Unit Energy Cost ($/$kWh_e$)	0.059 : 0.004	1 503

The total costs shown here cover energy consumed in operating guardhouses, parking lots, assay laboratories, camps, etc.

Figure 3.38 – General and Administrative Energy Costs



4

POTENTIAL SAVINGS: ACHIEVING BENCHMARK STANDARDS

4. POTENTIAL SAVINGS: ACHIEVING BENCHMARK STANDARDS

4.1 Context

In this section, we present some general estimates of potential energy savings from attaining the performance of the most energy-efficient operations. To determine the related potential cost savings, we used weighted average costs for each source of energy.

It should be noted, however, that the potential savings identified may not be realizable for a number of practical reasons. For example, savings may be related to economies of scale or the nature of the ore body, or customer requirements may dictate the use of a particular technology precluding the use of a more energy-efficient technology.

At the same time, there may be some offsetting arguments regarding the size of the potential savings when considering the following:

- There are opportunities for improvement in the lowest-cost, most efficient facilities. The fact that different firms lead in different stages of production provides even more evidence of the potential.
- There could be operations outside the study sample that have lower-cost, more efficient operations.

In light of the above observations, we present below a simplistic estimate of the potential savings achievable if each participant were to attain the most efficient level of energy consumption for each stage of production, using average energy source prices.

4.2 Potential Energy Savings: Mining

Mining Operations (Material Removed)

	Weighted Average kWh_e	Lowest kWh_e/kt	Savings kWh_e/kt	Average $/$kWh_e$	Total kt	Total Savings ($M)
Drilling	291	55	236	0.031	326	2.4
Blasting	448	284	104	0.034	326	18.2
Loading	707	389	318	0.036	533	6.1
Transport	3 258	2 359	899	0.033	533	15.8
Support	704	301	403	0.032	533	6.9
Total						**49.4 (36%)**

With respect to mining operations, potential identified energy savings represent a cost saving of about $49 million, or approximately 36 percent.

4.3 Potential Energy Savings: Milling

Iron Ore Concentration

	Weighted Average kWh_e	Lowest kWh_e/kt	Savings kWh_e/kt	Average $/$kWh_e$	Total kt	Total Savings ($M)
Crushing	1 282	253	1 029	0.021	95 018	2.0
Grinding	3 983	2 639	1 344	0.017	95 018	2.2
Further Processing	10 008	4 480	5 528	0.013	95 018	6.8
Tailings	1 857	1 503	354	0.015	95 018	0.5
Process Water	1 692	1 182	510	0.014	95 018	0.7
Other	2 730	1 382	1 348	0.006	55 101	0.4
Total						**12.7 (47%)**

With respect to iron ore concentration operations, potential energy savings identified are about $13 million, or approximately 47 percent.

Gold Milling

	Weighted Average kWh_e	Lowest kWh_e/kt	Savings kWh_e/kt	Average \$/kWh_e	Total kt	Total Savings (\$M)
Crushing	1 549	427	1 122	0.054	15 783	1.0
Grinding	13 009	7 280	5 729	0.063	15 783	5.7
Further Processing	6 248	2 744	3 504	0.058	15 783	3.2
Tailings	1 131	245	886	0.057	15 783	0.8
Process Water	538	79	459	0.063	15 783	0.5
Other	2 029	552	1 477	0.038	15 783	0.9
Total						**11.9 (53%)**

With respect to gold milling operations, potential energy savings identified are in the order of $12 million, or approximately 53 percent.

To sum up, potential annual energy savings identified with the most efficient operation for each production stage as the benchmark are about $74 million (about one third of total energy costs), as applied to the nine study participants.

On a cautionary note, we should point out that these savings are hypothetical and may not be achievable owing to circumstances faced by each mine, i.e. the nature of the ore body, technology employed, long-term contractual obligations, etc.