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Energy Consumption in Mining Comminution

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Abstract

The supply chain for metals used in manufacturing is usually from premanufacture (mining). Energy impact needs to be considered, with it being one of the five stressors that impact the environment. In this paper the energy needs for crushing and milling (comminution) are presented. A brief comparison is made with the energy needs for recycling of large scale waste products such as automobiles. A simple method for product designers, which uses Streamlined Life Cycle Analysis, is proposed for assessment of mining value chain impacts.

Keywords:
Energy; Mining; Crushing; Comminution

1. Introduction

This paper is about energy consumption by comminution in mining and assessing its environmental impacts with an SLCA, Streamlined Life Cycle Analysis. The intention is to provide designers with a brief review of comminution, the energy used, and how to use SLCA to assess its impacts. Product designers do not have this information immediately available and this paper intends to meet that need.

In SLCA, premanufacture is a euphemism used to describe the life cycle stage, stage 1, prior to manufacture, stage 2. Mining will be used in this paper, with the understanding that it is premanufacture stage 1.

When dealing with environmental concerns, it is useful to revisit the four anthropocentric, environmental "Grand Objectives": 1) Human species extinction, 2) Sustainable development, 3) Biodiversity, 4) Aesthetic richness [1, 2].

Specific details about each of these, *with material supply chain concerns italicized*, are: 1) *Minimize environmental toxicity*, provide basic needs, food, water, shelter; 2) Energy supply (sustainable), *availability of material resources and recyclability*, political stability; 3) *Maintain natural areas*, maximize biological diversity (ie: avoid monocultural vegetation); 4) *Control of wastes, minimize emissions, minimize dumping, minimize degradation of physical geography*, avoid land overuse. This list was made up in 2001 [1, 2] has withstood the test of time and is still applicable.

1.1 Assessing Environmental Impacts

The most detailed way of assessing environmental impacts is by doing a complete Life Cycle Assessment (LCA) [3, 4, 5, 6]. If done properly, an LCA will consume years to complete. Norgate et al [6] consider gross energy requirements for mining specific metals, but do not look at a method for looking at a specific mine energy requirements. An SLCA, Streamlined Life Cycle Assessment [2], is recognized as a reasonable method of assessing impacts, having a shorter time span for completion. SLCA will be used in this paper. SLCA does not appear to have been used specifically for mining before.

The five Life Cycle stages [2] are *Premanufacture (mining or recycling), Manufacture, Transportation, Use, and End-of-Life*. For this paper, *premanufacture (mining)* is the stage of concern. The environmental stressors are: *Materials, Energy, Solids, Liquids and Gases*. For this paper *energy* is of concern. Combining the stages and stressors gives a 25 cell matrix, with cells 1,1 to 1,5 being those of concern to mining. There are five 25 cell Environmental Responsible (ER) matrices: product (ERP), process (ERP), facility (ERF), service (ERS) and infrastructure

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(ERI). Weightings can applied to each matrix cell and also to each RR matrix. Each matrix cell is given a rating from 0 (poor) to 4 (very good), where 100 is an excellent score for a matrix. For example for a Facility (ERF) matrix, at the mining stage, with *energy as a stressor*, cell 1,2, the choices for assessment are [2]:

- Rate 0, for a complete new energy infrastructure installation;
- Rate 4, for non-modified, existing energy infrastructure. This assumes the existing energy infrastructure is at the lowest impact, most efficient level;

An assigned rating of 1, 2, 3, depends upon the degree to which the infrastructure meets *design for environment* preferences.

- The energy infrastructure site avoids emission impacts upon surrounding biota, rate 3;
- The energy infrastructure can be made operational with minimal energy expenditure, rate 2;
- The energy infrastructure enables delivery and installation of construction with minimal energy use, rate 1.

More examples are given in section 6.

Material use is also of concern, but is not discussed here. However, the designer must be cognizant of potential resource scarcity of metals such as lithium, indium and rare earths. Graedel [7] states: “determining criticality is a complex and sometimes contentious challenge”. What is missing in the discussion on material criticality, is an understanding of mining with respect to all three pillars of sustainability.

To be able to assess mining impacts basic knowledge if the process is needed, hence the following information about mining is included.

2. Mining

Mining is the first link in the supply chain for metals in manufacturing. Material in the supply chain is either from recycled material or mining, with *100% recycled material being the ideal optimum* (called a circular economy) thereby circumventing mining and reducing environmental impacts. However, it will be a long time before we live in a circular economy (total recycling), so we must ensure minimum impacts due to mining. Ultimately mining is concerned with: Percent metal present in the ore; Refining, or removing impurities or unwanted elements; Slag, waste matter separated from metals during smelting or refining; Flux, inorganic material that separates metal from unwanted material.

The flow charts for base metals in the mining supply chain and the value chain for raw materials are both shown schematically in figure 1 [8, 9]. Metal concentration, specifically processing and refining, comes immediately after the extraction process as shown in figure 1.

In the mined material supply chain, ore concentration is the process whereby the mineral being mined is separated from mineral bearing rock, either chemically or physically. Prior to this the ore must be crushed to a size suitable for grinding. Grinding is then done to produce fine particles which can be processed either chemically or physically.

Although this paper *concentrates on energy consumed in comminution (particle size reduction: crushing and grinding)*, the minimization of environmental toxicity or maintaining of natural resources is also directly and indirectly linked with the material supply chain, but is not discussed in this paper.

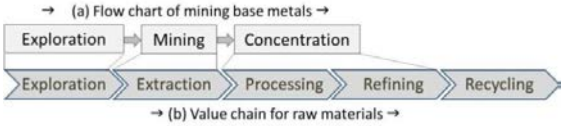

Figure 1. Flow charts and value chain for raw materials [8, 9].

2.1 Energy Consumption in Open Pit/ Underground Mines

There is a dearth of information about energy consumption specific to individual mines. One study [6], which is a collaboration that compares seven mine mill/concentrator operations: four gold and three iron ore mines. The average energy needed for seven mines is summarized in figure 2, where the energy requirement is broken down into six components: crushing, grinding, processing, tailings, process water, plant general (ancillary). Adding this energy to the average energy needed for an *open pit* mine, calculated as 11,766 kWh/kilotonne in [6], or the average energy needed for an *underground* mine, 10,241 kWh /kilotonne [4], the energy needs for an open pit with refining, will be ≈33,507 kWh/kilotonne [5].

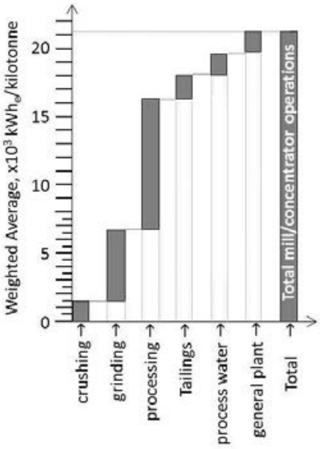

Figure 2. Average energy needs for mill/concentration operations [8].

Energy requirements for both open pit and underground mines include electricity and a variety of carbon fuels: natural gas, propane gas and diesel fuel [9]. Both open pit and underground operations are very different and have different energy needs, for instance, underground mines have HVAC energy needs, whereas open pit mines do not. Both mine types need pumps for water flowing in from the water table with pumps accounting for approximately 25% to 32% of total motor energy consumption on an average mine site. Globally it is estimated that all pumps consume 15% of available electricity. In addition, HVAC energy requirements can be at least 25% of underground mine energy needs [10].

Mining energy consumption contributes to mining operational costs and occurs at all stages of the ore recovery process: blasting, excavation, crushing, transport and grinding (comminution). For example, the copper mining industry is expected to consume 41.1 terawatt-hours (TWh) in 2025, an increase of 95.5 percent from 2013 [11]. New mining projects alone are predicted to consume 36.2 percent by 2025. The world’s biggest copper companies use concentration plants, which are energy intensive and use the world’s biggest pumps in their main production process. The distribution of energy at a mine site is 3 – 5% for blasting, 5 – 7% for crushing, and 80 - 90 % for grinding [10, 11].

Energy consumption occurs everywhere in the mining and manufacturing sectors. For relevance in energy consumption, table 1 compares energy consumption for certain parts of the mining sector with other global energy consumption.