# Table of Contents

## Summary

The ImpactMin demo site descriptions and background information are provided in report 3.1. Report 3.1 also contains information on: responsible mining, potential socio-economic impacts of mining, corporate social responsibility (CSR) in the mining industry, environmental and social regulations and standards that are used within the industry, in addition to providing a detailed socio-economic background of each of the demo sites used in this study. Report 3.2 presents the results of the comparative study across the seven ImpactMin demo sites, looking at what people think of mining and how mining has affected their lives. These findings provide information on what the socio-economic impacts of mining have been at each of the sites, including how mining companies develop social responsibility programmes, how they engage with different stakeholders and ultimately what the stakeholder perceptions are from people who have participated in the interviews and surveys.

The purpose of report 3.3 is to increase the understanding of what is being done in the mining industry to reduce its carbon footprint including demand reducing solutions, the potential for integrating renewable energy into mining technology and operations and offsetting.

This report comprises seven chapters: chapter 1 describes the drivers for reducing the carbon footprint in the mining industry, chapter 2 discusses minerals in Europe, chapter 3 mining technologies, chapter 4 carbon offsetting and trading, chapter 5 the case study of setting up a new mine in Rosia Montana and 6 discusses overall conclusions.

## Executive summary: Carbon footprint and the Mining Industry

There is now a consensus among the majority of scientists that anthropogenic climate change is a likely to produce significant changes which, ultimately, may severely affect the quality of life for humankind. Global temperature rise would result in global repercussions. The natural process of climate change has been magnified by human activity. This can be attributed to our enormous output of greenhouse gas (GHG) emissions. It is estimated that globally we produce 8 billion tonnes of $CO_2$ emissions each year (Heinzerling, 2010); nearly 22 million tonnes per day. If we are to maintain quality of life on our planet it will require a change in how we live, how we consume, and, specific to this report, how we produce our raw materials.

The phrase often proclaimed by the mining enthusiast to be , is irrefutable. Our world and lifestyles are irrevocably linked to mining and minerals. For example, the computer this report has been written on has necessitated the use of at least 66 minerals (NMA, 2006). These raw materials can be produced in an environmentally and socially responsible manner, thus preparing them for industries that take a responsible approach to manufacturing and consumption.

The mining industry is a major global energy user, making it one of the most significant GHG producers. The EU has set the goal of a 20% reduction in GHG emissions by 2020; if this is to be obtained carbon footprint reduction in the mining industry will play a crucial part.

The term carbon footprint is defined by the measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, event or productò (Carbontrust, 2010). A carbon footprint measurement considerers all the six of the Kyoto Protocols classified GHGs, this include:

¶ Carbon Dioxide ($CO_2$)
¶ Methane ($CH_4$)
¶ Nitrous Oxide ($N_2O$)
¶ Hydroflourocarbons (HFCs)
¶ Perfluorocarbons (PFCs)
¶ Sulphur Hexafluoride ($SF_6$)

$CO_2$ emissions were measured to Scope 2 requirements as defined by the GHG Protocol. There are three different scopes of GHG emissions, defined as:

¶ Scope 1: All direct GHG emissions.
¶ Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.
¶ Scope 3: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned

or controlled by the reporting entity, electricity-related activities (e.g. T and D losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

Whilst scope 3 emissions do have an impact they were emitted for two reasons. Firstly, they were beyond the scope of the data obtained from mining companies which would have made data collection extremely time consuming and inaccurate. Secondly they are beyond the immediate control of the mining operation. While the mine can, in many cases, choose the supplier of its goods, this is outside of the purpose of this report which will look at the GHG emission directly related to mining and how those can be reduced.

Overall, this report shows the growing need to reduce carbon emissions through energy reduction strategies. The increasing number of regulations and voluntary codes are discussed in chapter 1, such as the ISO 14000 environmental management system and the Kyoto Protocol and Copenhagen Accord. Chapter 2 deals with the European minerals market. Chapter 3 discusses in depth the possible solutions that are currently available to reduce carbon emissions, through evolving mining technologies such as: renewable energy initiatives that can be employed at mine sites, GHG reducing technology, methods of optimising mine site equipment and load and haul fleet technology and best practice. Chapter 4 details options for offsetting or trading carbon emissions using the case study of Roκia MontanŁ, Roma
Roκia MontanŁ, using it as a case study of be
emissions and energy consumption in establishing a new mine. This unique case takes a practical approach to discussing the best options available in the context of limitations at this specific site. Chapter 6 makes some overall conclusions and recommendations for further research.

**Figure list:**

**Table List:**

## Acknowledgements

This work would not have been possible without the kind assistance of a large number of people who we would like to thank, including: Professor Calin Baciu from the University of Babes-Boylai, Romania; Thomas Ejdemo, Professor Frauke Ecke and Dr Lena Alakangas from Lule¬ University of Techn Ivan Lovric, Professor Ivo Colak, Mirna Raiļ, Danijela M University of Mostar, Bosnia Herzegovina, Dr Valery Udachin, Dr Oleg Telenkov,Dr Pavel Aminov, Eugene Bazhenov and Ivan Startez from the Institute of Mineralogy, Miass, Russia; Dr Peter Whitbread-Abrutat from the Eden Project and Dr Matthias Varul from the University of Exeter. We would also like to thank Peter Gyuris the ImpactMin project coordinator and Jamie Keech for his Montan Ł. There are lots of other people across the 5 different sites who have supported the logistics of this work through various different ways, such as by helping translate and arrange the work schedule. We thank you all for your cooperation and assisstance with the project.

We would also like to acknowledge the support of the mining companies who helped in the research, including; Ro particular Mr Cecilia Szentesy Gold C and Adrian Minut; Western United Mines, Imerys, Boliden AB and other companies who kindly provided data .

# Chapter 1 Introduction

## 1.1 Aims of the project

ImpactMin Work Package 3 aims to create a better understanding of the socio-economic impacts of mining, investigating how we can develop corporate social responsibility policy that will incorporate and disseminate best practice within the industry. One of the reasons behind the ImpactMin WP3 work is the premise that in the future there will be a need to increase mining within Europe as a way of ensuring security of supply of mineral resources. One of the most urgent priorities of environmentally responsible industry is the reduction of carbon footprint and greenhouse gas emissions. Carbon emissions occur at all stages of the mining life cycle from exploration to closure. The purpose of this report is to explore the carbon footprint of mining projects throughout Europe and internationally. The focus will be on large scale mining operations, who produce the most significant carbon emissions, but also have the greatest means of leading the field in carbon footprint management.

## 1.2 Regulations

The information gathered within this chapter was based primarily upon the websites of mining companies, trade organisations, regulatory bodies, and governmental legislation. In addition to this a literary review of journal articles and related reports as well as interviews with industry professionals and academics were complied. Relevant guidelines were selected and reviewed based on their appropriateness to the minerals industry, their ability to address $CO_2$ related issues, as well as their popularity and ease of implementation. Guidelines that were considered narrow or limited to select portions of the industry were excluded in favour of examples that had wide ranging recognition and application. A particular focus was taken on regulations and legislature accepted and practiced with Britain the EU. Problems and areas of improvement within existing frameworks were identified and recommendations made where appropriate.

There is no single standard set to govern ñbest practiceò guidel footprint and $CO_2$ emissions in the mining industry. Al practicesò exist throughout governments have been fewer and initiatives in the mining industry. While legislation and metrics for acceptable levels of $CO_2$ emission do exist, they vary around the globe and lack detailed plans of action, recommendations, or standards specific to the mining industry about how it is expected to control and reduce its carbon footprint. Where best practice guidelines are being employed it is almost certainly due to the initiative of the company as opposed to any independent accrediting or governing body. Possible reasons for this include:

¶ The most energy intensive stage in producing a metal is often the extractions of the metals, via smelting or via hydrometallurgical prcesses rather than the mining and processing (Norgate and Haque, 2009). Figure 1 provides a graphical representation of the embodied energy of different metals. As can be seen the extraction process generally requires significantly more energy consumption than the mineral processing stages. These metal extraction processes make take place on site at the mine, or many thousand kilometres away at a separate plant. This graph does not account for the energy requirements involved in transport, manufacturing and packaging.

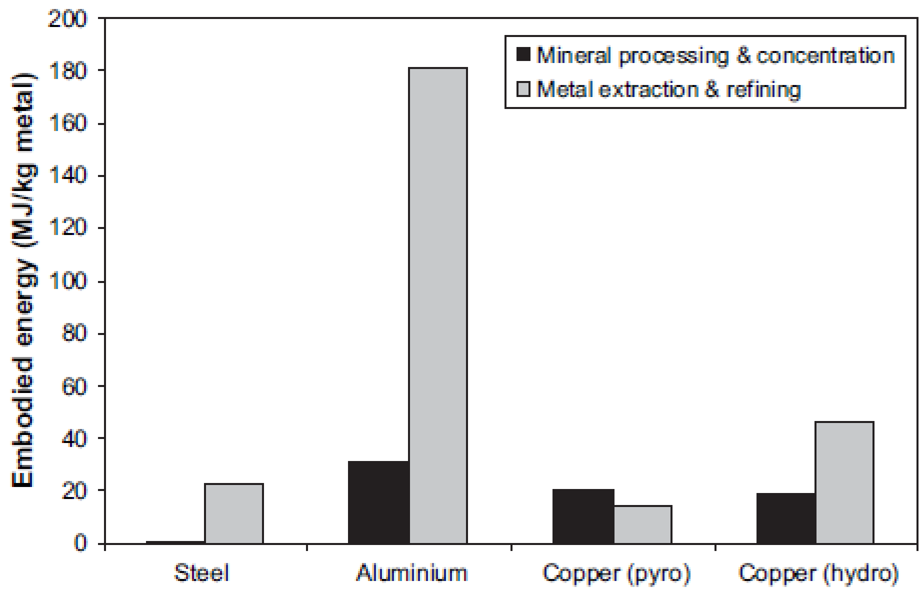



**Figure 1 Embodied energy in various metals (Norgate and Haque, 2009).**

- Another aspect is that mining often occurs in developing nations that lack the expertise and resources to develop and implement a reliable set of best practice guidelines. These countries are often more attractive to certain companies as their lack of environmental regulation can reduce the costs of operations. The host countries may be loath to lose this incentive to encourage mining companies.
- It is notoriously difficult to accurately and efficiently measure emissions as a result of mining and minerals processing. The fact that many emissions come from numerous sources which vary with terrain, time, and a host of other conditions, only adds to difficulties. For example, it would be both costly and time consuming to accurately measure the emissions of each blast at a mine.

Despite this, in the western world, particularly Canada, Australia, and the EU, there is an abundance of policy regarding carbon footprint, $CO_2$ emissions, and climate change.

### 1.2.1 IS0 14000

The International Standards Organisation (ISO) . ñs the worldôs large publisher of international standards. It consists of a network of the national standards institutes of 163 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system (ISO, About ISO, 2010)ò. ISO 14000 is the family of ISO standards that deals specifically with environmental management systems (EMS). According to the website the ISO 14000 system will provide users with a management tool able to:

- ¶ ñidentify and control the environmental impact of its activities, products or services, and to
- ¶ improve its environmental performance continually, and to
- ¶ implement a systematic approach to setting environmental objectives and targets, to achieving these and to demonstrating that they have been achieved ò (ISO, International Organisation for Standardization: 14000, 2010).

Unlike other standards and best practices mentioned in this report, the ISO 14000 system does not set specific standards and regulations, nor is it specific to mining or carbon footprint management. Rather the ISO 14000 system provides th for a holistic, strategic approach to the organisationôs environmental polic actionsò (ISO, International Organisation for Standardization: 14000, 2010). This in turn allows the organisation employing the ISO 14000 system to adapt it to their specific needs and industry standards and requirements. It allows an organisation to develop an EMS or set of best practices relevant to their industry.

The ISO 14000 family also lays out guidelines dealing specifically with carbon footprint quantification and greenhouse gas reduction strategies for affiliated organisations. Standards exist for a variety of carbon footprint related topics for example:

- ¶ ñ**ISO 14067** on the carbon footprint of products will provide requirements for the quantification and communication of greenhouse gases (GHGs) associated with products. The purpose of each part will be to: quantify the carbon footprint (Part 1); and harmonize methodologies for communicating the carbon footprint information and also provide guidance for this communicationò (Part 2) (ISO14000, 2009).
- ¶ ñ**ISO 14069** will provide guidance for organisations to calculate the carbon footprint of their products, services and supply chain ò (ISO14000, 2009).

The ISO 14000 guidelines provide a comprehensive and adaptable set of environmental management principals and are widely used within the mining industry for developing EMSs. One of their greatest strengths is their ability to be tailored to the specific needs of an organisation. ISO 14000 is able to adapt to external expectations such as regional environmental expectations, and internal objectives, whilst simultaneously ensuring that the organisation is conforming to international standards and is committed to continuous improvement (ISO14000, 2009).

Mining companies all over the world currently employ the ISO 14000 Environmental Management System. ISO 14000 compliant companies include: Barrick Gold, Teck, Rio Tinto, and BHP. As previously mentioned, the EMSs are tailored to the companiesô needs and the regulatory standards of the region. These may or may not include dealing with carbon footprint calculations and reduction, greenhouse gas emissions reduction and other environmental issues. That said, the aforementioned companies are organisations that have taken a proactive approach to GHG reductions and include GHG reduction in their EMS strategy (Rio Tinto, 2006).

### 1.2.2 European Emissions Trading Scheme (EU ETS)

The European Emissions Trading Scheme (EU ETS) was the first and is currently the largest multinational emissions trading scheme of carbon dioxide (Ellerman et al., 2007). Launched in 2005, the scheme aimed to reduce greenhouse gas (GHG) emissions by 21% from 2005 levels by 2020 (European Commission, 2010). The scheme has run for three periods, the first running from 2005 until 2007, the second from 2008 to 2012 and the third will run from 2013-2020. The EU ETS shares, in many respects, various similarities with the approach taken by the Kyoto Protocol, placing an obligation upon significant GHG contributors to record and inform a regulatory body of its emissions. In the example of the EU ETS, companies that emit significant amounts of carbon dioxide are obliged to monitor, annually report and inform their government of its emissions. Under the ETS, governments of the EU Member States initially agree upon national emission caps which are then subsequently passed down and reallocated to industrial operators. Companies that successfully fall within their allotted emissions limit have the opportunity to keep or sell the remaining emission allowance onto a company for profit. On the other hand, a company which surpasses its emissions allowance will be fined (Phylipsen, 2005).

Despite the similarities of the approach that is taken by the EU ETS and Kyoto, it is clear that the objectives of these two óschem
ETS, the ñcap and tradeò approach has establ
company appraisal of carbon trading, a resolution that is in stark contrast to the nation by nation included within the Kyoto Protocol. The obvious shortfall of the EU ETS is its consideration only of carbon dioxide emissions. This is clearly a major drawback given that approximately 17% of EU Member GHG emissions are not carbon dioxide (Phylipsen, 2005). Other greenhouse gases are effectively neglected from auditing however work is currently ongoing into the feasibility of including other greenhouse gases in EU ETS making up the LETS update study. In the first period ETS covers, for example power stations and factories making cement, glass, lime, bricks and ceramics. In 2008, the proposal was made to include aluminium and ammonia producers. In addition, the date for the inclusion of freight transport by road and mining is to be specified by 2013. The proposals were to exclude any of less than 35 MW installations and 25,000 tonnes of $CO_2$ equivalent of reported emissions in each of the preceding three years. In addition, carbon capture and storage projects are to be financed (OUZKħ, ).2008

### 1.2.3 Carbon Pollution Reduction Scheme (CRPS)

In 2008, the Australian Government released its proposal for a Carbon Pollution Reduction Scheme (CPRS) which was intended to serve as a cap-and-trade system for anthropogenic greenhouse gases ï a policy which was due to be introduced in 2010. The emissions covered represent around 75% of (Department of Climate Change and Energy Efficiency, 2010). Under this scheme, businesses and industries covered by the CPRS will need to surrender an emissions unit for each tonne of $CO_{2e}$ that they have emitted during the compliance period. The CPRS will include all greenhouse gases included under the Kyoto Protocol. The objective of this proposal initially targeted at coal mining companies, was to introduce a carbon tax on mining facilities that achieved a threshold of 25,000 tonnes of carbon dioxide per annum inclusive of emissions generated by transport and processing infrastructure. Additionally, coal mines will have to serve as proxies for domestic users of coal which fall below the 25,000 tonnes $CO_{2e}$ per year (Taberner, 2009). This scheme was intended to form part of Australiaôs long term commitment to emissions by 60 per cent compared with concentrations from 2000, a clearly ambitious target given that mining alone consumes appro energy consumption. The Australian government has committed to providing assistance to the coal mining sector through the Coal Sector Adjustment Scheme (CSAS) and the Coal Mining Abatement Fund. The CSAS assistance would be 60% of fugitive emissions and available to the coal mines that have fugitive emissions intensity (gassy coal mines) above a threshold of 0.1 tonnes of $CO_{2e}$ per tonne of saleable coal produced. For the latter fund, a quarter of the project cost would be granted for coal sector abatement projects and capital grants with a priority for electricity generation from waste coal mine gas (Department of Climate Change and Energy Efficiency, 2010). Since the measure and mitigation of the coal fugitive emissions technologies are still at the experimental stages. The Australian Coal Association noted that the major coal competing nations of Australia excluded and have yet to commit to applying the coal fugitive emissions pricing (Pegler, 2011).

## 1.3 Kyoto Protocol

One of the most significant and prolific attempts at controlling climate change and reducing greenhouse gases, on a global scale, is the Kyoto accord (UNFCCC, An Introduction to the Kyoto Protocol Compliance Mechanism, 2010). The stated objectives of the Kyoto accord are:

ñThe stabilisation of atmospheric concentrations of greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to (UN, United Nations n a su Framework Convention on Climate Change, 1997).

The Kyoto protocol set the target of reducing participating countries GHG emissions by an average of 5.2% per annum for five years (2008-2012) using the level of emissions produced in 1990 as a benchmark (UNFCCC, Kyoto Protocol, 2007). Thirty seven first world countries and the EU (referred to as Annex I countries) committed to meeting these targets. The emissions targets set by the Kyoto Protocol, unlike those in the Kyoto accord that merely recommended goals, are legally binding for all Annex I countries. The Kyoto Protocol was officially adopted on the December 11$^{th}$ 1997 and enforced as of February 16$^{th}$ 2005 (UNFCCC, Kyoto Protocol, 2007). Figure 2 is a map representing the countries which have signed the Kyoto Protocol as of June 2009. The countries coloured green have committed to the protocol, the grey countries are undecided, and the red countries do not indend to sign the treaty. (UNFCCC, An Introduction to the Kyoto Protocol Compliance Mechanism, 2010)

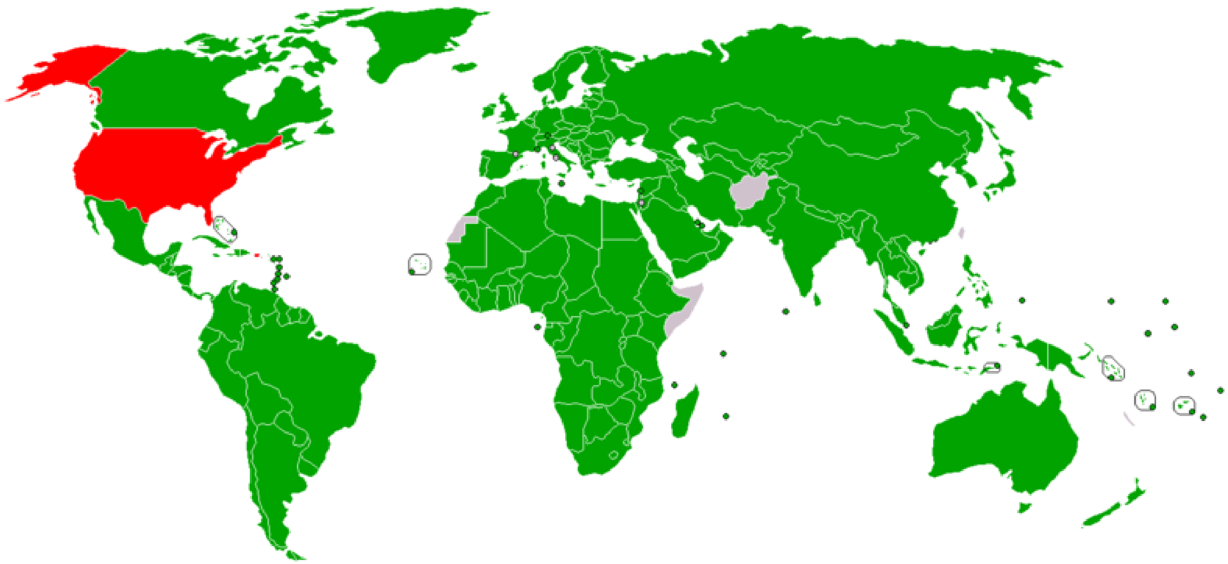


Figure 2 Kyoto protocol participation (UNFCCC, Kyoto Protocol, 2007).

The Kyoto Protocol affects the mining industry in that, like all industries in Annex I countries, it will have to reduce emissions over the five-year period in order to comply with the established targets. Table 1 lists the countries/regions with the top 10 GHG emissions.

Table 1 Ranking of the Worldôs to.p ten emitters (MNP, 2007)

| Rating | Country | Global % of GHG Emissions | Per-Capita Emissions (tonnes of GHG per-capita) |
|---|---|---|---|
| 1 | China | 17% | 5.8 |
| 2 | U.S.A | 16% | 21.1 |
| 3 | E.U. | 11% | 10.6 |
| 4 | Indonesia | 6% | 12.9 |
| 5 | India | 5% | 2.1 |
| 6 | Russia | 5% | 14.9 |
| 7 | Brazil | 4% | 10.0 |
| 8 | Japan | 3% | 10.6 |
| 9 | Canada | 2% | 23.2 |
| 10 | Mexico | 2% | 6.4 |

As can be seen from the above table many of these countries represent nations with major mining industries. The Kyoto Protocol will have an effect on all participating nations. Ensuring industry in those nations will be committed to reducing their carbon footprint. The mining industry is no exception to this.

## 1.4 Copenhagen Accord

The Copenhagen accord occurred on the 18th of December 2009 at the United Nations framework convention on climate change and is the attempt at a successor for the Kyoto protocol. However, unlike the Kyoto protocol, the Copenhagen accord is not a legally binding document; rather the participating countries agreed to take note of the recommendations laid out in the accord (Wynn, 2009). The convention had been considered widely unsuccessful by media and many countries, in fact the conference was found to have a larger carbon footprint than any climate change conference to date (Graham-Harrison, 2009).

Countries signed the accord with the ñintent
from 40% to 1.8% of their original 1990 emissions level (UN, Copenhagen Accord, 2009). The intention of the conference had been to start work on developing a successor to the Kyoto protocol which ends in 2012. In this respect the conference is considered to have been a failure. However the more generous reports state that the accord was at least successful in increasing the awareness of climate change issues and in taking illuminating the need for further work in this area (Black, 2010). Although the Kyoto Protocol will certainly affect the Carbon footprint and greenhouse gas emissions ñbest practicesò of the mining indu that the overall impact of
the Copenhagen Accord will be very significant at this time on the mining industry; given the uncommitted nature of the accord.

## 1.5 Life Cycle Assessment (LCA)

A life cycle assessment (LCA), also known as
14000 recommended tool used to assess the environmental and social impact of a product throughout its useful life; from its start as a raw material to disposal (ISO, International Organisation for Standardization: 14000, 2010). Mining is the first phase in the lifecycle of a material, and as such it is extremely important; it can often set a material on the path to be used responsibly throughout its lifecycle. In its efforts towards sustainability, the mining industry has used several environmental and economic indicators to assess its performance. In recent years, Life Cycle Assessment (LCA) has proved to be one of the most attractive approaches for this task. As such, it is an excellent tool that can be used to evaluate environmental performance and support decision-making in the mining industryò(Durucan *et al*., 2004).

The mining industry first began experimenting with the LCA approach in the mid 1990ôs
originally utilising Life Cycle Inventories (LCIôs) in
customers with design and choosing products (Durucan *et al*., 2004). Eventually LCAs began to be used in project and process selection with a strong focus on the processes occurring during concentration and refining. LCAs have been used with less frequency in the extraction phase of an operation (Stewart, 2001). The following is a list of examples where LCA applications are utilised within the mining industry:

- ñ Copper production from primary and second fabrication to semi-finished and final products ;
- Smelting of sulphide ores ;
- Gold, coal, base metals, platinum group metals, ferroalloys and beach sands production ;
- Aluminium ore extraction, smelting, transportation and energy use ;
- Mining, production, packing and shipping of boron products ;
- Various processing routes for nickel and copper production with emphasis on greenhouse and acid rain gas emissions ;
- Base metal refining and producing primary nickel; iron and steel processes ;
- Lead and zinc smelting;
- Uranium ore production;
- Aluminium and steel industry pr (Durucan, Korre and Munoz-Melendez, 2004).

Figure 3 shows a graphical representation of the different mining and refining processes that can be managed using LCA to minimise environmental and social impacts.

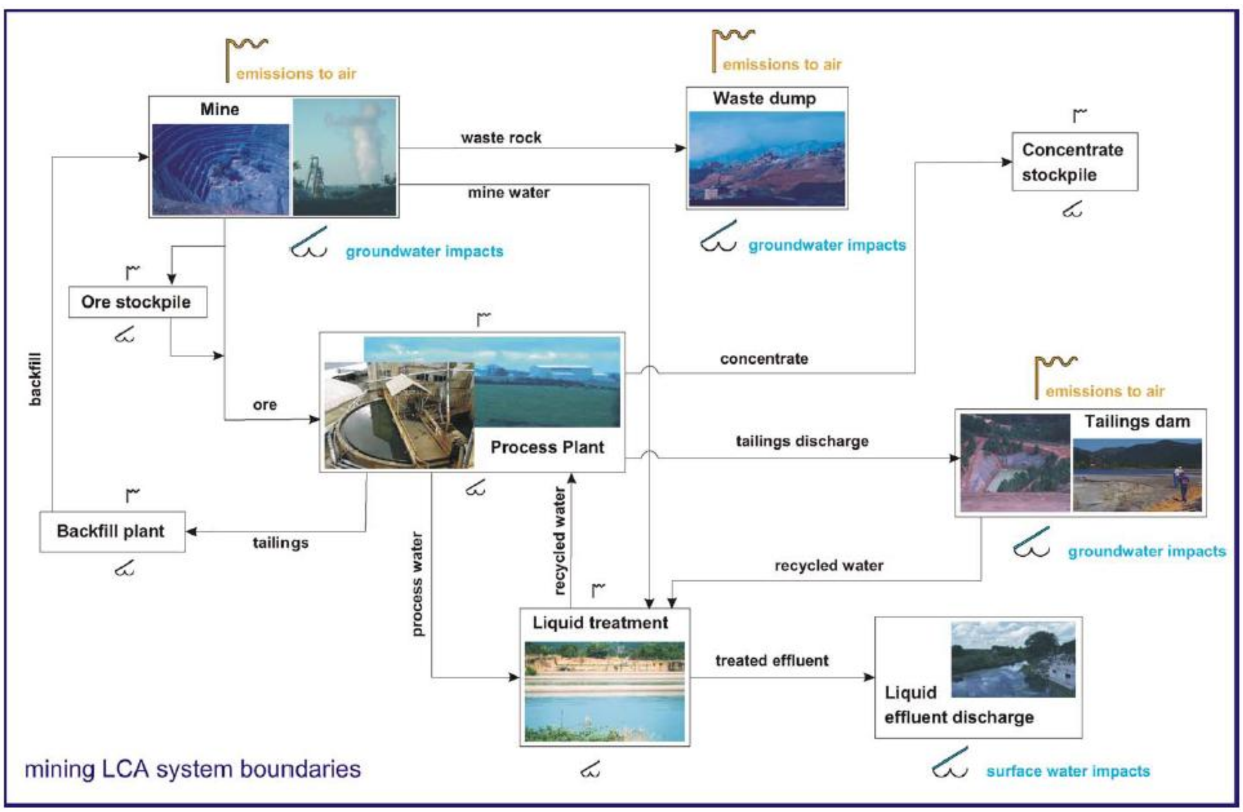



**Figure 3 Mining LCA assessment system and model boundaries (Durucan, Korre and Munoz-Melendez, 2004).**

Measuring the carbon footprint and $CO_2$ emissions is an important aspect of this process and is represented on the figure above by the smoke stack icon over the areas they apply. LCA helps a company material at the mine into de the a set of processes. These processes can then be broken down and analysed; working to develop the most environmentally and socially friendly method of completing the process. In the case of carbon footprint and greenhouse gas emissions, analysis of the processes can reveal inadequacies and inefficiencies, allowing the relevant processes to be adjusted to maximise efficiency and interact in a way that minimises the projectôs carbon footprint (Mudd, 2009).

## 1.6 Best Available Techniques (BATs)

Best available techniques, or BATs, are a concept defined as the ñmost effective advanced stage in the development of an activity and its methods of operation, which indicate the practical suitability of particular techniques for providing, in principle, the basis for emission limit values designed to prevent or eliminate or, where that is not practicable, generally to reduce an emission and its impact on the environment as a wholeò (EPA, Best Available Techniques Guidance Notes, 2010). This definition has been broken down further in Table 2.

Table 2 BATs breakdown (EPA, 2010).

| | |
|---|---|
| **B** | **óbestô** in relation to techniques, means the most effective in achieving a high general level of protection of the environment as a whole |
| **A** | **óavailable** means those techniques developed on a scale which allows implementation in the relevant class of activity under economically the technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced within the State, as long as they are reasonably accessible to the person carrying out the activity |
| **T** | **ótechniquesô** includes both the technology used and the way in which the installation is designed, built , managed, maintained, operated and decommissioned. |

The concepts of BATs was created by the European Integrated Pollution Prevention Control Bureau (IPPC) as part of their óDirective on Indus has been in place for over ten years, with the most recent version adopted on the 21st of December 2007 and coded as óDirective (IPPC) 2008/1/

2008). The purpose of this directive is to advise and encourage the exchange of information member states on standards and best practices regarding environmental management. This is accomplished through the use of BAT reference documents (BREFs) which are used to relay detailed information to members states regarding the BATs for ñspecific industrial s(s) in the (EIPPCB, 2010). The stated objectives of the BREFs are to:

- ñ Acomplish a comprehensive exchange of information and views and through the publication of reference documents to help to redress any technological imbalances in the European Community;
- Promote the worldwide dissemination of limit values and techniques used in the Community;
- Assist Member States in the efficient implementation of this Directive. (EPA, Best Available Techniques Guidance Notes, 2010)ò

An example of some of the BREFs relevant to the mining industry include: BREF on Non Ferrous Metals Processes; BREF for Mineral Oil and Gas Refineries; BREF for Surface Treatment of Metals and Plastics, and BREF for Management of Tailings and Waste-Rock in Mining activities (EIPPCB, 2010). Each of these documents contains recommendations and best practice strategies detailing how each process can be undertaken with a minimum environmental impact. This will include strategies on reducing carbon footprint and greenhouse gas output. In this manner the EU has employed BATs as a means of instituting standards and best practice guidelines throughout its member states.

## 1.7 The International Council on Mining and Metals (ICMM)

óThe international council on mining and metalsô(ICMM) was established in 2001 to act as a catalyst for performance improvementò(ICMM, 2010). It now consists of 19 mining and metal companies along with 30 mining ass the core sustainable development challenges faced by theò(mining industry (ICMM, 2010). Encompassed within this is a commitment to reducing the environmental impact of the mining industry; including carbon footprint. The ICMM strives to work with member companies within the mining industry t (the mining industry capacity to improve environmental performanceò(ICMM, 2010). ICMM aims to align the goals of mining companies with governments and local communities to work together to ensure mining is a mutually beneficial enterprise with limited negative impacts. Essentially ICMM works to create a framework, supported by some of the biggest mining companies, committed to carrying out exploration and mining activities in a sustainable and responsible manner. It also acts as a way of disseminating information within the industry and propagating and improving best practices. From outside of the industry, it acts as a catalyst of increasing awareness about the mining industry.

## 1.8 Discussion and Conclusions

It is clear that whilst there is no definitiv
relating to carbon footprint in the mining industry; there are an array of options and resources available to organisations to help control and manage their carbon footprint. While some provide emission limits and regulations, such as the Kyoto Protocol; others provide the guidelines and structure to create an internationally recognised environmental management system tailored to the needs of the organisation and demands of the stakeholders; such as ISO 14000 and BATs. As it stands the closest option to an international standard for best practices
an organisation with a framework to create an internationally certified EMS and a comprehensive set of best practice guidelines for its operations. In addition to this ISO 14000 is recognised and employed throughout numerous and varying industries and organisations; not simply the mining industry. The next step in the process is international legislation and best practices concerning carbon emission, and greenhouse gases with regard to the mining industry. Whilst it is unlikely that governments or the international community, such as the UN, will produce mining specific $CO_2$ regulations on a global scale, it is possible that trade organisations, such as the International Council on Mining and Metals may help to defin standards. Through organisations like the ICMM standards and best practices can obtain widespread acceptance and permeate throughout the industry. It is also essential for the major international senior mining companies (e.g. Barrick, BHP, Anglo American, Rio Tinto) to uphold these standards both in the countries with strict environmental standards and $CO_2$ emission regulations (Canada, Australia, the EU) and countries currently lacking the necessary infrastructure (DRC, Eastern Europe, South America). Only in this manner will carbon footprint reduction best practices develop and propagate in the mining industry and gain international acceptance and implementation.

# Chapter 2 Promising minerals in Europe

## 2.1 General Market

The market for minerals across the European Union requires careful assessment in order for the Member States to be best prepared for the future extraction and usage of its mineral resources. Owing to the move towards a more sustainable energy economy, this assessment must be balanced and challenge the traditional approach to resource issues. A 2010 report by the Commission sought to identify the importance and risks of 41 minerals and metals (European Commission, 2011a). Fourteen raw materials were considered critical for the EU, including: antimony, beryllium, cobalt, fluorspar, gallium, germanium, graphite, indium, magnesium, niobium, platinum group metals, rare earths, tantalum, and tungsten.

The trend away from heavy extraction in the industrialised nations towards the Global South has garnered the much attention lately. Key industries in the EU economy, including aerospace, automotive, chemicals, construction, information technology, and telecommunications, are all heavily dependent upon raw materials being readily available and thus maintaining a secure and sustainable supply is essential for economic stability and/or growth.

Current consumption of minerals necessitates EU states to reach outside their borders and import minerals or finished products to fulfil industry and consumer needs. As of February 2011, the EC adopted a new strategy, which acknowledges and emphasizes promoting sustainability, increasing efficiency, and recycling (European Commission, 2011b).

Depending on whether one is focusing upon just the European Union or more broadly, including the European continent, current estimates of mineral availability differ dramatically. For example, Russia holds vast resource wealth and the inclusion of the state along with other countries on the EUôs periphery must be considered when calculating the European situation.

Owing to inequalities in geological resources, the competition for specific minerals and ores in particular, requires a clear approach and str development. Unfortunately, the amount of imports coming into the EU are much greater than the exports in this sector, ill markets, especially for metallic minerals.

The presence of mining companies on the London Stock Exchange is both visible and more significant than any other international exchange, illustrating the strength of European industry in the financial sector. Still, many raw materials which are traded globally are not present on stock exchanges at all, or there are other issues related to transparency of the markets. These issues hinder the ability to accurately forecast where potential shortages may emerge.

With changes in supply and demand, price variation may dramatically affect consumption and availability. Long-term forecasts should consider wide variability between past tendencies and possible precarious futures.

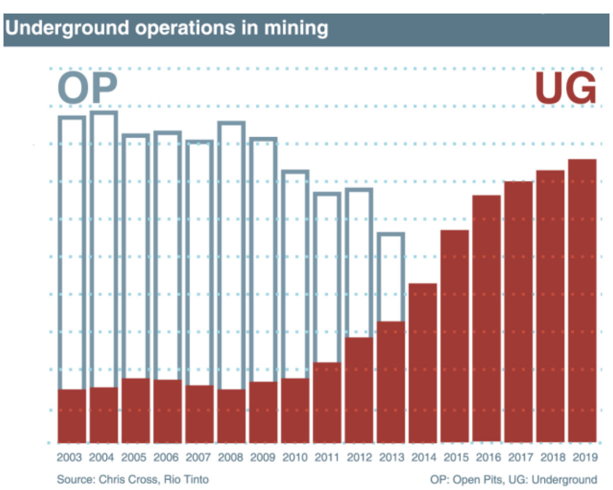
## 2.2 Availability of Specific Minerals

With respect to construction minerals, EU Member States generally have adequate supplies of aggregate minerals, such as raw materials for concrete, fill, and sand (Hetherington *et* al., 2008). Reports on these minerals are relatively transparent, but as we look at the supplies of other minerals, there are often discrepancies with reporting and this weakness needs to be addressed. As for non-construction industrial minerals, the distribution of supplies is more uneven across the Union. Statistics about these minerals are harder to find and potentially less accurate than for metals. Energy minerals are well-reported and wide scale analysis has been undertaken to forecast their future supply. The scope of energy is far too broad to address in this document, but the obvious push towards renewable energy illustrates the desire for the EU to be less dependent upon importing energy supplies.

The EU is most dependent on imported metals. The EU consumes more than a quarter of the world's metals and this trend looks set to continue despite the dependency and increasing prices (Hetherington *et* al., 2008).

## 2.3 Environmental Issues

Two major environmental concerns are directly associated with the extractive industries. First, the extraction of minerals, which are non-renewable, impinges on future generations. Their use also can have a negative impact upon the environment itself. Monitoring the full life-cycle of extraction activities is essential to accurately understand the potential long-term damage from mining. Second, the waste from such activities must be dealt with in an appropriate manner. To ensure the most efficient use of resources, as well as to limit the pollution output, the EU Mining Waste Directive legislates on the management of waste products.




Variation across the EU in environmental standards also requires consideration. The difference between some of the New Member States and older ones requires new approaches to reach harmonisation and compliance. Better planning for addressing land use, waste discharge, and environmental standards can move the extractive industry towards more sustainable practice.

Another issue revolves around the usage of certain minerals for environmental protection. The environmental impact of mining may be negative in some cases, but it also provides the tools to improve the curren

## 2.4 Socio-Economic Factors

Trends in society will greatly affect the extractive industries, along with economic and political developments. The growing world population will definitely place pressures upon the worldôs resources. Inequities in markets and distribution, possibly greatly altering consumption patterns. But while worldwide population is expected to grow, primarily in developing countries, Europe is aging. This possible population decrease and new age profile, unless countered by migration patterns, will lead to new consumption styles. Additionally, the movement towards and into urban environments may require new minerals or demand different materials.

These developments will alter and must influence the political decisions of EU leaders. Current consumption is not related to production and extraction of minerals from within the EU market. The unsustainable patterns must be reconsidered to match the supply of European resources, or at the bare minimum, come closer to sustainable levels. GDP may decrease in areas short of resource supplies or without much to trade; this possibility is more than a political one, but could have tangible affects upon the quality-of-life for many Europeans.

Introducing new technologies into the European extractive industry is bound to enhance and improve the field, but also greater incorporation of SMEs into activities may be more beneficial in the long run than supporting potential large scale activities. Mining is an important employer, with many communities heavily dependent upon the industry to support them. Enhancing local extraction activities could boost regions, increase high-tech work, and wean the EU off imports.

# Chapter 3 Mining technologies

## 3.1 Renewable Energy

This chapter will review renewable energy technologies as a means of GHG emissions reduction. Renewable energy, energy which is derived from naturally replenished resources, accounts for ñone quarter of glob delivered 18 percent of global electricity supply in 2009ò (REN21, 2010). The mining industry, like many sectors, has begun to embrace a variety of renewable energies on a global scale. Renewables are utilised as a means to reduce energy costs, greenhouse gas emissions, and negative environmental impacts; they are capable of providing significant sources of energy with minimal negative impact. This section will discuss various renewable energies currently available to the mining industry along with some innovative technologies with the potential to reduce the carbon footprint of mining in the future.

**Wind Power**

Wind power is one of the most successful, popular, and fastest growing forms of renewable energy available today. In 2009, wind power was estimated to produce 157.9 GW of energy per annum worldwide; that figure having grown by 31% from 2008 (GWEC, 2010). There can be no doubt that wind farms are a significant and growing energy source. The mining industry, like many other sectors, governments, organisations and individuals, has begun to embrace the benefits of wind farm technology. The drawback of wind power is that conditions must be appropriate for it to be a viable and reliable source of energy. A high average wind speed alone does not guarantee the feasibility of a wind farm. A wind turbine performs best under consistent wind speeds; normally around 10 to 15 metres per second. At low speeds a windturbine does not produce as much energy to be profitable and under very high speeds the windturbine may have to be turned off owing to dangerous high frequency rotations. It has been found that windturbines often produce a large portion of their energy output in relatively short periods of high wind speed. The New Mexico Wind Resource Assessment case study, completed by the Sandia National Laboratories at their facilities at the Lee Ranch testing centre in 2002 found that 50 % of the energy was produced in óbursts of windô over 1 50% of the (SNL, 2002). Because of the inconsistent nature of wind, and thus the inconsistent energy production of windmills they are best used in conjunction with another, more reliable, power source. Research shows windturbines are more effective behaving as a fuel conserver then as a primary power supply (Czisch, 2008). Figure 4 provides a graphical representation between the hours a windmill is used at a given wind speed and its energy output found at the Lee Ranch in New Mexico.

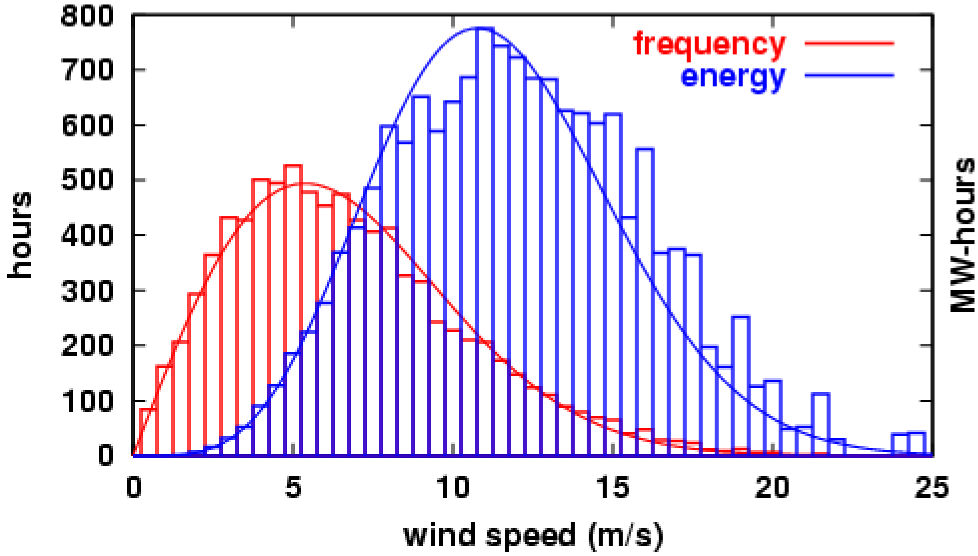



**Figure 4 Lee Ranch wind speed / energy correlation (SNL, 2002).**

As many mining and processing operations occur in remote locations, where access to grid power supply is unavailable or cost prohibitive, operations are often reliant on diesel electric generators. A popular emerging alternative to diesel only, is to use combination wind/diesel generators; which are optimised at 40% wind generated energy and 60% diesel power (Neilson, 2007). An average mine site diesel generator reduces $CO_2$ emissions by 1.8 lbs per kWh when used in conjunction with wind power. A one mega watt wind farm responsible for 35% of the power supply will generate an average of 3,066,000 kWh of electricity per annum; thereby reducing $C0_2$ emissions by up to 2,759 tonnes per year (Neilson, 2007). In addition to this wind power typically costs \$0.06-\$0.08 USD per kWh which is lower than the average diesel power generator which costs between \$0.09-\$0.19 USD per kWh under typical conditions (Neilson, 2007).

An example of a mining company employing the benefits of Wind Power is Barrick Gold, the world's largest gold producer. In 2007, they received approval to build a US$70 million wind farm in the Coquimbo region of Chile (Barrick, Beyond Borders: A Barrick Gold Report on Responsible Mining, 2010). They have constructed ten wind turbines that provide 36 MW of power to the Chilean grid each year. This is currently the largest wind farm in Chile and an excellent example of a mining company not only reducing their own carbon footprint but working to reduce the carbon footprint of the region they operate in. Unfortunately more information is regarding as to how the turbines will interact with the mines energy requirements are unavailable. It does appear though that the turbines will feed directly into the Punta Colorada regional grid (Barrick, Building Pascua-Lama, 2009).

An associate of the mining industry who currently works at an undisclosed metal mine was contacted for telephone interview as part of this study. They explained that their mine currently leases a 30 MW wind turbine which supplies electricty directly to the national grid. It is thought that the mine in question is participiating in a Feed-in tariffs (FIT) policy, whereby fixed rates are paid by national government to the mine and indeed other such producers of electricity for feeding it into the national grid. The Renewable Energy Sources Act (EEG) implemented in Germany is an excellent example where FIT has actively encouraged the production and selling of renewable energies such as wind and solar power to the national grid, offering financial incentives in retun for facilitating government to achieve its set national targets of carbon footprint reductions.

**Discussion**

Whilst wind power may offer mining companies (in the right locations) an excellent opportunity to capitalise on renewable energy there are some drawbacks. The most obvious being the significant upfront costs of wind turbines. As mentioned previously Barrick Gold spent upwards of US $70 million on a single wind farm. Despite the fact that wind farms are a proven energy source the power they provide is quite small given the significant costs of construction and maintenance. In this case, costing nearly US $2 million per MW produced, it is also important to note that wind farms are unlikely to be running 24 hours a day due to weather variations. This compares with Barrickôs natural gas power plant in Nevada which cost $100 million to build and produces 115 MW, or US $869,000 per MW, 24 hours a day 365 days a year. Although there are numerous wind farms worldwide today most are heavily subsidised by governments. In recent years in Spain the government has made a drive towards green energy significantly subsidizing the costs of wind power; as a result electricity costs have risen by up to 60%. It was said that this initiative created 50,000 jobs in the ógreen
each job was subsidised by the Spanish government at an average of 571,000 Euros (Gorham, 2010).

Despite this, wind farms are a proven form of energy and are known to work very well in conjunction with conventional power sources. As a carbon reducing initiative they are an excellent form of energy and they produce virtually no carbon after they have been constructed. While they may never be an economic so
needs they are certainly a viable means of a projectôs GHG emissions.

**Solar Energy**

Solar energy is a form of power that utilizes sunlight to generate electricity. In 2008 solar energy accounted for 0.02% of global energy consumption (Solarbuzz, 2009) and just 0.08% in the USA (Hutchinson, 2008). In recent years solar power has come to play a growing role in the mining industry. With mining companies building solar power systems ranging in size from small projects acting in combination with other energy supplies to large facilities powering nearby communities and homes. Solar power is typically produced in one of two ways:

**Photovoltaics (PV)**

Photovoltaics is a type of solar power which converts solar radiation directly to electricity. This is done by utilising a system of solar panels made up of silicon cells consisting of thin layers of semiconductors carrying opposing charges (+ and -). The electron imbalance caused by sunlight striking the charged panels cause electrical flow, aka electricity (Strathclyde, 2005). Thus is represented in Figure 5.

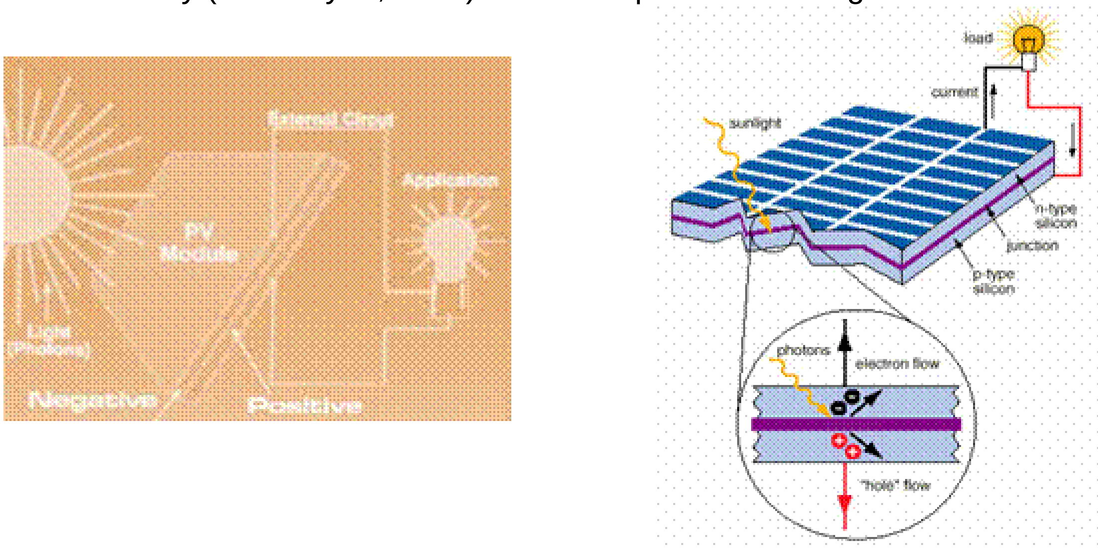



Figure 5 PV solar panel diagram (Strathclyde, 2005).

PV solar panels are typically used for small-scale applications such as satellites, private homes or consumer products (such as calculators or watches). Figure 6 shows a chart of the breakdown of PV use worldwide.

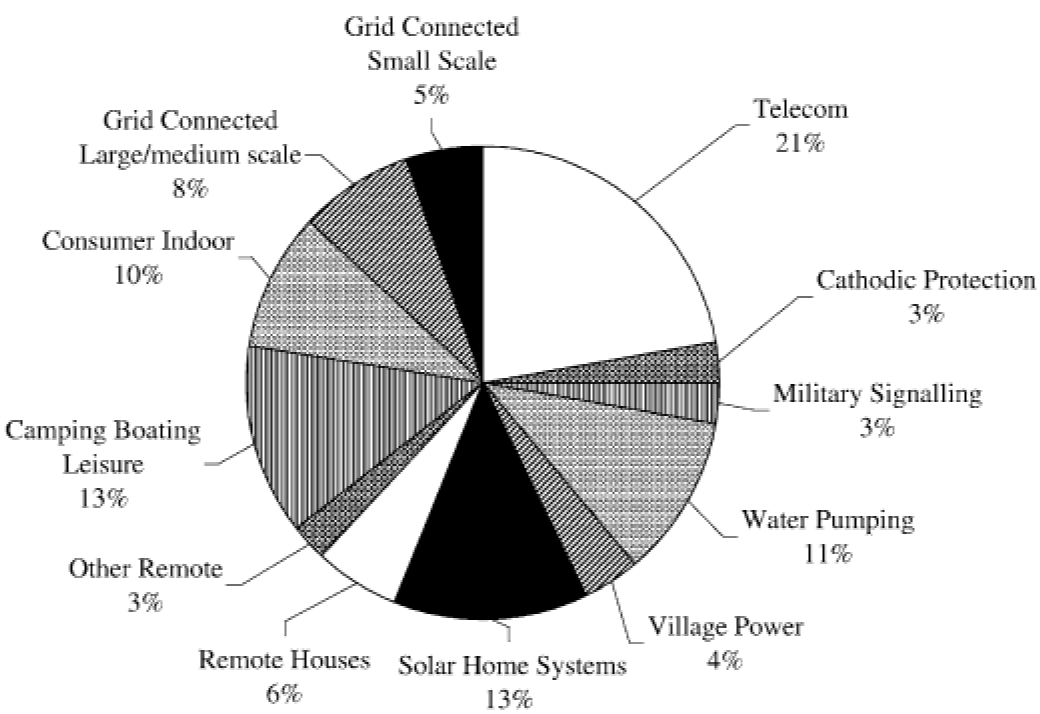



Figure 6 Worldwide PV breakdown (Oliver and Jackson, 1999).

Despite this PV solar panels represent a growing solar industry as they are continually increasing in efficiency and versatility. ñWorld solar photovoltai installations reached a record high of 5.95 gigawatts (GW) in 2008, representing growth of 110% over the previous year (Solarbuzz, 2009)ò. Although PV panels would be poorly suited for large scale power generation at a mine site or even working in tandem with a alternative energy source (ex. Diesel) there is potential for application in small scale activities. Solar panels of this nature are already widely in use by Barrick Gold, the worldôs largest gold mining company, on their and other small scale equipment (Josich, 2007); Namdeb, diamond producer in Namibia, uses solar panels to power their security cameras and Cliff Resources iron ore mine at Koolyannobbin, Western Australia use solar panels for geotechnical monitoring equipment (F. Wall, pers comm.). In addition to positive environmental effects it is likely that after initial installation costs the addition of PV panels could have financial benefits as well. They will enable organisation to forgo maintaining expensive power lines to remote locations where only small amounts of electricity are needed. Further research needs to be comple[illegible] is re financial benefits as well as carbon emissions reduction.

**Concentrating Solar Power (CSP)**

The second type of solar energy is óconcentra energy. This type of solar energy is produced by utilising either mirrors or lenses to concentrate sunlight into a small area and then projecting this energy onto a photovoltaic surface or to heat a working fluid.

When solar energy is used to produce heat for the purpose of generating electricity it is referred to as concentrating solar thermal (CST). This is normally done by using the heat produced from the concentrated sunôs ray as molten salt or oil (Nenter and Netshilaphala, 2006). The heated fluid or the concentrated sunlight is then used in a conventional power plant (or engine) to produce electricity. This is normally done by heating water to produce steam, which in turn spins a turbine (Hutchinson, 2008). CSP systems can produce heat up to 788 $^{o}$C and obtain energy conversion efficiencies up to 31.25%. CSP systems vary in design from long parabolic troughs that all work together to power central turbine (one of which exists in Boulder City Nevada that produces 64 MW; with 13 more on the way) to solar dishes that can be used to power individual motors (40 of which can produce up to 1 MW)(e.g. Figure 7).

**Figure 7 Parabolic trough and solar dish CSP (Hutchinson, 2008).**

Concentrated photovoltaics (CPV) on the other hand function by utilising the lenses or mirrors to focus the sunôs rays on photovolta directly; without the steam. This works in a similar manner to PV solar power except that the sunôs rays have been conce The PV surface is typically a smal constructed from silicon but can also be cadmium telluride; a much more economic alternative (Hutchinson, 2008).

## Discussion

Solar power represents numerous opportunities to the mining industry. With its range of options and versatility in application it can be harnessed to provide power solutions to both small and large scale issues. An excellent example of this would be the use of PV panels. Although as previously mentioned they are in use in small scale applications (ex. monitoring, road signs etc.) it is the opinion of this author that it would be worth while investigating the application of PV panels to open pit haul trucks, conveyor belts or mobile crushing units. This would clearly be dependent on climate and weather conditions but it is reasonable to assume that PV panels used in conjunction with diesel generators or other conventional power supplies could significantly reduce fuel consumption, thereby lowering energy costs and harmful greenhouse gas and $CO_2$ emissions; thus reducing the operations carbon footprint in a small way. It is unlikely at this time, given current technology, that this would reduce costs but with advances techniques it is certainly an opportunity to examine in the future. Perhaps a more economic alternative to this would be utilising solar panels with a trolley assist system (explained in section 3.2) this would reduce the possibility of damaged equipment (as it wouldnôt be moving) increase the area available. Both of these options require significantly more research before true costs can be known.

Concentrated solar power currently represents the greatest opportunity for the mining industry. Its ability to work on large scale and in conjunction with conventional power plants makes it an ideal power supply in the right climates. Although it will act primarily as a fuel conserving measure for diesel and coal plants it could represent significant savings for companies. Several companies have already begun to implement the use of

solar power plants. An example of this is Barrick Gold who recently spent US $ 10 million on a 7,404 panel solar power plant in northern Nevada capable of producing 1 Mw of power, or enough to power as much as 300 homes. This solar farm will work in tandem with a $100 million 115 MW natural gas power station already built by Barrick (Seelmeyer, 2008). In 2004 Rio Tinto one of the worldô
a 31 kW PV solar power system in Western Australia; which at the time was the largest system of its kind in the area. This system run as a solar-diesel hybrid consists of 260 solar panels and is estimated tpo mñe.e.t. ctdhnet rniabtui
power needsò (RioTinto, Social, Safety and Environment Report 2004, 2004). BHP and Rio Tinto are also working together to create
at an estimated US $ 1 billion; at an estimated start date of 2011 (Mine giants Rio and BHP bet on solar power, 2008).

While solar power is a proven method of utilising renewable energy, there are some pitfalls. Solar power is an extremely expensive power source both in terms of upfront costs and maintenance. It has been estimated that PV solar panels can take roughly 100 years to pay back installation costs (note: the maximum life of a PV panel is 30 years) (Hickman, 2008). Even concentrated solar power plants require highly skilled experts to build and run, and in general are heavily subsidised, being afforded funding and tax breaks not available to regular power sources. In addition to this the power output of a solar farm is almost negligible to the energy requirements of most mining operations. As previously mentioned, Barrickôs 1 MW 7,404 panel power plant in northern Nevada was built next to their 115 MW natural gas power plant, the solar plant being built largely to satisfy state legislation. Given the solar plant cost 10% of the cost of the gas plant and produces 1% of the energy, these numbers bring into question the long term sustainability of solar energy as practical and self sustaining technology. That being said, solar power technology is constantly improving and with the help of subsidies today and legislation encouraging solar energy they may be a cost effective and economic option in the future.

## Biofuel

Biofuel is a term which encompasses a wide va
bio wasteò. These fuels can be used for any purposes, but the main use for which is in the transportation sector (Biofuel, 2010).ò Biofuels offer an excellent opportunity to reduce the $CO_2$ and greenhouse gas emissions of almost all fossil fuel burning mining equipment, from haul trucks, to jumbos, to dozers. Biofuels have been used both underground and on surface to a wide degree of success; and are on their way to becoming a major part in the mining industry (Blades, 2010).

## Biodiesel

Biodiesel is a form of diesel fuel created from vegetable oil or animal fat. The general description given of biodiesel by the national biodiesel board in the United States is: ñBiodiesel is a domestic, renewable fuel for
soybean oil, and which meets the specifications of ASTM D 6751ò (NBB, 2010). Biodiesel can be used in any regular diesel burning engine without modifications; it can

be used either on its own or in a mixture with regular petrodiesel, referred to as a biodiesel blend (NBB, 2010). Biodiesel can be made from a variety of products and is typically made from the soya beans and rapeseed in the USA. But biodiesel is also made from mustard, flax, sunflower, palm oil, coconut and hemp throughout the world (NBB, 2010). Table 3 Biodiesel emissions (NBB, 2010). Table 3 summarises the difference in emissions produced by biodiesel and those produced by petrodiesel. Where B100 refers to 100% biodiesel and B20 refers to a mixture of 20% biodiesel and 80% petrodiesel.

**Table 3 Biodiesel emissions (NBB, 2010).**

**AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA**

| Emission Type | B100 | B20 |
|---|---|---|
| **Regulated** | | |
| Total Unburned Hydrocarbons | -67% | -20% |
| Carbon Monoxide | -48% | -12% |
| Particulate Matter | -47% | -12% |
| Nox | +10% | +2% to -2% |
| **Non-Regulated** | | |
| Sulfates | -100% | -20%* |
| PAH (Polycyclic Aromatic Hydrocarbons)** | -80% | -13% |
| nPAH (nitrated PAH's)** | -90% | -50%*** |
| Ozone potential of speciated HC | -50% | -10% |

*** Estimated from B100 result**
**** Average reduction across all compounds measured**
***** 2-nitroflourine results were within test method variability**

As can be seen from the above figure, biodiesel burns significantly cleaner than its petro alternative, and operations all over the world have taken to incorporating a biodiesel blend in their machinery. Biodiesel is particularly useful in underground workings because it burns much ócleanerô creating a safer/heal strain off of the ventilation system. Figure 8 shows data taken from two underground mines examining the level elemental carbon in air. The introduction of biodiesel to the operations shows a clear reduction in elemental carbon levels (Biodiesel, 2009).

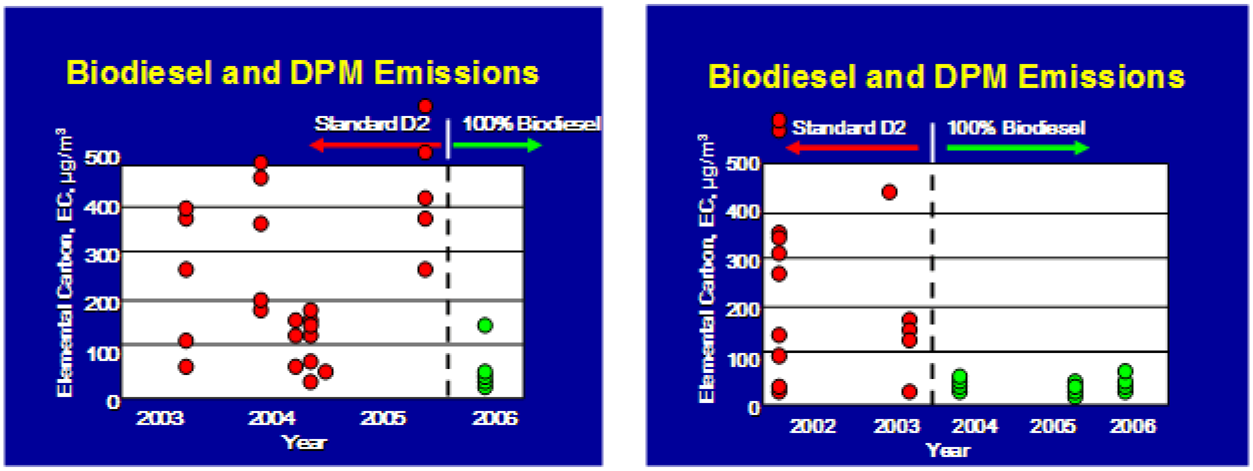



Figure 8 Elemental carbon emissions of biodiesel and diesel particulate matter (Biodiesel, 2008).

## Biogasoline

Biogasoline (ethanol or butanol) is a substitute for standard fossil fuel gasoline. Both are alcohols that can be produced from biomass. Ethanol is the most common and the average automobile engine can run with up to 15% ethanol and 85% gasoline, without requiring modification. Butanol is similar to ethanol though chemically closer to gasoline. It can run most engines without any modifications but does not have as high an octane rating as ethanol; thus produces slightly higher $CO_2$ emissions. Alcohol based fuels do not have the same energy efficiency as gasoline and thus require more volume and a higher flow rate of fuel to do the same amount of work. Biogasoline is much more expensive than conventional fuels. On top of this given the high carbon costs of producing biofuels: heat intensive processing, farming crops, fertilising crops, pesticide production and application, transport of materials and product etc. the actual reduction in carbon footprint is very small (Biofuel, 2010). Despite this some companies are beginning to use biogas and biogas blends in their operations.

## Discussion

Many mining companies are whole-heartedly embracing the advantages of biofuels in their operations. Given their low upfront costs (they work in unaltered engines) their versatility (they work a blends or in pure form) and their ease of use and implementation biofuels are one of the most effective and low risk (if they are ineffective companies can stop using them at little or no loss) renewable forms of energy available. The most important biofuel to the mining industry today is biodiesel. Just as the most important petroleum fuel is diesel, this stems from the fact that most mining equipment runs on a diesel engine, including: haul trucks, jumbos, in pit crushers, dozers, and graders to name a few. Although biogas is an important biofuel it plays a smaller role in the mining industry purely do to the limited number of gasoline engines requiring fuel. One prime example of the importance of biodiesel can be seen by again looking at Barrick Gold. Barrick has been using biodiesel in their underground operations in North America, and in their compressor controls and fuel management programmes for the last couple of years (Barrick, Environment: The Opportunities Around Us, 2010). In 2008 alone it is estimated that the use of a biodiesel blend in Barricks underground North American mines offset 4,800 tonnes of GHGs, which would have been produced with conventional petrodiesel (Barrick, Biodiesel use in North America, 2008). In 2009 Barrick burned 6,960 cubic metres of biodiesel (Barrick, Environment: the opportunity around us, 2010). Rio Tinto has also adopted the use of biofuels and in 2009 reported the consumption of 1.3 million tonnes of biodiesel and 16,000 tonnes of renewable waste fuels (Anglo, 2010). In 2009 Vale invested US $305 million to construct a biodiesel plant and purchase 41% of a raw palm oil production company. The plant is expected to produce 160,000 tonnes per year of biodiesel. The Biodiesel will be turned into a B20 blend and used in Vale's locomotives and equipment at the Carajas mines in Brazil (miningmagazine, 2010).

The largest draw back to the use of biodiesel in mining applications is the cost implications involved. Studies have found that cost is prohibitive when prices are over US $3.00 per gallon of biodiesel. When costs fall to US $1.50 per gallon, neat biodiesel was found to economic for light-duty equipment. At costs over US $ 1.50 per gallon filters tend to be a more popular option (Fruin and Tiffany, 1998). Despite these cost implications, filters are effective at filtering out particulate matter (PM) but have little effect on greenhouse gas emissions; leaving biodiesel as the most effective means of $CO_2$ (and PM) reduction for diesel mining equipment. As mentioned previously, this is particularly effective in underground mining where the decrease in PM and emissions takes some of the strain off of the ventilation system thereby saving electricity consumption.

Despite some benefits, biogasoline is not commonly used or seen frequently on mine sites. So much so that it has been nearly impossible to find specific example of use in the literature. This is likely to be due to the fact that gasoline requirements are significantly less then diesel requirements at most operations, in turn making the reduction of $CO_2$ emissions from biogas less important. That said, Russell Blades of Barrick gold commented in an interview that
some of their North American operations (Blades, 2010)ò .This refers generally to support vehicles (ex. pickup trucks) and personnel carriers (Blades, 2010). This may imply that even though it is not publicly stated many companies may indeed be utilising biogas at their mines sites. Despite cost restrictions biofuel remains one of the most accessible and effective renewable energies available to the mining industry. As manufacturing processes become more cost effective and conventional fuel prices rise it is reasonable to expect biofuels to become an ever more popular option available to the mining industry.

**Hydropower**

Hydropower is electricity generated by the movement of water. It is a form of renewable energy and produces no greenhouse gas emissions (apart from those resulting from the manufacture of the equipment required). This is often accomplished with the help of strongly moving rivers, waterfalls, and tides and waves. When water is not already flowing hydroelectric dams can be used to induce motion to generate electricity. Turbines are the most common means of converting the energy in the water to

electricity. Hydropower is responsible for 19% of th
China, Canada, Brazil, and the United States representing the largest consumers (EIA, 2009) (Figure 9).

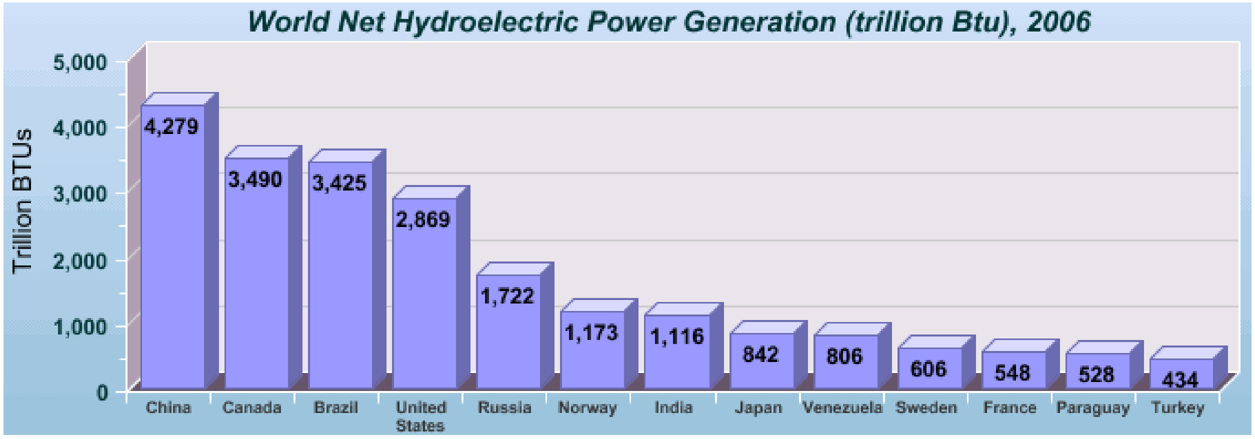



Figure 9 Global hydroelectric power consumption (EIA, 2009).

Hydropower provides unique opportunities for the mining industry. Although it is rare for a mine to be located in a position where hydropower is readily available, it is not uncommon for mining companies to build hydroelectric plants elsewhere in the region and to power their operations and surrounding communities. An excellent example of this is BHP Billitonôs 2,500 MW hydropower p
Congo in the DRC; which should begin construction in 2014. The plant will provide power to BHPôs projects in the a (BHP, 2010)s well l
Mining operations can also utilize small scale hydroelectric power to operate mining equipment such as drills. This is common in the deep level South African gold operations where a standing column of water (~2km deep) is used to hydraulically power the drills. This water column negates the use of compressors, known for their significant losses from pipe leakage and compressor inefficiencies (Penswick, 2010). Efficiency from hydro power is estimated to be at 28%, while efficiency from compressed air sits somewhere in the region of 2% (Cloete, 2008).

Barrick Gold has gone a step further and has begun utilising ñend-of-pipeò hydroele
power generation. The Zaldivar mine in northern Chile is capable of producing a 100 kW from a turbine being powered by the flow of tailings through a pipe on their way from the processing plant to the storage facility. This power is then redirected back into the processing plant (Blades, 2010). Unfortunately it was impossible to find more information on this process as Mr. Blades was unable to provide more detail in the interview and was not available for further questioning.

## Discussion

Hydropower provides a plethora of opportunities for mining companies to produce clean electricity, free of GHG emissions. They range from the standard (such as the use of hydroelectric dams), to the innovative use of existing processes. The largest drawback of hydroelectricity is simply availability. Whilst hydro power is a cost effective, reliable, and proven renewable power source it needs a consistent water supply. While in Canada and the United Sates this is a viable option in Australia and much of Africa hydro power would be impossible. Another drawback is often the sheer scale of many hydroelectric projects. Costing up to hundreds of millions of dollars and remaining long after the life of the mine. The advantage to this is that they often provide enough power to provide for the local community and can provide an industry after the mine has closed (BHP, 2010). The next step is to combine small scale hydropower options on mine sites, that when working in unison will create significant energy savings, and $CO_2$ reductions.

## 3.2 GHG Reducing Technologies

Section 3.2 discusses existing and emerging technologies that may be used to reduce the GHG emissions of a mining operation. They range in effectiveness, cost and availability but all offer potential solutions to the problem of GHG emissions.

### Natural Gas (LNG)

Natural gas is a form of fossil fuel comprised primarily of methane gas. Natural gas is used worldwide as a major source of electricity generation; in the United States alone “...energy from natural gas accounts for 24% of total energy consumed” (NaturalGas.org, 2010). Gas provides one of the lowest carbon footprints of any fossil fuel. It burns much “cleaner” then either coal or [illegible] $_2$ than coal and 30% less than petroleum (NaturalGas.org, 2010). Table 4 shows a comparison of emission levels of natural gas to other fossil fuels.

**Table 4 Fossil fuel emission levels comparison (NaturalGas.org, 2010).**

**Fossil Fuel Emission Levels**
**- Pounds per Billion Btu of Energy Input**

| Pollutant | Natural Gas | Oil | Coal |
|---|---|---|---|
| Carbon Dioxide | 117,000 | 164,000 | 208,000 |
| Carbon Monoxide | 40 | 33 | 208 |
| Nitrogen Oxides | 92 | 448 | 457 |
| Sulfur Dioxide | 1 | 1,122 | 2,591 |
| Particulates | 7 | 84 | 2,744 |
| Mercury | 0.000 | 0.007 | 0.016 |

Because of natural gases ability [illegible] “cle[illegible] starting to take notice and utilise natural gas to power their operations. Barrick gold is currently involved in optimization studies to utilize natural gas at their Donlin Creek project in Alaska, which are expected to be completed in mid 2011. The use of natural gas is expected to reduce overall operating costs of the project (Barrick, Donlin Creek, 2010). Barrick also owns and operates a 115 MW natural gas generating station in western Nevada (BarrickGold, 2007). In 2008 Rio Tinto invested US $400 million in a natural gas power plant to supply energy to its iron-ore operations in Western Australia. It is estimated that the new natural gas plant will generated 25% less $CO_2$ emissions then the two steam power stations currently meeting the regions power needs, which accounts for an estimated savings of 200,0 ... tonnes per annum (Merwe, 2008).

Natural gas is also being used in the form of liquefied natural gas (LNG). LNG is simply natural gas that has been liquefied to ensure ease of transport and storage. It is then possible to use the LNG to fuel mining equipment, most commonly haul trucks. One of the most popular LNG burning haul trucks is produced by the Canadian company Westport Innovation Inc. with their LNG system for heavy duty trucks (WestportInnovations, 2010). Westport estimate that their LNG systems reduce GHGs by 20-25% from conventional diesel engine emissions (Siuru, 2007). Serious testing of the use of LNG as a means of fuelling haul trucks for mining applications began in the early 2000ôs by Westport at a ... mine in (CMJ, 2002). Barrick Gold has started utilising LNG at many of their operations as an alternative to diesel in their haul trucks. They are currently operating fleets of haul trucks of up to 2,500 horse power (Blades, 2010). A new US $138 million LNG plant was recently built in Western Australia specifically to provide LNG to heavy duty vehicles, providing up to 157 tonnes a day of LNG (GasToday, 2007). Drawbacks of LNG is the fact that the process of converting natural gas from gaseous to liquid form is energy intensive and produces significant $CO_2$ emissions. It is estimated that burning LNG produces 20-40% more $CO_2$ then domestic natural gas (LNGpollutes, 2010).

Despite these gains in GHG emissions, Natural Gas and LNG represent a valuable opportunity for mining companies to reduce emissions. Even with added carbon costs, LNG is still much ócleanerô than diesel a ... The use of LNG in haul trucks is still relatively new technology and efficiency improvements and technological gains are being made all the time. Mining companies all over the world are utilising this technology, providing significant savings in GHG emissions (Blades, 2010).

**Organic Rankine Cycle (ORC)**

The organic rankine cycle (ORC) is a thermodynamic process which is used to recover and recycle waste heat generated by low temperature sources such as conventional power plants or diesel engines (Quoilin and Lemort, 2010). To understand the o... rankine cycle we must first understand the rankine cycle. The rankine cycle is the process by which external heat is applied to a closed loop where water (usually) is heated until a phase change occurs and steam is produced the ñ...supe... generated in a boiler and then expanded in a steam turbinesò (Cogeneration, 2010) which in turn drive a generator. The generator then produces electricity. The organic rankine process utilizes a high molecular chemical (such as Freon, butane, propane, and ammonia) in the place of water. The chemical is capable of recovering heat from ólow heat sourcesô such as a diesel engine a... energy, such as electricity. Figure 10 shows a typical schematic diagram of the ORC.

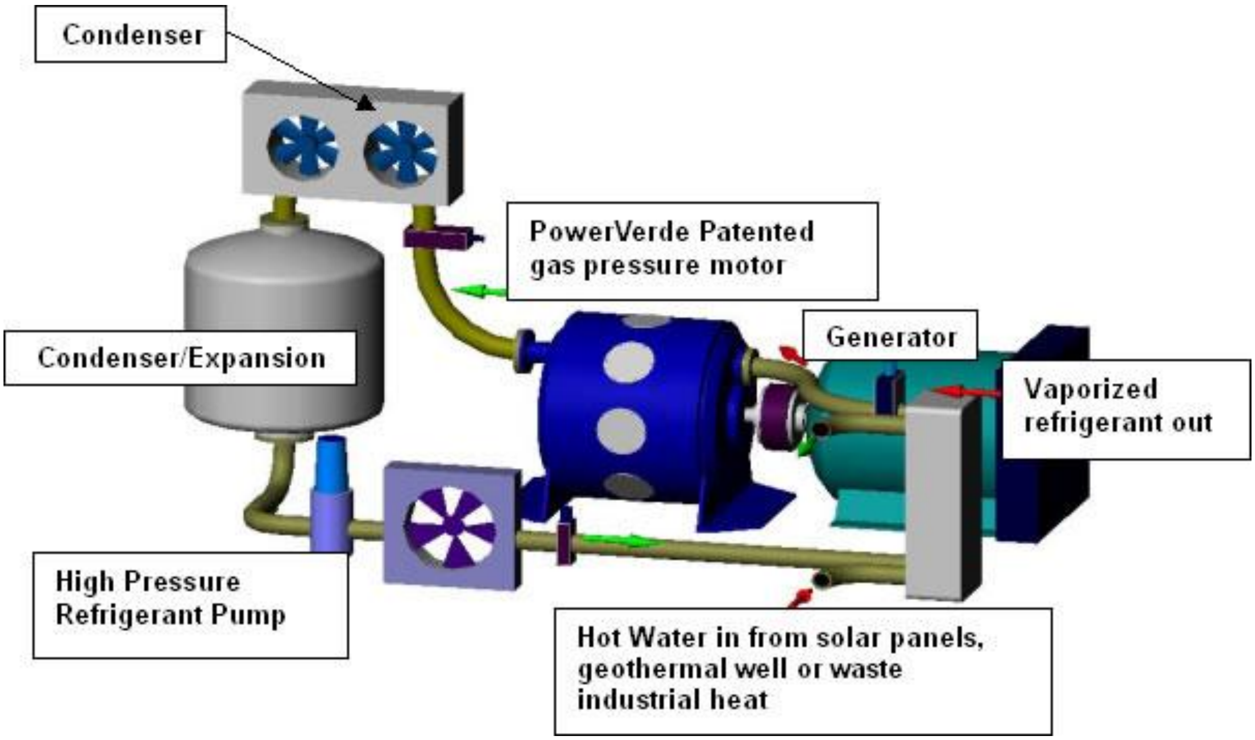



Figure 10 Organic Rankine Cycle Technology (Powerverde, 2010).

Because of the ORCs ability to be used in conjunction with various heat sources and its ability to generate local and small scale power the ORC provides an excellent opportunity for the mining industry to conserve energy and reduce GHG emissions on many fronts; thereby lowering an operations carbon footprint as well as saving money in energy costs (Quoilin and Lemort, 2010).

The ORCs ability to convert excess low temperature heat to energy means it is an ideal process for capturing and utilising the heat produced by internal combustion engines. In the mining industry this means: haul trucks, loaders, drills, dozers, and a host of other equipment. For example in ña typical 1.4 litre Sp
efficiency ranging from 15 to 32%, 1.7 to 45 kW are released through the radiator (at a temperature close to 80-100 ÁC) and 4.6 to 120 kW through the exhaust gas (400 - 900 ÁC) (El Chammas and Clodic, 2005). This accounts for up to 165kW of wasted energy and unnecessary GHG emissions. In the 1970ôs prototypes
horse power haul truck incorporating ORC technology were found to create a 12.5% increase in fuel efficiency (Quoilin and Lemort, 2010). Current prototypes have been able to increase engine thermal efficiency by up to 28.9-32.7% (Endo, 2007). This represents huge gains in fuel efficiency and GHG reduction. If implemented on a fleet of 250 tonne haul trucks it could also represent enormous financial savings each year. Although this technology is still in the experimental/prototype stage, mining companies are investigating the potential of incorporating ORC technology with diesel haul trucks says Russell Blades sustainability manager at
(Blades, 2010). In 2009, BMW found that the use of an ORC system can increase power output by 10% on a four cylinder engine. Honda, for example, has found that by

incorporating ORC technology into their hybrid cars they are able to improve thermal efficiency of their engines by 3.8%. On top of this, researchers at Loughborough University and the University of Sussex have found increases of 6.3% to 31.7% in fuel efficiency when using ORC systems in light-duty vehicles (GCC, 2009). This technology contains enormous potential for mining companies, with the thousands of litres of fuel being consumed each year by mine support vehicles (pickup trucks, personnel carriers etc.). Add to this the fact that the typical 200+ tonne diesel mining haul truck gives off significantly more heat than a standard vehicle, the economic benefits, as well as the potential reduction in GHG emissions, could be substantial. Further research is required to fully understand how this technology can be adapted to operate in the demanding conditions of a mining environment, however, the potential for both energy conservation and carbon footprint reduction is prolific using this type of technology. With companies like Barrick leading these changes it is very possible we will see the technology adapted to the rigors of the mining industry in the near future.

In addition to its ability to optimise the performance of combustion engines the Organic Rankine Cycle technology has potential for large scale applications. As ORC can be utilised with almost any heat generating process this opens up a wide range of potential opportunities at any given mining operation. ORC has been used successfully in conjunction with conventional power plants such as coal and gas, as well as renewable power sources such as solar farms. ORC also represents a significant opportunity to increase the energy efficiency and reduce the carbon footprint of mineral processing plants, given the energy intensive process of mineral liberation.

In recent decades the ORC has gained increasing popularity as a means of energy conservation within conventional power plants. ORC has been employed on plants ranging in size from 300 kW to 130 MW. One such example is the 6.5 MW Gold Creek power plant in Alberta Canada. The plant was built in 1999 and utilises ORC technology. As a result $C0_2$ emissions are reduced by 25,000 tons per year. Clearly it is not a stretch of the imagination to conclude that this technology could be successfully applied to many of the diesel, natural gas or coal power plants currently being used to power mining projects around the globe. Another example of successful large scale application of ORC technology being the 1.5 MW Heidelberger Zement AG Plant in Lengurt, Germany. The ORC technology in this cement plant reduces $CO_2$ emissions by 7,000 tons a year (Bronicki, 2009). ORC technology has been employed to recover heat lost throughout the plant both by means of power production and other stages in the cement making process. This makes an excellent comparison to the mineral liberation processes. With the access heat produced via crushing, grinding, and heap leaching, etc there is ample opportunity to employ ORC technology within mineral processing plants.

In addition to its popularity in conventional power plants, ORC technology has become a popular component in renewable energies such as geothermal energy, and biogas generation plants (Schuster *et al*., 2007). As both of these forms of power are becoming more and more important to the mining industry, by reducing their energy needs the carbon footprint of the mining industry is in turn being reduced. The Neustadt-Glewe geothermal plant in Germany uses the ORC process to convert geothermal heated waters of $98^{0}$ C to 210 kW of electricity (Schuster *et al*., 2007). It is estimated that there are ñapproximately 600 MW of geothermal power (ORC technology) have been installed in 18 countriesò. ORC modules ranging in power from 1 to 30 MW have been installed in over 40 geothermal power plants, such as a 125 MW geothermal power plant in the Philippines (Bronicki, 2009). ORC also has significant potential of being utilised within biogas plants. Due to the substantial amount of waste heat generated in the biodiesel production processes ORC technology offers an opportunity to help improve the feasibility of biogas as a potential alternative fuel source. The incorporation of the ORC could save significant amounts of energy and help ensure that heavily subsidised biogas plants as economically sustainable. Thus benefiting the mining industry, and reducing carbon footprint (Schuster *et al*., 2007).

## 3.3 Optimization

In any mining project, the company has a range of choices to make from mining method, open pit or underground, shaft or ramp, and a variety of other choices. Each choice will impact on recovery, costs, timeline, and the environment.

### 3.3.1 Haul Ramp vs. Shaft (underground)

The pros and cons of haul ramps vs. shafts in underground mining is a heavily debated subject within the mining industry. Both have benefits and draw backs in terms of costs, efficiency, safety and environmental impact. Whilst shafts appear to be more prevalent in North America, haul ramps dominant underground mining in Australia. Whilst numerous studies have been completed which take into account depth, grade, deposit type, gradient, and fuel costs versus electricity costs the main focus tends to be economic benefits of the design. Whilst safety issues play a part, there seems to be little consideration of the environmental effect of the decision, in particular the carbon footprint. This could be because it is yet to be considered an important issue in the decision or alternatively because it seems quite obvious. The shaft appear the ideal choice (in terms of $CO_2$ output) as an electric hoist would emit considerably less $CO_2$ than a fleet of diesel engine haul trucks; it would also place significantly less pressure on the ventilation system. That said if the mine is in a country like South Africa, or Romania, that is heavily reliant on coal fuelled power plants to produce electricity the overall reduction in carbon footprint could less then imagined. In addition to this it may be found that the haul trucks are able to deliver the material far more efficiently and in less time and few loads meaning the mine will spend shorter time in production; drastically lowering carbon footprint. While generalities do exist (ex. Shafts produce less carbon emissions) it is necessary to explore the merits of both systems on a case-by-case basis. Currently no literature exists on the issue and in-the-field research into this problem is beyond the scope of this study. It is the recommendation that further research need be accomplished in this area before conclusive statements regarding the carbon footprint optimization of the ramp vs. shaft comparison can be made.

### 3.3.2 Truck vs. Conveyor

The comparison of the carbon emissions of haul trucks to mine conveyor systems is similar to that of ramps to shafts. A conveyor system is clearly a
transport method in terms or emissions. This again comes down to the fact that conveyors are typically powered by electricity as opposed to the diesel of haul trucks. In addition to this, conveyors will significantly decrease the distance the ore has to travel, owing to the fact that conveyors take the ore in a relatively straight line as opposed the switchback roads the trucks are forced to follow. In South Africaôs Pala
implementation of an in pit crusher with a conveyor was able to reduce hauling distance by 4km (one way) (Penswick, 2010). Needless to say, this represents an enormous reduction of diesel consumption, replaced instead with electrical power. It must be noted again, however, that this occurred in South Afri
generated via burning coal, thus producing significant amounts of GHG emissions.

Figure 11 demonstrates the power consumption of a 5.2 km conveyor located in Germany, designed by Conveyor Dynamics Inc, based on throughput in tonnes per hour.

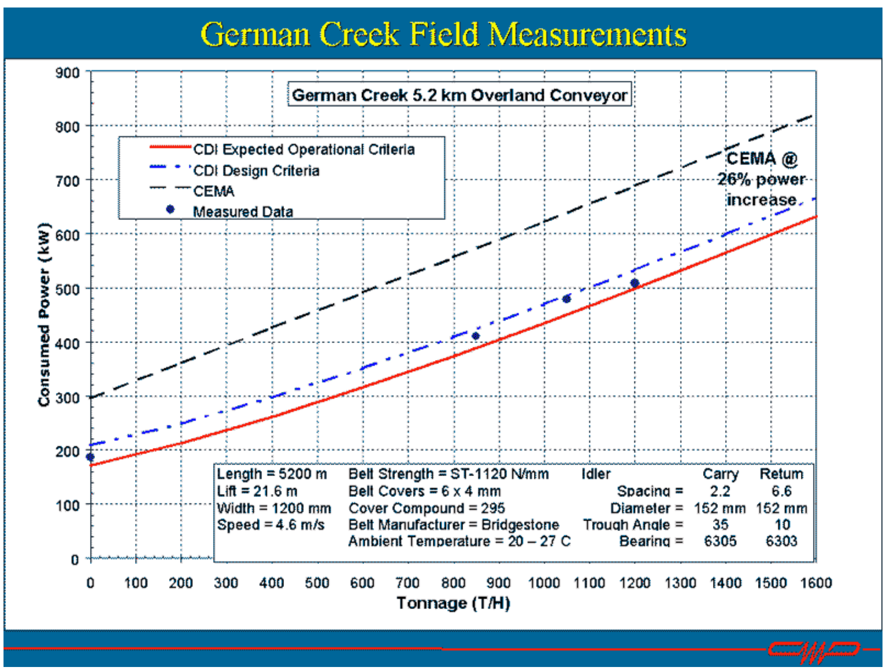



Figure 11 Conveyor power consumption (Nordell, 2010).

In order to deliver 1200 tonnes per hour of ore this would take nearly 6 haul trucks travelling the 5.2 km at 14 km/h to do the same work as the conveyor has. In reality, it would take longer than this as these simple calculations do not take into account such aspects as: slower travel on grade, longer distances of travel (due to switch backs), trucks not always carrying full loads, inexperienced drivers, bad weather conditions, refuelling and maintenance delays, delays due to shift changes and loading/dumping times. Assuming the truck is burning 100 gallons per hour when fully loaded on grade (Hutnyak, 2004) (and this accounts for 70% of the travel time) and 50 gallons per hour on the return journey than nearly 446 gallons of diesel will be consumed per hour of operation. This would result in a total of 5.47 tonnes of $CO_2$ emitted per hour. The conveyor belt on the other hand will consume just over 500 kW to deliver 1200 tonnes per hour. This would result in just 425 kg of $CO_2$ emission for a coal power plant, 295 kg for an oil power plant, and 185 kg for a natural gas plant. Assuming: "Existing power stations emit around 850kg of CO2/MWh; oil-fired stations emit 590kg/MWh and gas stations give out 370kg/MWh" (Jha and Macalister, 2008).

As can be seen from the example above, the use of a conveyor system represents a significant savings in energy consumption and $CO_2$ emissions. Not only are hauling distances shorter with the use of a conveyor system, the speed with which a conveyor can deliver the ore (tested at up to 1200 tonnes per hour) would require a significant fleet of haul trucks working around the clock. The millions of gallons of diesel saved per year represent a significant reduction in $CO_2$ emissions. However, there are many other factors to be considered when deciding to use a conveyor system of haul trucks. Conveyors represent at significant upfront investment for any operations and are usually only justifiable in large scale projects. There are a host of maintenance and technological costs associated with a conveyor. And unlike haul trucks if the conveyor malfunctions it can shut down the entire operation for a significant period of time. Conveyors are also only really favourable in warm dry climates. Excessive cold or precipitation makes it difficult or impossible to employ a conveyor system (ex. Canada, Romania, Scandinavia, etc.). Whilst a conveyor system can offer an operation a significant reduction in carbon footprint, this is only one of many factors that must be considered and unfortunately usually one of the less urgent.

## 3.4 In-Pit Crushing and Conveying

### 3.4.1 Introduction

This section is the study on applying the in-pit crushing and conveying system (IPCC) into a mine as the reduction strategy for reducing CO2 emissions. The background of the system will be introduced together with the advantages and disadvantages.

Material transportation significantly affects the capital and operating costs. A conventional truck haulage system is the most common in open-pit mining due to its reliability and flexibility. The haulage cost can be up to 50% of total mining costs (International Mining, 2011). The cost depends on fuel, tyre, labour and maintenance expenditures. With the rising fuel prices and environmental responsibilities being highlighted, in-pit crushing and conveying are considered to have great advantages in terms of fuel savings and CO2 ($CO_2$) emissions (Parker, 2008).

**How it works**

An in-pit crushing and conveying system consists of the crusher near the mine face in the pit, accompanied by belt conveyors that transport the crushed materials to their destination out of the pit. The crushing unit can be jaw gyratory, gyratory, hammer, impact, roll, and jaw crushers. The systems are classified by their mobility capabilities that range from fully mobile crushers to fixed crushers. The fixed crushers have low mobility while the fully mobile crushers are mounted on a frame base, allowing the unit to be moved by a transporter, such as a crawler system or a walking mechanism. The units rest on the bearings and mechanics so maintenance cost is the highest of the other in-pit crushers and the lowest in availability (Parker, 2008). Lastly, semi-mobile crushers stand on the ground closer to the mine face. The relocation takes a few days, in which the operation is completely stopped. This makes them a popular choice in terms of the cost-benefit ratio (Parker, 2008).

The in-pit crushers are fed by typical excavator-truck fleet with the short haulage distance that gradually increases from the mining face. The moveable crushers, with their ability to move the crusher along the mining face, can be fed directly by the excavator. A crawler-mounted lifting device is used, to move the components to a new position in the pit. (Table 5)

**Table 5 Comparison of in-pit crusher systems (Tutton and Streck, 2009)**

| Feature | Fixed | Semi-fixed | Relocatable | Moveable |
|---|---|---|---|---|
| Capacity | High | High | Medium | Medium-low |
| Typical crusher | Gyratory / Jaw | Gyratory / Jaw | Twin roll crushers or sizes | Twin roll crushers or sizes |
| Relocating | Rarely relocated | Every 3-5 year | Every 6-18 months | Often relocate to follow the shovel |
| Common feature | Associated with transport tunnel | Associated with transport tunnel or wide truck ramp | Multiple crushing stations with conveyor ramps and conveyor distribution point | Feed onto bench conveyor or conveyor bridge |

During the design phase, a number of factors are to be considered to install the in-pit crushing system, including the rigidity of the conveyors, the layout of the infrastructure and electricity, energy required, the width of the haul road and traffic management and the mine layout. Relocation of the system also needs some considerations, such as the relocation of the ramp, bridge, ground compaction and power lines that need moving.

**Advantages ï disadvantages**

The advantages of truck haulage system are that they are flexible and manoeuvrable (Hartman and Mutmansky, 2002). They have moderate gradeability and can handle coarse or blocky rock. On the other hand, trucks require good haul roads, high operating cost and they are slowed by bad weather. The advantages of belt conveyor systems are that they can deliver high and continuous output with very good gradeability and low operating cost. This study also noted that the belt conveyor systems help reducing the labour requirement have better operational system safety and more environmentally friendly than trucks. However, they require a high investment cost. Furthermore the conveyors are inflexible and limited only to carrying small or crushed rock. Crushing is required to limit the maximum lump size for conveyor transportation of hard rock even if it is not needed later, (for example, waste material) and this could increase crushing costs and $CO_2$ emissions.

The ñrule of thumbò by McIntosh Engineering economical than truck haulage if the conveying distance is further than 1 km. While beyond 1 km distance, CEMA handbook states that the weight-distance cost of transportation by belt conveyor may be as low as one tenth of cost by haul truck. Trucks also tend to be empty on the return journey (Yardley and Stace, 2008). Furthermore only 40% of the energy consumed is expended hauling material. The remainder is employed hauling the truck itself while the conveyors consume some 80% of the energy delivering the payload. In addition, energy consumption for truck is 3 times greater than for conveyors on the level and up to 8 times greater lifting the payload out of the pit.

**Table 6 Comparison of truck haulage and in-pit crushing units**

| | Truck haulage | In-pit crushing and conveyor |
|---|---|---|
| Flexibility | Flexible | Inflexible |
| Size | Possible for coarse rock | Limited size to crushed rock |
| Gradeability | Moderate gradeability | Ability to operate over a range of grades |
| Operating and maintenance cost | Higher | Lower |
| Initial investment cost | Lower in most cases | High |
| Power | Mostly fuel | Mostly electricity |

Environmental benefits also include reducing of pollution because the conveyor can be housed in enclosures retaining dust and noise. Since fewer trucks are required, the belt conveyors use less fuel and most importantly, produce lower CO2 emissions (Table 6).

However, a study that evaluated belt conveyor and truck haulage systems in an open pit mine using life cycle assessment showed an unexpected result in terms of environmental impact. The study was conducted using a hypothetical hard rock gold mine in Canada with the transport distance of waste and ore of 4 and 15 km respectively. The results show that, for 4,000 tph, the conveyor has 2,820 kg $CO_{2e}$ per functional unit, compared to 648 kg for the truck option. It is to be noted that the study included the production and transportation of oil and electricity (coal-fired power plant) in addition to the operation of the mine site (Awuah-Offei *et al*., 2009).

### 3.4.2 Recent projects

IPCC are widely used in the continuous loading such as bucket wheel excavator as well as in the lateral and unconsolidated deposits with wide benches such as coal and oil sand and most of projects that can be found are in the coal mines. S (2003) suggests that it is not profitable to dig homogenous material with discontinuously working excavators, and that type of material is best dug by continuously working excavators.

This study focuses on the IPCC in the gold mine case studies. The section will represent the projects related to IPCC in open-pit mines that develop vertically. This is known as the case of large open pit mines which can be found, for instance, in iron ore, copper and gold mines. The main challenges for consideration are hard rock, deep pit, phase or push back development, narrow bench width, impact of blasting and flexibility where waste and ore deposit in the same bench and the materials go the a number of destinations. Furthermore, it is also necessary to consider the fully mobile unit or the semi mobile unit. In hard rock and stone mining, there is little possibility of hauling by conveyor without preliminary sizing. Therefore the UK hard rock quarries employ blasting and out-of-pit primary stage crushing, off-highway trucks with a degree of flexibility far in excess of fixed position belt conveyors, truck still predominate(Yardley and Stace, 2008). However there is a successful example in a hard rock mine at Midland Quarry Products Cliffe Hill granite quarries in Leicestershire, UK. The quarries conveyed its rock 1.44 km from the semi-mobile primary crusher at the old site through a 713 m long tunnel to the new plant at up to 2500 tonne per hour (Yardley and Stace, 2008). This example points out that material has to be crushed before transported by belt conveyor which means waste rocks also needs to be crushed using this system. In the gold mines, for example, where the stripping ratio is relatively high, this factor needs to be considered.

In a recent project, CITIC Pacific Mining, a large iron project has installed four in-pit crushers from ThyssenKrupp, each with the capacity of 4,250 tonnes of magnetite iron ore per hour. The systems are powered electrically and moved by crawler units (CITIC Pacific Mining, 2010). There is also information that in China, conveyor belt systems in opencast iron ore mines are becoming popular especially in large open pits of more than 100 m deep (SBM, 2011).


**Figure 12 Example of IPCC in large open-pit mines. a and b (Tutton and Streck, 2009), are from Chuquicamata mine in Chile with a steep conveyor. C is Escondida mine, Chile (Schröder, 2003), and d is Highland Valley Copper in Canada.**

Some open pit copper mines use IPCC (Figure 12). However, these crushers were in fixed locations with relocation on a project basis. This can be regarded as the vertical in-pit conveyor and also Chuquicamata mine is the example for the waste crusher in hard rock open pit mines (Tutton and Streck, 2009).

A case study of a semi-mobile crusher in copper mine from ThyssenKrupp shows that the system has 8,000 tph capacity (40 million tpa) and a short truck haul. With an average distance of 0.75 km and a depth up to 600 m, $CO_2$ reduction compared with a truck system would be 150,000 tpa (Tutton and Streck, 2009).

For a fully mobile system, Tutton and Willibald (Tutton and Streck, 2009), stated that the relocatable systems are not common in deep hard rock mines as well as to date (2009), no fully mobile systems in large scale, hard rock mines yet. The comments from Dave Tutton can also be found in the International Mining magazine, May 2011 (International Mining, 2011), that the IPCC for large open pit copper and gold mines will require more flexible systems and the ability to accommodate them within the mine plan without significantly impacting the metal and waste schedules. The systems are currently still being examined.

The study of replacing trucks by fully mobile crusher and conveyors in Carajas, the largest open pit iron ore mine in Brazil claimed to be the first metalliferous, deep open pit operation in the world to consider a fully mobile system. The system was designed to have two fully mobile crushing plants with a capacity of 3,900 tons/hour each for waste. The result was feasible and the system would replace 15 haul trucks. For the ore, three units of fully mobile crushers at 2,000 tons per hour each would be applied. The system would replace four trucks. $CO_2$ reduction accounts for up to 133,000 tons per year (L ¼cei *et al.*, 2009).

There are some general statements for the IPCC system listed by Sandvik for basic overview of the system feasibility before the detail study (International Mining, 2009):

- Mine life: at least 4 years to pay back capital and more than 10 years is ideal
- Tonnage: at least 10 Mtpa per stage and 25 Mtpa is preferred
- Energy cost: electricity costs per kWh less than 25% of diesel price per litre
- Space for operation: at least 100 m is needed
- Rock strengths: up to 150 MPa
- Gravity: conveyors can generate power on downhill runs
- Truck cycle times: IPCC may not work well below 25 minutes cycle times

## 3.5 Load and haul fleets efficiency

Mining heavy equipment, especially haulage fleets, consume large volume of fuel as presented in chapter 3. Only slightly saving results in significant volume of fuel used. Energy efficiency plays a vital role in fuel saving and $CO_2$ emissions.

In Australia, mining operations have to conduct the energy mass balance (EMB) to meet the requirements of the Energy Efficiency Opportunities (EEO) program, as detailed in the EEO legislation. The aim of the EMB is to improve understanding of the overall energy system and to provide insights into potential energy efficiency opportunities. The key requirements include the data collection process, the energy analysis process and a comparison of performance to theoretical and actual energy use. For electricity and gas consumption, the scope for error marg
data and larger for some energy and mass flows that cannot be accurately measured (The Energy Efficiency Opportunities, 2010).

In this study, energy efficiency of haulage fleet is conducted to identify potential opportunities on saving fuel resulting in $CO_2$ emissions. Comparisons of performance of theoretical and actual fuel use are estimated in some cases.

**Cycle time analysis**

Cycle time consists of the time to complete one cycle of operation including loading, hauling, dumping and returning to the operation area. The cycle time changes depends on the changing of working face, distance, material, haul road conditions and excavating conditions. The optimum matching fleet can be estimated from the points that truck capacity should be approximately four times of excavator bucket capacity at minimum and it should not exceed 6-8 times at maximum (Ekka, 1989).

Loading and hauling account for a large proportion of total fuel consumption in open pit mine as presented in chapter 3. Idling trucks lower production and waste fuel so match time of equipment is important. A way to reduce emissions from fuel usage is to improve the mining fleet efficiency. This can be done using cycle time analysis. In this section, actual cycle time from field observed was used. Potential production can be calculated from truck and excavator time.

**Haul road condition**

An important measure of haul road surface conditions is the rolling resistance. Rolling resistance is the force needed to maintain the forward movement of a truck or the energy lost from tyre penetration. Rolling resistance affects wear and tear on the truck, reduces fleet productivity, and increases fuel consumption (Tannant and Regensburg, 2001) (Figure 13).

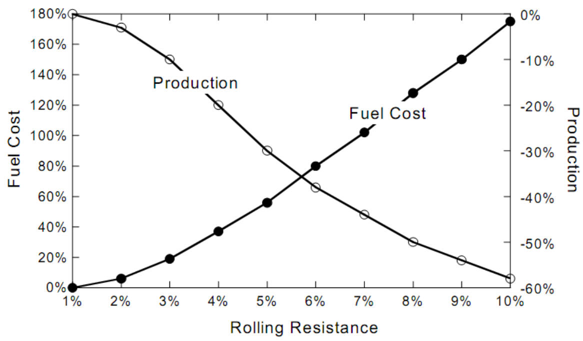



**Figure 13 Rolling Resistance versus performance (Tannant and Regensburg, 2001).**

A study on CAT 777 operating on a 7.3 km 7% incline, decreased rolling resistance from 8% to 4% would reduce capital cost by 29% and operating cost by 23% for 5 million tons per annum rate (Thompson and Visser, 2003). Another analysis on rolling resistance highlights that for CAT793, if rolling resistance increased from 6% to 15%, the truck has to change from 5$^{th}$ gear at 35 km/hr to 4$^{th}$ gear at 20km/hr or lower. This means the truck will consume more fuel to travel the same distance (Tannant and Regensburg, 2001). In this section, the study on effect of Rolling Resistance on $CO_2$ emissions was conducted. This section used the data from Truck handbook cycle time comparison section (Case A, CAT777) and different Total Resistances were applied. This analysis was conducted on 3.6 million tonnes at 46.2 l/h fuel burn rate. Given 2,883 m one-way haul distance on surface ground, assuming grade resistance equal to zero (flat surface), and 7.4 minutes of loading, dumping and waiting time. Rolling Resistance from 4% (good road) to 10% (poor road) was applied. Total truck travel time ranges from 8.3 to 19.2 minutes (Table 7).

**Table 7 Effect of total Resistance on fuel consumption and $CO_2$ emissions.**

| Total Resistance | 4% | 6% | 8% | 10% | |
|---|---|---|---|---|---|
| Truck cycle time | 15.6 | 18.7 | 22.4 | 26.6 | mins |
| Potential production | 345 | 288 | 241 | 203 | tph |
| Potential hour | 10,518 | 12,602 | 15,057 | 17,882 | hour |
| Fuel used | 485,921 | 582,235 | 695,637 | 826,127 | litre |
| $CO_2$ produced | 1,237 | 1,483 | 1,772 | 2,104 | t $CO_2$ |
| $CO_2$ produced | 0% | 20% | 43% | 70% | |

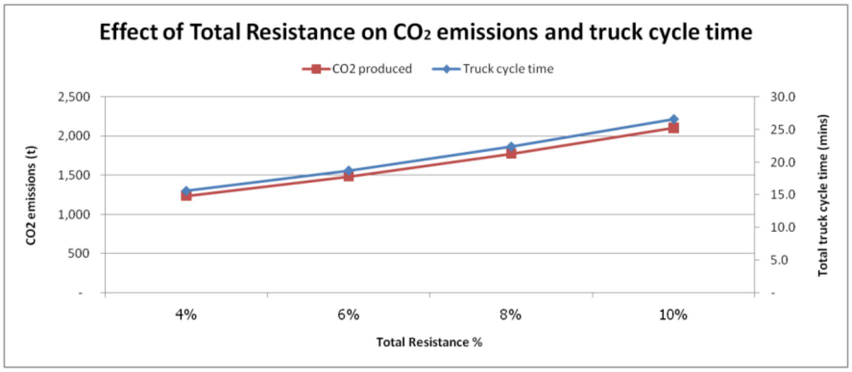



Figure 14 Effect of Total Resistance on $CO_2$ emissions and truck cycle time

Increased Total Resistance results in increased cycle time and has a negative effect on fuel consumption and $CO_2$ emissions (Figure 14). If Rolling Resistance increased from 4% to 10%, $CO_2$ emissions, at the same rate as truck cycle time, increases by 70%.

**Engine load**

Another factor that control fuel consumption is engine load factor which determines the portion of full power required to operate the machine. Low engine load also means low fuel burn rate. To simplify, loaded journey uses more power than empty journey and travelling uphill needs more power than downhill. Estimation of engine load factor and fuel consumption can be found in the performance handbook. Load factor guide from Caterpillar are as listed (Table 8).

Table 8 Load factor guide (Caterpillar, 2007)

| Engine load factor | Operation at gross weight | Haul roads | Overloading | Load factor |
|---|---|---|---|---|
| Low (20%-30%) | An average gross weight less than recommended. | Excellent | No overloading | Low |
| Medium (30%-40%) | An average gross weight approaching recommended. | Good | Minimal overloading | Moderate |
| High (40%-50%) | At or above maximum recommended gross weight | Poor | Overloading | High |

According to Runge (1998), fuel consumption can be determined from the following equation (Kecojevic and Komljenovic, 2011):

Fuel consumption (L/hr) = Engine power (kW) x 0.3 x Load Factor

**Payload management**

Gross weight of truck has large influence on fuel consumption. For example machine weight and payload are needed to determine maximum speed attainable, gear range and available rimpull using the Rimpull-Speed-Gradeability curve. The Australian

Energy Efficiency Opportunities guidance presented the effect of payload to fuel consumption for CAT789C truck as seen a l § (Figure 15).

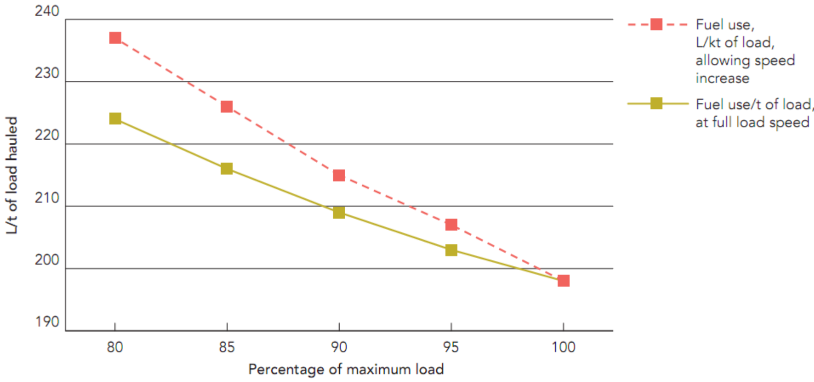



**Figure 15 Sensitivity analysis: Effect of velocity constraints on fuel intensity (The Energy Efficiency Opportunities, 2010)**

Fuel consumption per tonne is at its lowest when the truck is fully loaded and increases as payload decreases. Reducing load to 80% of maximum can increase fuel consumption rate by 20%.

Caterpillar also mentioned that for its 793F electric truck which is heavier than its mechanical one consumes more fuel and has higher emissions (Jamasmie, 2010). At Blair Athol, Rio Tinto's electric m were upgraded, and bucket and rigging weights were decreased. This improvement saved 4,300 tonnes $CO_{2-e}$ emissions per year (Queensland Resources Council, 2010). Moreover, Thiess has identified potential of $CO_2$ reduction from improvement of payload management in several coal mines in Queensland. It argued that this has the potential to reduce up to 8,200 tonnes $CO_{2-e}$ emissions per year (Queensland Resources Council, 2010).

**Operational practice**

Equipment operating practices can sometimes provide greater fuel efficiency benefits than improved engine technologies. For example, equipment operator training could yield energy savings of about 10% (The Energy Efficiency Opportunities, 2010). Some examples of fuel efficiency from operating behavior are listed as follows.

**Driving behaviour**

A recent study recorded fuel consumption and engine speed during the dumping cycle of seventy two 240-ton haul trucks and found thatt fluctuation in fuel consumption was explained by the observation that the operator pushed the accelerator pedal while dumping (Modular Mining Systems, 2010). This raised the engine speed from 1500 rpm to the excess of 1900 rpm. However the dumping time was not affected by the engine speed and this behaviour consumed 80% more fuel. Theoretical fuel savings estimation associated with solving excessive engine speed was conducted across a range of 30 to 100% of total loads. Fuel savings were 83,000 ï 275,000 litres per year or up to 736 t $CO_2$ (Modular Mining Systems, 2010).

**Excavator operating**

Proper excavator operating position provides efficient digging. Suggested positions from the machine handbook should be considered. Ideal operating positions for Caterpillar series 300 are provided for a clear idea, as listed (Caterpillar, 2007).

1. Bench height and truck distance should equal to stick length for consolidated materials and less for unconsolidated material. And the truck body rail is below the boom stick hinge pin.
2. Figure **16 Recommended excavator and truck operating position**
3. , a)
4. Optimum work zone and swing angle should b machine center or about equal to undercarriage width. Trucks should be positioned as close as possible to machine centreline. (
5. Figure **16 Recommended excavator and truck operating position**
6. , b)
7. Distance from the edge, for the best breakout force and time saving, should be that the stick is vertical when the bucket reaches full load. And the operator should begin boom-up when the bucket is 75% of the way through the curl cycle, as the stick nears the vertical position. (
8. Figure **16 Recommended excavator and truck operating position**
9. , c)
10.

**Figure 16 Recommended excavator and truck operating position**

Sammut, Komatsu Germany, argues that the correct position with the excavator on the higher level with the bucket raking up the fa result in cycle time as low as 20-23 seconds. While if the truck is on higher level the efficient drops as the shovel operator has to load the bucket and swing and lift to load the truck. Moreover, double-side loading proved to be a more productive because the excavator does not have to wait for trucks (Fiscor, 2010) (Figure 17).