Flexible Delivery Flat-Pack Module

An Overview of Energy Efficiency Opportunities in Mining and Metallurgy Engineering

Produced by

The University of Adelaide and Queensland University of Technology (The Natural Edge Project)

The EEERE Project:

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Project Background

Energy efficiency is widely recognised as the simplest and most cost-effective way to manage rising energy costs and reduce Australia's greenhouse gas emissions. Promoting and implementing energy efficiency measures across multiple sectors requires significant development and advancement of the knowledge and skills base in Australia, and around the world. Engineering has been specifically identified as a profession with opportunities to make substantial contributions to a clean and energy-efficient future. To further enable skills development in this field, the Department of Industry commissioned a consortium of Australian universities to collaboratively develop four innovative and highly targeted resources on energy efficiency assessments, for use within engineering curricula. These include the following resources informed by national stakeholder engagement workshops coordinated by RMIT:

1. *Ten **'flat-pack'** supporting teaching and learning notes for each of the key disciplines of engineering (University of Adelaide and Queensland University of Technology);*
2. *Ten short **'multi-media bite'** videos to compliment the flat-packs (Queensland University of Technology and the University of Adelaide);*
3. *Two **'deep-dive case studies'** including worked calculations (University of Wollongong); and*
4. *A '**virtual reality experience'** in an energy efficiency assessment (Victoria and LaTrobe Universities).*

These resources have been developed with reference to a 2012 investigation into engineering education[1] funded by the Australian Government's former Department of Resources, Energy and Tourism (RET), and through further consultation workshops with project partners and industry stakeholders. At these workshops, participants confirmed the need for urgent capacity building in energy efficiency assessments, accompanied by clear guidance for any resources developed, to readily incorporate them into existing courses and programs. Industry also confirmed three key graduate attributes of priority focus for these education resources, comprising the ability to: think in systems; communicate between and beyond engineering disciplines; and develop and communication the business case for energy efficiency opportunities.

Content

1. 'Allen Key' Learning Points

Mining and Metallurgy Engineers will be a key part of the World's response to climate change, from optimising vehicle use and logistics to significantly reduce diesel use on mine sites, through innovating new processes and technologies to reduce energy used in crushing and grinding, to using recycled steel to reduce the energy demands of steel making. Mining and Metallurgy Engineers have critical skills the economy needs to thrive in a carbon constrained future. The following learning points provide a summary of the Mining and Metallurgy Engineering video – our 'Allen keys' to building the flat-pack content!

Watch the '***Mining and Metallurgy***' MMB

1. Given that mining focuses on the extraction and basic processing of raw materials and metallurgy refines those materials to make useful products they are both very complimentary and can both deliver significant energy efficiency improvements.
2. The mining industry in Australia faces significant challenges in that ore deposits are become less concentrated and require greater levels of energy to extract the same volumes, and energy costs and labour costs in Australia are quite high. The industry is moving from investment in new mines towards the ongoing operation of existing mines; meaning costs need to be cut in order to be globally competitive.
3. Even if reducing greenhouse gas emissions is not important to owners of mining sites the potential to save energy through the reduced use of energy provides an important cost saving option. A crucial skill for engineers is to be able to communicate the business case for investing in energy efficiency improvements in a way that makes financial sense for a company and speaks to the CEO and CFO. A key way to represent this opportunity is by developing an energy mass balance to show the flows of energy in the operation and to then attribute the associated costs to create an energy cost balance.
4. The mining industry is one of the largest energy consumers in Australia, representing some 11% of energy demand, and this presents a number of opportunities to improve energy efficiency. For instance transportation of material between the mine and the processing mill is a major energy demand, with much of this material being transported being waste.
5. Also the crushing and grinding of rock down to a size where we can extract the valuable minerals is an energy intensive process. Given that grades of ore are declining, in order to maintain production of a tonne of copper say, greater volumes of material must be transported and then crushed and grinded, leading to increasing energy demands and associated costs.
6. An example is the Palabora Mining Company in South Africa, where due to an increase of some 300% in energy costs a review was undertaken to identify opportunities to reduce demand. Based on an understanding of the 'energy mass balance' and 'energy cost balance' for the operation the review identified that there was potential to save up to 30 per cent of the energy consumption by targeting the most energy intensive processes, which translated to a potential cost saving of US $20 million per year. Based on this review the team were able to take actions in the first year alone that deliver a 10 per cent reduction in energy costs.

2. Energy Efficiency and Mining and Metallurgy Engineering

2.1. Why is Energy Efficiency important for Engineers?

In the 21st Century much of the world will experience untold wealth and prosperity that could not even be conceived only a century ago.[2] However as with most, if not all, of the human civilisations, increases in prosperity and population have accumulated significant environmental impacts that threaten to result in what Lester Brown refers to as '*environmentally-induced economic decline*'.[3] There have been a number of significant advances in technology over the last 300 years that have delivered a step changes in the way industry and society has operated, as shown in Figure 1. Given the now advanced level of technological development we are in a very strong position to harness this technology to create a '6th Wave' that can deliver significant reductions in a range of environmental pressures, such as air pollution, solid waste, water extraction, biodiversity loss and greenhouse gas emissions.[4]

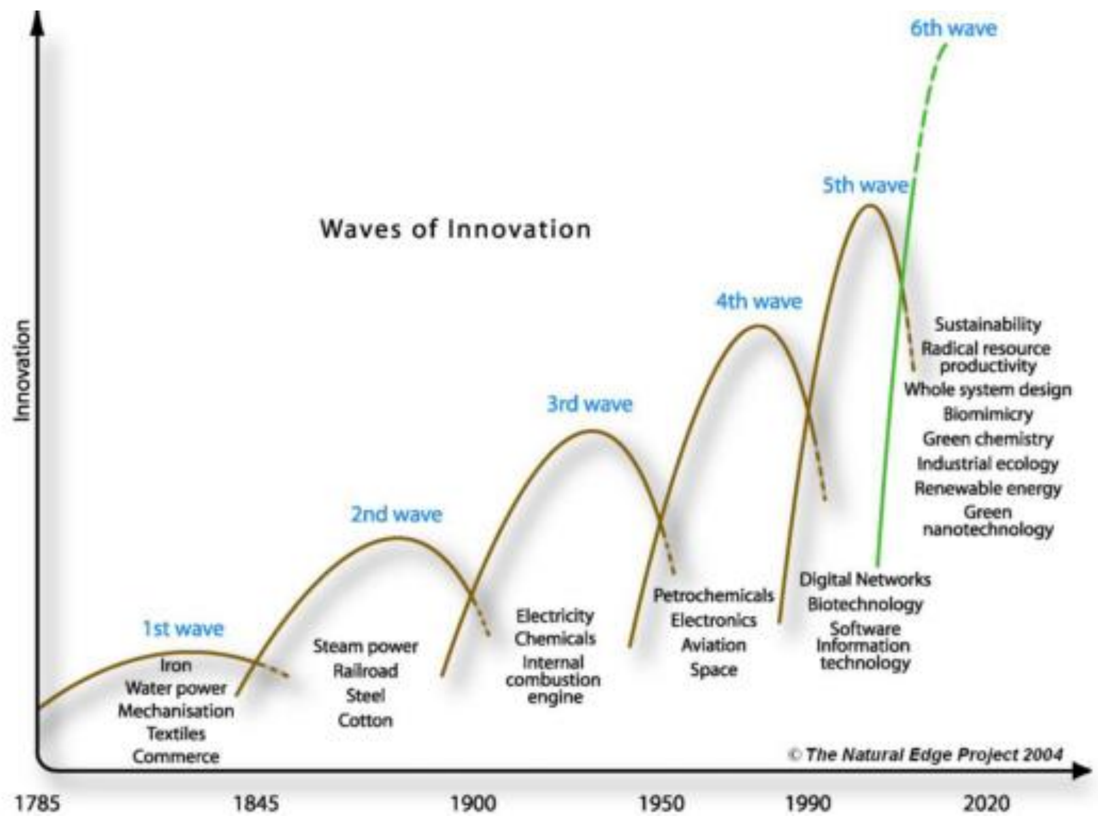

Figure 1: A stylistic representation of waves of innovation since the Industrial revolution[5]

What this means is that over the coming decades the impact we are having on the environment will have a direct negative effect on our economies and societies, this will, and is, lead to louder and lauder calls to reduce negative impacts on the environment which will need innovation and creativity. In particular there is a fundamental need to shift from fossil fuel based energy to low/no carbon energy sources, preferably renewable options, in order to significantly reduce greenhouse gas emissions. Building on the technologies and processes from the previous waves of innovation engineers are now in a strong position to deliver such a shift and create a range of innovative and creative solutions to the meet the needs of society, with a key part of this achieving greater efficiency of the use of resources and energy.

According to the World Business Council for Sustainable Development (WBCSD) in their 1992 publication 'Changing Course', the term 'efficiency' was used to seek to encapsulate the idea of using fewer resources and creating less waste and pollution while providing the same or better services, and entailed the following elements:

- A reduction in the material intensity of goods or services,
- A reduction in the energy intensity of goods or services,
- Reduced dispersion of toxic materials,
- Improved recyclability,
- Maximum use of renewable resources,
- Increased durability of products, and
- Greater service intensity of goods and services.

Each of these approaches provides valuable tools to reduce a range of environmental pressures, especially greenhouse gas emissions.

Identify a Mining or Metallurgy example of the application of each element.

For each element identify the potential for collaboration with other engineers.

Since the late 1990's Engineers Australia has advocated for Engineers to play a key role in supporting the achievement of such ambitious targets, and cautions that, '*The need to make changes in the way energy is used and supplied throughout the world represents the greatest challenge to Engineers in moving toward sustainability.'*[6] By the end of 2014 this shift had built significant momentum with the European Union committing to reduce emissions by at least 40 per cent by 2030 (compared to 1990 levels), China setting the goal of 40 to 45 per cent by 2020 (compared to 2005 levels), India setting the goal of 20-25 per cent by 2020 (compared to 2005 levels), and the United States of America setting the goal of 26-28 per cent by 2025 (compared to 2005 levels). Further the Intergovernmental Panel on Climate Change (IPCC) reports that all nations will need to achieve significant reductions in greenhouse gas emissions in the order of 60-80 per cent by 2050.[7]

> ***These ambitious targets will create significant pressure to reduce emissions in the coming decades, in particular between 2015 and 2030; and all industries grapple with the challenge of reducing greenhouse gas emissions in a manner that delivers ongoing prosperity, jobs, and profits.***

A key part of this energy transition is to swiftly reduce the growing demand for energy across society as this will generate numerous cost savings that can be invested in the shift to low/no carbon energy, along with reducing demand levels that need to be met by the new energy solutions. Reducing the energy demand say of a building or a processing plant delivers the following benefits:

- *Generates cost savings* by reducing the energy charges, extending the life of equipment by reducing the loading, reducing operating times and levels of equipment and even allowing decommissioning of some equipment, and often reduces heat generated from equipment or lighting that adds load to the HVAC system.
- *Creates capital for investment* in the transition to the use of low/no carbon energy, often by investing in onsite renewable energy generation options that can harness waste heat from the existing system while providing security of supply for the operation of the building or plant.

- *Creates demand for new products and services* that will be needed around the world to assist industries and economies to reduce energy demand. This will translate into significant opportunities for Australian engineering firms that can innovate low/no carbon solutions ahead of international competition.[8]

Energy efficiency as a concept has gained significant attention over the last few decades, as governments and industries around the world have grappled with issues such as rapidly expanding needs for energy, the cost of supplying infrastructure to meet peak demand, the finite nature of fossil based energy reserves, and transition timeframes for expanding renewable energy supplies. Coupled with a growing number of cases of companies achieving significant fossil fuel consumption reductions in a timely and cost effective manner, energy efficiency is quickly becoming a core part of the practice of engineers, as shown in Table 1.

Where are greenhouse gas emissions generated in mining and metallurgy?

How could energy efficiency provide benefits to a mining or metallurgy operation?

Table 1: *Example opportunities to significantly reduce greenhouse gas emissions*

Sector	Best Practice Case Studies
Steel Industry[9]	Leading US steel company, Nucor Steel, is around 70% more energy efficient than many steel companies around the world,[10] using state-of-the-art electric arc furnace systems, adopting leading practices such as net shape casting, and by implementing options such as energy monitoring, systems for energy recovery and distribution between processes.[11]
Cement Industry[12]	Ordinary Portland cement manufacture is responsible for between 6-8% of global greenhouse emissions and this is rising with demand. The good news is that an Australian company Zeobond Pty Ltd, based in Melbourne, is now making geo-polymer cement which reduces energy usage and greenhouse gas emissions by over 80%.[13] Geo-polymers can be used for most major purposes for which Portland cement is currently used.[14]
Paper and Pulp Industry[15]	Catalyst Paper International improved their energy efficiency by 20% across all operations since 1990, saving the company close to US$26 million between 1994 and 2004. At the same time, they've reduced their greenhouse gas emissions by 69% through greater use of biomass and sourcing electricity from hydro power.[16] The pulp and paper sector has the potential in both existing and new mills to become renewable electricity power generators through the use of Black Liquor Gasification-Combined Cycle technologies.[17]
Transport Vehicle Efficiency[18]	Integrating technical advances in light-weighting, hybrid electric engines, batteries, regenerative breaking and aerodynamics is enabling numerous automotive and transport vehicle companies to redesign cars, motorbikes, trucks, trains, ships and aeroplanes to be significantly (50-80%) more fuel efficient than standard internal combustion vehicles. Plug-in vehicle technologies are opening up the potential for all transportation vehicles to be run on batteries charged by renewable energy.[19]
Transport Efficiency from Modal shifts. (Passenger)[20]	Shifting transport modes can also lead to significant energy efficiency gains. One bus with 25 passengers reduces energy and greenhouse gas emissions per capita by approximately 86% per kilometre compared to 25 single occupant vehicles (SOV).[21] Trains are even more efficient. Typically, rail systems in European cities are 7 times more energy-efficient than car travel in US cities.[22]
Transport Efficiency from Modal Shifts (Freight)[23]	Shifting freight transport from trucks to rail can also lead to large efficiency gains of between 75 and 85%.[24] Several countries are moving to improve the efficiency of their transport sectors by making large investments in rail freight infrastructure, including improving the modal interfaces. For instance, China has invested US$292 billion to improve and extend its rail network from 78,000 km in 2007, to over 120,000km by 2020, much of which will be dedicated to freight.

Source: Based on von Weizsäcker, Hargroves, K. *et al* (2009)[25] as presented in Hargroves, K., and Desha, C. (2014)[26]

Considering Buildings, efficiency expert Joseph Romm explains that key to delivering improved energy efficiency of buildings is the understanding that the design phase is critical, pointing out that, '*Although up-front building and design costs may represent only a fraction of the building's life-cycle costs, when just 1 per cent of a project's up-front costs are spent, up to 70 per cent of its life-cycle costs may already be committed*'.[27] As pointed out in the book '*Whole System Design: An Integrated Approach to Sustainable Engineering*',[28] the cost of design changes increases significantly through the design and construction process, and as such it is important that early in the concept design phase opportunities for energy efficiency are identified and incorporated into the design rather than retrofitted at a later date, especially as buildings and civil infrastructure are designed with an operational life of some 50-100 years.[29]

A key part of the design is to consider the potential for compounding energy efficiency savings. Energy efficiency expert Alan Pears uses the example of an electric motor driving a pump that circulates a liquid around an industrial site.[30] If each element in the chain is improved in efficiency by 10 percent, the overall efficiency is not improved by 10 per cent but rather 47 per cent as the overall efficiency is the product of the component efficiencies: 0.9 x 0.9 x 0.9 x 0.9 x 0.9 x 0.9 = 0.53. Applying this systems approach can deliver significant energy demand savings, such as: [31]

– By focusing first on reducing both the mass of a passenger vehicle and the aerodynamic drag by 50% this can reduce rolling resistance by 65%; making a fuel cell propulsion system viable and cost effective, and delivering significantly better fuel consumption per kilometre.

– By using the right-sized energy efficient components to reduce generated heat, a computer server can be designed to have 60% less mass and use 84% less power than the equivalent server, which would reduce cooling load in a data centre by 63%.

A key outcome of a focus on energy efficiency is that it often also delivers multiple benefits across the system can be often overlooked. For example energy efficient cleaning systems may use less water and detergents, light-weighting vehicles to improve fuel efficiency may reduce material consumption, reducing cooling loads in a building through external shading may extend the operating life of air-conditioning equipment, reducing pumping loads in a system may lead to decommissioning of unneeded pumps, reducing residential energy demand during peak times can significantly reduce overall capacity requirements and defer infrastructure upgrades.

2.2. Why is Energy Efficiency important for Engineering Students?

In 2006 the Australian Government created the Energy Efficiency Opportunities (EEO) Act with the objective to '*improve the identification, evaluation, and public reporting of energy efficiency opportunities by large energy-using businesses, to increase the uptake of cost effective energy efficiency opportunities*'.

The EEO Act was applicable to corporations that used over 0.5 petajoules of energy per year; this represented some 300 companies and just over half of Australia's total energy use. Participating companies were required to undertake an energy efficiency assessment and report to the government on the findings.

Watch an Introduction to the EEO Program

Between 2006 and June 2011 participants in the program identified the potential for annual energy savings of 164.2 PJ through a focus on energy efficiency across each major sector, as shown in Figure 2. As part of the program 89 PJ of energy was saved, the equivalent of 24 billion kWh's per year.

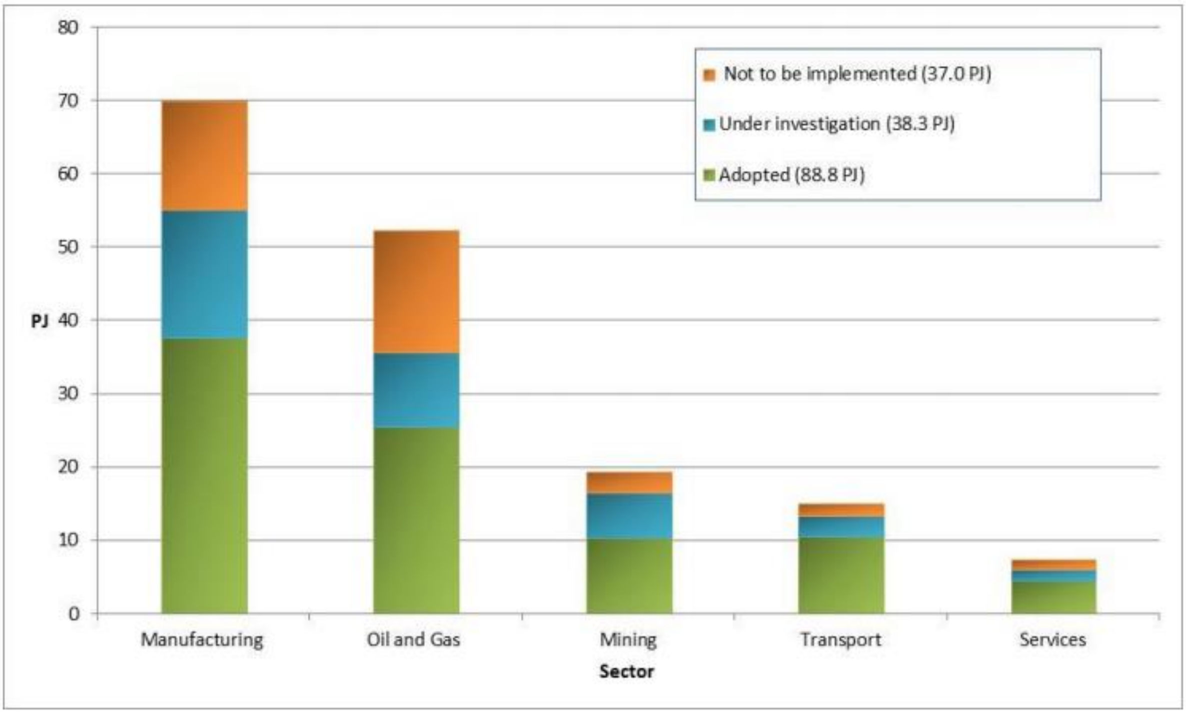

Figure 2: Summary of energy efficiency achievements in by participants in the Australian Government Energy Efficiency Opportunities (EEO) program (2006-11)[32]

This energy saving is estimated to have resulted in an annual economic benefit of just over $800 million, with the majority of investments to achieve the energy savings having either a 1 year or 2 year return on investment.[33] The significance of this program for engineering students is that the largest energy using companies in the country have developed processes to undertaken energy efficiency assessments and the ability to contribute to such assessments is likely to become a part of graduate recruitment preferences given the strong economic results from the EEO program.

> ***In 2011 an investigation found that 6 out of the 10 largest engineering companies operating in Australia provided in-house training on energy efficiency to supplement graduates formal training, and 4 out of the 10 had included energy efficiency requirements in graduate recruitment criteria.[34]***

Of further interest to engineering students is that the participants in the program listed an aggregate of 38.3 PJ of energy saving opportunities (or some 10 billion KWh per year) as being 'under investigation', meaning that graduates can differentiate themselves by ensuring they are well versed in energy efficiency.

List a specific opportunity for Mining and Metallurgy Engineers to achieve energy efficiency improvements in each of the sectors shown in Figure 1.

3. Key Knowledge and Skills for Mining and Metallurgy

According to the NSW Minerals Council, '*The mining industry is constantly reviewing ways to increase the efficiency of their operations and be more competitive, this includes actively pursuing energy efficiency. With the price of energy increasing substantially across gas, oil, and electricity and with this trend likely to continue, it makes good business sense to support energy efficiency measures*.'[35] This is in line with Australian Institute for Mining and Metallurgy (AusIMM) commitment to '*aiming for a sustainable minerals industry that provides benefits to all Australians*', and the institute has formed Sustainability Committee.[36]

The NSW Minerals Council identifies a range of methods to monitor and improve energy efficiency that will involve engineers, including:[37] energy audits, energy metering, process and productivity improvements, investment in efficient equipment and technology, equipment maintenance, strategic management of transport fleets, and selection of fuel types (eg. selecting liquefied natural gas or biodiesel over diesel fuel). Considering the graduate attribute, "*Ability to Participate in/Contribute to Energy Efficiency Assessments*", in Mining and Metallurgy Engineering this should include:

- Planning for both underground and surface operations, such as finding energy efficiency opportunities in the integrated functions of mining and beneficiation,
- Identifying the most appropriate ore bodies, and selective mining processes (as they affect the quantity of material to be handled in a beneficiation plant, and therefore energy consumption),
- Finding energy efficiency opportunities in different transportation alternatives, including minimising need for transport,
- Utilising coal seam gas (CSG) liberated during coal mining processes, and
- Designing for closure, to reduce legacy costs and energy requirements (i.e. Life of Mine Design and Planning).

As part of the consultation with Engineers Australia it was suggested that the following knowledge and skills should be of focus in Mining and Metallurgy Engineering education:

- Proficiency in identifying energy efficiency opportunities related to mining methods, including for example, rock breakage (use of explosives and communition) and transportation.
- Ability to 'design for closure', to reduce legacy costs and energy requirements (Life of Mine Design and Planning)
- Ability to undertake energy balance and consumption calculations, and greenhouse gas accounting, including analysis and optimisation skills

4. Energy Efficiency Examples in Mining and Metallurgy

*Here we provide a summary of key materials outlining energy efficiency opportunities related to Mining and Metallurgy Engineering. This section informs **'Tutorial Exercise 6: Identify examples of energy efficiency opportunities in particular engineering disciplines'** from the Introductory Flat-Pack.*

READING

4.1. Diesel use in the Mining Industry

The efficiency of a process is improved most effectively when all aspects of the process are thoroughly investigated – it is possible for improvements to come from unexpected areas which can have a large impact on overall efficiency gains. As part of the Energy Efficiency Opportunities program by the Australian Federal Government, a number of resource companies found that efforts to reduce diesel usage for mine haul and transport operations may provide substantial savings, and rigorous investigations into the factors that affected fuel efficiency were undertaken. The following summary provides key findings from these investigations.[38]

Reducing Stoppage Time for Haul Trucks

In the case of Fortescue Metals Group, an analysis of the different operating modes of their trucks was undertaken, examining fuel consumption rates, vehicle speeds, trip distances and other parameters in each operating mode (including: travelling empty, loading, stopped while loaded, travelling loaded, and stopped while empty). The average time in each of these modes was determined for the fleet and it determined that trucks spent the greatest time stopped while empty; this then resulted in the modelling of scheduling options to minimise idle time.

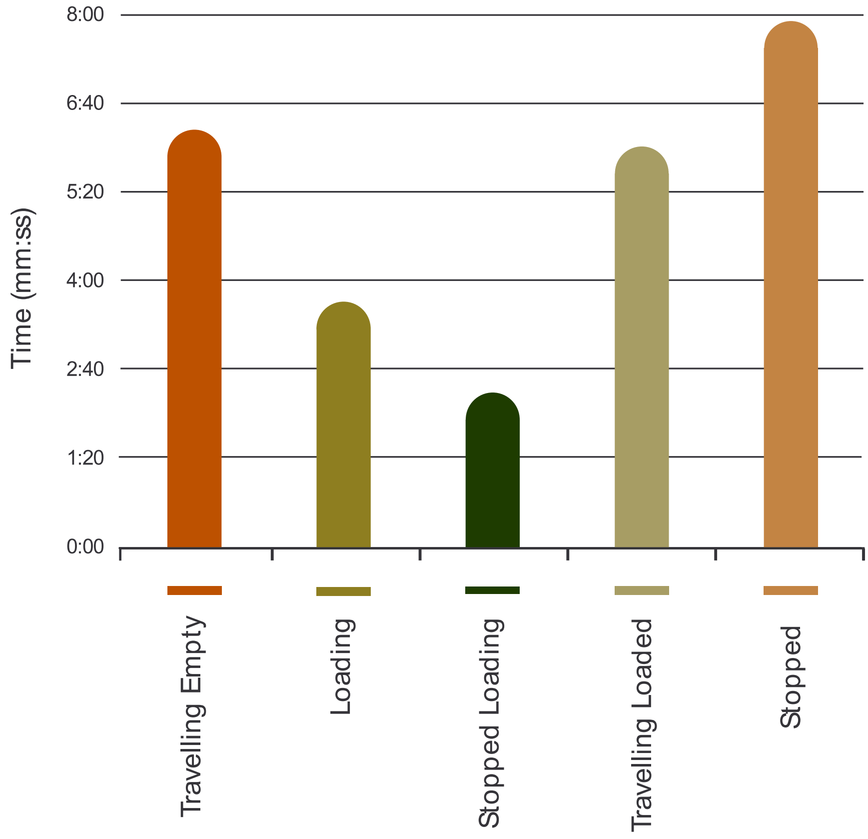

Figure 2: Average time per loading cycle spent in each operating mode for the FMG mine haul truck fleet[39]

Another of the main sources of inefficiency identified for mine haulage was that of trucks stopping unnecessarily, and then having to accelerate back up to operating speed, wasting energy in acceleration and time slowing and speeding up. FMG worked with their truck manufacturers to quantify the effects of this braking-acceleration cycle, as compared to travel at constant speed, and calculated the additional fuel use. FMGs fleet moves 55 million tonnes of ore per annum, and when the energy costs of unnecessary braking and acceleration were extrapolated across the haul fleet, additional fuel usage was determined to be 361,000L of diesel (13,935GJ of energy) per annum for its Caterpillar 777 trucks, and 407,000L (15,710GJ) per annum for its Terex 3700 fleet, *for every additional stop per payload cycle*. Reducing the number of stops would also decrease wear on the truck braking systems, reducing maintenance costs. This information could then be integrated into mine planning costs, and the energy efficiency of FMGs fleet improved as a result.[40]

Identify 5 variables that would need to be considered to model the scheduling of mine site trucks to minimise idle time.

Considering the Equivalent Flat Haul

Downer EDI Mining has developed the Downer Energy and Emissions Measure (DEEM) that considers the effects on energy demand of all of the variables which can affect mine efficiency. The consumption of fuel for the various pieces of equipment is then normalised across all equipment, and the resultant measure, GJ or tonnes CO_2-equivalent, is calculated per tonne-kilometre. To compliment such a measure Downer EDI have developed a measure of Equivalent Flat Haul (EFH) to normalise elevation changes in order to take into account the surprisingly large impact on energy demand on equipment from changes in elevation as they move around the site. This information must be accounted for if the intention is to alter the mine design and operation of the plant and fleet to improve efficiency.

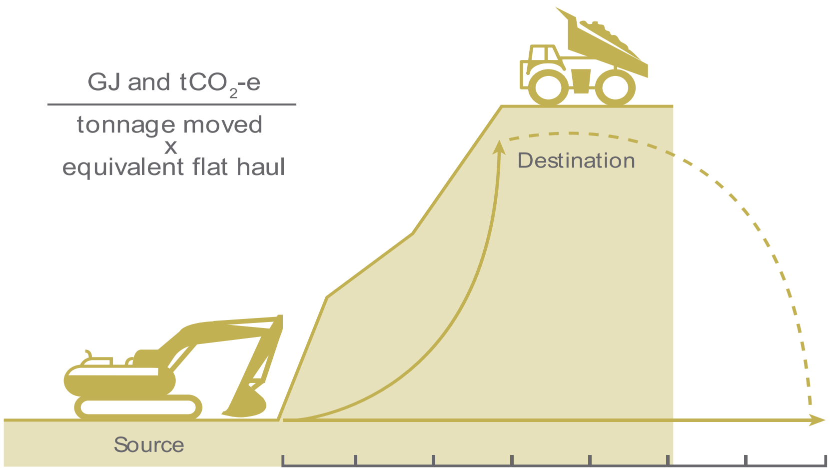

Figure 3: Equivalent flat haul accounts for characteristics of the route taken, as well as the distance travelled[41]

Using these measures, Downer can track performance of their mine sites, and assess the impact of different factors on energy efficiency, such as changes in mine design or equipment size, changes to production schedules, the performance of individual operators, and even weather. Accurate reporting allows these changes to be correlated with changes in efficiency with the energy performance of sites tracked over time. This information informs improvements to processes and equipment to deliver reduced energy demand, saving the operation money while delivering a reduction in associated greenhouse gas emissions.[42]

Benchmarking Best-Practice in Mining Operations

Leighton Contractors have developed a system to use benchmarking to measure and identify best-practice at their sites and using this information to improve practices at other sites. Leighton's Best Truck Ratio (BTR) assessment tool, which is used to determine optimum mine design and hauling parameters, uses a theoretical benchmark (the 'best truck') as a measure of assessment for vehicle and site characteristics; parameters such as slope grade and payload (both shown below), truck model, and surface rolling resistance are assessed for efficiency. For a defined task, the BTR is the ratio of actual energy consumed divided by the best-practice benchmark energy consumption. The measure allows Leighton to compare performance between sites, trucks, operator, and other parameters, and individual haul trucks can be tracked during a day to examine differences between haul cycles.[43]

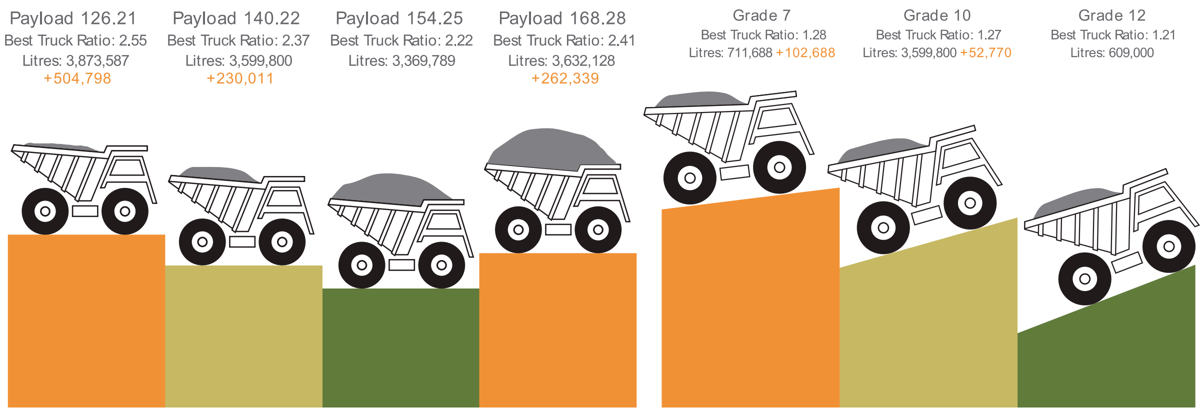

Figure 4: Using the BTR to assess the effect of different payload amounts (left) and slope grade (right) – the fuel consumption values are based on 20 million tonnes of ore moved, the lower the BTR the higher the fuel efficiency.[44]

The results of these assessments can be used to help plan hauling practices, equipment choice, and mine design; for example, the figure above shows a comparison of the efficiency of a truck for two different parameters:

1. Different payloads: The efficiency of a specific truck model can be optimised using the BTR model, providing the greatest haul for a given amount of fuel. This data can be used when planning truck numbers required for site operations.
2. Different slope grades: Truck efficiency actually increases with increasing slope to a certain level, as the steeper slope corresponds to a shorter travel distance to exit the pit, and this has a greater effect on the fuel consumption than extra load on the engine due to the steeper incline.

The information used for these calculations is harvested from actual haul cycle data, mine site information and GPS data, and more information is fed into the model over time, increasing the accuracy of its predictions, and allowing better optimisation of equipment, hauling practices and mine design, further increasing efficiency.[45]

4.2. Steel Production

As the 2010 book '*Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity*' pointed out, the energy efficiency of steel manufacture can be increased by as much as 80 per cent. The following part contains material extracted from the book 'Factor Five' that has been edited to be relevant to mining and metallurgy education by Charlie Hargroves and Cheryl Desha, co-authors of '*Factor Five*'.

Electric Arc Furnaces for Steel Production

The bulk of steel produced in the world uses either a 'Basic Oxygen Furnace' (BOF) or an 'Electric Arc Furnace' (EAF), each with different energy demands. A BOF generates heat for the steel making process by injecting pure oxygen at high pressures onto molten iron; and an EAF generates heat by running an electric current through electrodes to create an arc that melts iron and metal. Given the use of electricity the EAF process presents the possibility of using renewably generated electricity for steel making, substantially reducing the associated fossil fuel demand. According to a study in 1994, '*Electric arc steel furnaces use one-tenth of the fuel compared with traditional basic-oxygen blast furnace steel plants.*'[46] According to the OECD EAF technology emits over four times less CO_2 per unit of steel produced than BOF technology.[47] A study by the US Department of Interior and the US Geological Survey forecast in 1998 that EAF plants would produce the majority of steel in the world.[48] Both processes can use scrap steel as feedstock with the EAF process being most energy efficient when using 100% scrap steel, achieving a low as 9.1 GJ/t compared to an optimum minimum of 19.8 GJ/t for the BOF process, as shown in Figure 5.

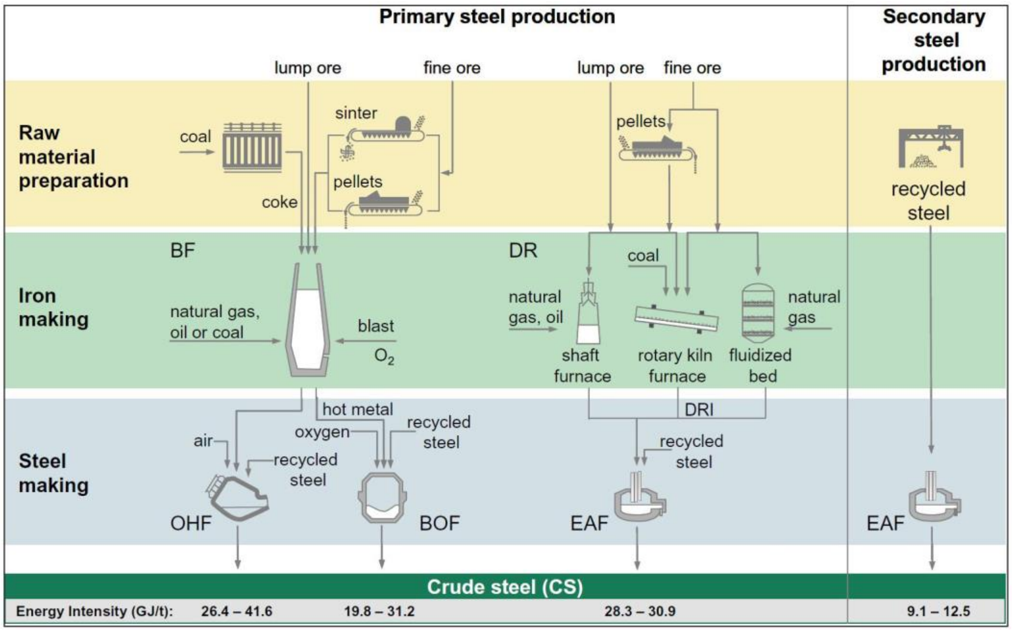

Figure 5: *Energy Intensity of various steel making processes (1) BOF Process (58% of global operations[49]), (2) EAF/DRI process (7%) and (3) EAF process (27%)*

Source: World Steel Association (2008)[50]

As the EAF process can produce all types of steel products this means that the smaller and cheaper plants have the potential to replace most BOF plants around the world.[51] Hence, as the EAF process can make steel cheaper, faster and more efficiently compared to the BOF processes, they are highly attractive in periods of economic downturn, allowing steelmaker Nucor to not only be one of the most profitable steel companies in the USA, but the only company in the sector to maintain its workforce, with all staff taking a 50% pay cut, during the 2008-2009 global financial crisis, despite over 25,000 worker layoffs in the steel sector in the US.[52]

> ***How much scrap steel is generated each year internationally?***
>
> ***Which country is the largest importer of scrap steel?***

Improving Energy Efficiency of Blast Oxygen Furness Steel Plants

As part of a transition to EAF plants Metallurgy Engineers can initially focus on improving the energy productivity of existing BOF processes. The 'Hismelt' process can reduce the energy intensity of a BOF process by up to 50 per cent as it allows the smelting reduction process to be undertaken without the need for a coke oven or a sinter plant, and can run on cheap non-coking coals.[53] This is particularly important to allow greater flexibility in the output levels of the process, as according to the Institute of Materials, Minerals and Mining, '*running traditional oxygen blast furnaces is expensive, as they are inflexible and generally uneconomic to run at anything less than full capacity*'.[54] Hence such innovations can significantly reduce both the operational and up-front capital costs, allowing the process to more cost effectively vary its output to optimise production with market price signals.[55]

Researchers at the Ernest Orlando Lawrence Berkeley National Laboratory have identified a number of specific energy efficiency technologies and measures that are available to improve the energy productivity of BOF's as shown in Table 1.

Table 1: Indications that Steel Companies are improving the energy productivity of BOF plants

Iron Ore Preparation (Sintermaking)	***Casting***
– *Sinter plant heat recovery*	– *Adopt continuous casting*
– *Use of waste fuels in the sinter plant*	– *Efficient ladle preheating*
– *Reduction of air leakage*	– *Thin slab casting*
– *Increasing bed depth*	***Rolling***
– *Improved process control*	– *Hot charging*
Coke Making	– *Recuperative burners in the reheating furnace Controlling oxygen levels and variable speed drives on combustion air fans*
– *Coal moisture control*	– *Process control in the hot strip mill*
– *Programmed heating*	– *Insulation of furnaces*
– *Variable speed drive on coke oven gas compressors*	– *Energy efficient drives in the hot rolling mill*
– *Coke dry quenching*	– *Waste heat recovery from cooling water*
Iron Making - Blast Furnace	– *Heat recovery on the annealing line (integrated only)*
– *Pulverized coal injection (medium and high levels)*	– *Automated monitoring & targeting system*
– *Injection of natural gas*	– *Reduced steam use in the pickling line*
– *Top pressure recovery turbines (wet type)*	***Overall Measures***
– *Recovery of blast furnace gas*	– *Preventative maintenance*
– *Hot blast stove automation*	– *Energy monitoring and management systems*
– *Recuperator on the hot blast stove*	– *Variable speed drives for flue gas control, pumps, and fans*
– *Improved blast furnace control*	– *Co-generation*
Steel Making - Basic Oxygen Furnace	
– *BOF gas & sensible heat recovery (suppressed combustion)*	
– *Variable speed drive on ventilation fans*	

Source: Worrell et al (1999)[56]

Improving Energy Efficiency of Electric Arc Furness Plants

In the case that a DRI process is used to reduce iron to supplement scrap steel inputs the FINEX process can be used to eliminate the sintering and coke making steps. This can result in substantial cost and energy savings, along with reductions in air pollution - with the emission of sulphur oxides (SOx) and nitrogen oxides (NOx) falling to 19% and 10%, respectively.[57] Assuming 100% scrap steel feedstock is available research shows that productivity of the EAF process can be improved by as much as 50%, with such options outlined in Table 6, such that "*a typical mid 1990s energy requirement was 550 kWh per ton of product, but best practice is now considered to be around 300 kWh, with 'ideal' theoretical performance around 150 kWh.*"[58] As with BOF plants, researchers at the Ernest Orlando Lawrence Berkeley National Laboratory have identified a number of specific energy efficiency technologies and measures that are available to improve the energy productivity EAF plants as shown in Table 2.

Table 2: Indications that Steel Companies are improving the energy productivity of EAF plants

Electric Arc Furnace Operation	***Rolling***
– *Improved process control (neural networks)*	– *Hot charging*
– *Flue gas monitoring and control*	– *Recuperative burners in the reheating furnace Controlling oxygen levels and variable speed drives on combustion air fans*
– *Transformer efficiency measures*	– *Process control in the hot strip mill*
– *Bottom stirring/gas injection*	– *Insulation of furnaces*
– *Foamy slag practices*	– *Energy efficient drives in the hot rolling mill*
– *Oxy-fuel burners/lancing*	– *Waste heat recovery from cooling water*
– *Post-combustion*	– *Heat recovery on the annealing line (integrated only)*
– *Eccentric bottom tapping (EBT)*	– *Automated monitoring & targeting system*
– *Direct current (DC) arc furnaces*	– *Reduced steam use in the pickling line*
– *Scrap preheating*	***Overall Measures***
– *Consteel process*	– *Preventative maintenance*
– *Fuchs shaft furnace*	– *Energy monitoring and management systems*
– *Twin shell DC arc furnace*	– *Variable speed drives for flue gas control, pumps, and fans*
Casting	– *Co-generation*
– *Adopt continuous casting*	
– *Efficient ladle preheating*	
– *Thin slab casting*	

Source: Worrell et al (1999)[59]

Near Net Shape Casting of Steel

Casting steel into its final form is an energy intensive component of the steel making process and companies that are positioning themselves well for future economic performance will be using or transitioning to the use of processes such as 'Near Net Shape Casting' that can offer significant energy productivity improvements. The process involves steel being cast as close to its intended form as possible to minimise machining and finishing. According to a 2004 study if by 2025, 40% of US steel is cast using this new process this would result in an estimated primary energy saving equivalent to 10% of total projected primary energy use in the steel industry, and that if there was an uptake of 100% by 2025, this would be the equivalent of an approximately 25% energy productivity improvement across the US steel-making industry.[60] Nucor installed its first commercial Near Net Shape Casting facility at its Crawfordsville plant in Indiana USA - developed by Nucor working with BHP (Australia) and IHI (Japan) – and allowing Nucor to delivering steel with 60 – 70% less energy intensity than BOF competitors.[61]

The Use of Alternate Fuels for Steel Production

Steel plants can use a range of alternate fuels such as waste plastic, rubber, oils and car tires, with appropriate emissions control. According to the American Iron and Steel Institute (AISI), the use of such fuel alternatives can be expanded to provide a viable fuel supply for steel production globally,[62] especially considering the growing levels of municipal solid waste generation that contains many of these substances. Other alternatives include coal gasification and the use of charcoal as a replacement for coke in primary steel production that can lead to GHG emissions reductions of over 60%.[63]

Researchers at the University of New South Wales have shown that waste plastic can be used to offset energy requirements by up to 30%.[64] The research also shows that plastic not only replaces coal to provide the source of carbon, it reduces the energy consumption of the furnace as it provides additional combustible fuel. Professor Veena Sahajwalla reflects that, '… *if you look at its chemical composition, even something as simple as polyethylene that we all use in our day to day lives, has about 85% carbon and 15% hydrogen, so it's simply a carbon resource*'.[65]

Identify a case study of the use of alternate fuels in the steel production process and the greenhouse gas emissions to with the use of fossil fuels.

5. Case Studies of Energy Efficiency in Mining and Metallurgy

Building on the multi-media bite on Mining and Metallurgy Engineering and energy efficiency the following example provides further details on the energy efficiency improvements related to Mining and Metallurgy Engineering. This section is also designed to inform ***'Tutorial Exercise 7: Review industry case studies for areas of energy efficiency opportunities'*** *from the Introductory Flat-Pack.*

5.1. Iluka Resources Installations

Large industrial plants typically offer significant opportunities for improving efficiency, saving energy and money simultaneously. Iluka Resources, as one of the larger Australian resources companies, provides a number of good examples of ways in which efficiencies can be found; everything from upgrades to single components in existing systems, through upgrades to site infrastructure, to major process alterations. David Robb, Managing Director of Iluka Resources, has stated that he is, *"committed to the process of improving energy efficiency within Iluka operations as it is the responsible thing to do and it makes good business sense."*[66]

The Challenges

Overall efficiency of a site can be enhanced by examining existing equipment, and determining whether it is still the best option to perform its particular operation – in some cases, reviews of existing systems identify changes to operating conditions which can provide opportunities to save energy. The following challenges were identified as part of the Iluka operations:

1. At the Iluka Mid West operations pumps are used in the process water circuit of the mineral separation plant. The operations manager has asked the design team to assess the energy demand of the system for possible savings.
2. At the Jacinth-Ambrosia site pumps are used to boost capacity to an elevated location in the water circuit. The operations manager has asked the design team to assess the energy demand of the system for possible savings.
3. The mineral separation system uses a process of electrostatic separation that requires the minerals to be completely dry with the drying carried out by gas-fired dryers. Considering that the wetter the input stream the more energy is required for the drying operation the operations manager has called for the design team to assess the energy demand of the system for possible savings.

The Solutions

1. The process water circuit pumps at the Iluka Mid West operations were investigated and compared to more efficient options and it was found that upgrading the pumps would save 3,700 GJ of energy – and $72,000 – per year, and the changes would pay for themselves in under a year.[67]
2. The pumping system at the Jacinth-Ambrosia site was assessed and it was found that by redesigning the system to move parts of the piping circuit to a lower elevation the pump was no longer needed, resulting in saving of a 4,900 GJ of energy - and $165,000 – per year.[68]
3. The design team undertook a whole of system assessment of the mineral separation system and identified that processes in the pre-drying stages could be modified to minimise the water

content of material entering the dryers, despite this requiring greater energy input in the drying stage the overall result was a saving of 30,800 GJ of energy – and $164,000 - per year across the entire process, with a payback period of less than 2 years.[69]

Key Lessons

Each of the savings in energy demand achieved by the design team came from considering the system as a whole and considering if the efficiency of parts of the system could be improved (such as in the case of the pump upgrade at the Mid West operations), if the configuration of the system could be improved to reduce energy demand (such as in the Jacinta-Ambrosia site), and parts of the system could be changed to result in an overall reduction in energy demand across the entire system (as in the minerals separation process).

Taking this approach to an even larger scale, Iluka conducted an *energy-mass balance*[70] on their South West kiln operations in 2009, it enabled them to look through the process of synthetic rutile production, and determine where there was energy input, energy transformation, and energy loss from the system. It allowed the assessment team to track how much energy was being used – and potentially how much was being wasted or lost – at each stage of production. The plant was already operating with systems designed to enhance energy efficiency in that the plant ran a waste heat recovery system that utilised exhaust gases from the kiln to generate steam, which in turn powered a generator, providing power for downstream physical and chemical processing systems in the plant. The energy-mass balance conducted identified that the waste heat recovery system was not operating as efficiently as it could and an optimisation was undertaken.[71]

The resultant optimisation enabled the plant operators to maximise the re-use of waste heat and optimise the steam turbine generator. The energy-mass balance undertaken allowed key plant performance indicators to be quantified and optimised, enabling the operations team to further optimise the running of the plant, and the resultant energy savings – 338 TJ per annum – were equal to 8.7 per cent of the total energy use of the plant. The energy savings meant that the modifications made had a payback period of less than 2 years, and the success of the energy efficiency work was highlighted when the lessons learned from the work were applied at another of Iluka's sites (Mid West Operations), where similar energy savings were made. There, approximately 179 TJ of energy per annum, or 4.7 per cent of the total energy use of the site, was saved.[72]

5.2. Barrick Gold

Optimisation of a single, energy-intensive process can have a significant impact on the energy use of an operational site, as in the case of the grinding processes used on Barrick Gold installations.[73]

The Challenge

Ore grinding is an essential process in gold recovery, but is very energy-intensive - ore grinding can account for 60% of a mine site's electrical power load and more than 35% of CO_2-equivalent emissions, and in Barrick's case, the ore grinding machinery they have on-site (at 19 of their 26 operations) accounts for 55% of on-site energy use, and 21% of total energy use by the company, and corresponds to 1.7 million tonnes of CO_2-e emissions. The cost of this energy is also significant – electricity for grinding machinery costs Barrick $300 million per annum, out of a total $1 billion in total energy cost.

The Solution

An examination of the grinding process was undertaken to identify opportunities for savings in energy and cost. A comprehensive model of the grinding circuit at each site was developed, with help from an internal expert. The model allowed assessment of the circuit efficiency compared to its theoretical efficiency (which is calculated for the specific ore hardness encountered in the grinding process for the site). Modifications can be assessed using the model, and on the basis of the model results, the most effective modifications can be applied to on-site machinery. The resultant changes in efficiency are then recorded for the altered process, which allows the accuracy of the model to be assessed, and provides further data for additional modification of the specific circuit, and other circuits on other Barrick sites, enabling continuous improvement of the process.

At Barrick's Cortez site the grinding circuit operated efficiently at the start of the site's operation and processing was well-matched to the mine production, but over time, as the depth of the mine pit increased, the ore being processed became harder, and one component of the circuit (the semi-autogenous grinding mill, or SAG mill) became a limiting factor in the process. Modelling and analysis of the grinding process identified a number of options for increasing process efficiency, including: changing the profile of the SAG mill liner and lifters, making improvements to the slurry pumping system in place, and changing the profile of the cone crusher in the circuit. These improvements were undertaken, and the energy savings were significant, totalling 71,000 GJ of energy per annum, and 13,900 tonnes per annum of CO_2-e emissions.

The changes also resulted in improvements to the process apart from increased energy efficiency – the changes to the liner and lifters in the mill allowed its rotational speed to be reduced, reducing wear and smoothing operation; changing the profile of the cone crusher lead to an increase in its power draw, but this improved the process as a whole, as the cone crusher is several times more efficient than the SAG mill, and the change meant that the cone crusher output particle size was reduced, which corresponded to the SAG mill having to do less grinding (a smaller recirculating load); and there was a decrease in the amount of over-ground ore that passed through to the discharge filtering system, which has to be collected and processed.[74]

6. Key Supporting Resources

The following resources are recommended by the research team to assist lecturers to expand the content contained in this introductory level lecture. For guidance as to embedding such materials into existing course see the 2014 book 'Higher Education and Sustainable Development: A Model for Curriculum Renewal'.[75]

6.1. Australian Government

Energy Efficiency Exchange (EEX)

Opportunities - Mining: A number of initiatives which can help improve the energy efficiency of the Mining and mineral processing sector are outlined below. These strategies rely on an integrated approach to realise the full potential of the opportunities.[76] (See Resource)

Energy Efficiency Opportunities Program (EEO)

Analysis of Diesel Use for Mine Haul and Transport Operations: This Case Study aims to provide mining companies with examples of comprehensive analyses of diesel use in mining operations used by Fortescue Metals Group Ltd, Downer EDI Mining Pty Ltd and Leighton Contractors Pty Limited. It provides several examples of analytical techniques that have been used in the mining sector to develop a rigorous understanding of energy and material flows, and enable the identification of energy savings for haul truck operations and rail operations.[77] (See Resource)

6.2. The Natural Edge Project (TNEP)

Opportunities for Energy Efficiency in the Aluminium, Steel and Cement Sectors: The Aluminium, Steel and Cement Sectors are significant contributors to greenhouse gas emissions. Hence the educational aim for this lecture is to provide an overview of the energy efficiency opportunities in the aluminium, steel and cement sectors, and to provide access to the best online resources, outlining in detail the energy efficiency opportunities for each sector.[78] (See Resources)

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