Measuring sustainable development in industrial minerals mining

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Abstract: This paper presents a set of SD indicators for mining with a specific focus on the extraction of industrial minerals. The proposed metrics are based on the International Council of Mining and Metals 10 SD Principles and are organised into a mining life cycle framework that includes four stages: 1) exploration and mining; 2) processing; 3) transportation and logistics; 4) markets. The goal of the proposed metric is to provide a standardised but flexible format that can be broadly applied across a range of industrial minerals. A key aspect of this approach is that it ensures a standardised framework while offering the option of tailoring the individual indicators to meet the needs of and maintain relevancy for specific minerals that may not fit a single set of indicators.

Keywords: mining; industrial minerals; life cycle analysis; sustainability; environmental impacts.

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1 Introduction

Over the past decade the mining industry has increasingly focused on sustainably extracting and processing industrial minerals. This trend has been driven by higher energy costs, diminishing water resources and sensitivity towards environmental stewardship. Industrial minerals have been used throughout human history as low cost, naturally occurring, materials. Today they are critical components of recycled packaging, energy efficient building materials, light weight paper coatings, and other products critical to the responsible utilisation of global resources. As industrial minerals become more widely used in 'green' products, mining companies have established best practices for the sustainable management of industrial minerals mining and processing. These management practices include reducing energy consumption, minimising water usage, increasing waste recovery through recycling and process optimisation, and maximising the amount of ore extracted per acre of disturbed land. With the commitment to sustainable development (SD) principles, quantitative methods for objectively measuring SD performance have become increasingly important. Measuring sustainability impact is a valuable tool for effectively applying SD principles and for making choices that balance sustainable development against other business objectives.

2 Sustainable development and mining

Sustainable development is a term that has become a common part of our lexicon; however, it has multiple meanings and interpretations leading to a sometimes confusing and contradictory array of definitions. The absence of a single, precise definition reflects the fact that SD is a broad concept or paradigm that offers guiding principles as opposed to a specific set of criteria or regulations.

While a principle based conceptual approach allows businesses to broadly apply SD practices that are tailored to their specific situation, it has also led the public to sometimes view voluntary corporate SD programs with a degree of skepticism (Walker and Howard, 2002). This is particularly true in the mining industry. One reason for this skepticism is that the relationship between SD and mining is misunderstood and to many, sustainably developing non-renewable mineral resources is a contradiction (Rajaram et al., 2005). However, this view is based on a narrow interpretation of SD. The second is that mining carries a legacy of poor environmental stewardship that does not accurately reflect current mining industry environmental practices.

Many minerals companies have adopted the Brundtland Comission's definition of SD (United Nations, 1987):

> "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

This definition is very broad and can be interpreted in a number of ways. It provides a general context for sustainable development and is not intended to provide detailed guidelines addressing specific aspects of sustainable development. To fill this gap the following SD principles were drafted by the international minerals community in 2003 (ICMM, 2003):

1. Implement and maintain ethical business practices and sound systems of corporate governance.
2. Integrate sustainable development considerations within the corporate decision-making process.
3. Uphold fundamental human rights and respect cultures, customs and values in dealings with employees and others who are affected by our activities.
4. Implement risk management strategies based on valid data and sound science.
5. Seek continual improvement of our health and safety performance.
6. Seek continual improvement of our environmental performance.
7. Contribute to conservation of biodiversity and integrated approaches to land use planning.

8 Facilitate and encourage responsible product design, use, re-use, recycling and disposal of our products.

9 Contribute to the social, economic and institutional development of the communities in which we operate.

10 Implement effective and transparent engagement, communication and independently verified reporting arrangements with our stakeholders.

These guidelines insure that SD concepts are applied equally across the industry while setting a clear performance standard and benchmark against which to evaluate success. By adopting these principles and issuing the Milos Statement (Minerals Professional Community, 2003), which provides a more detailed vision for integrating SD into everyday business operations, the minerals industry has embraced SD as a core corporate value. The unifying and holistic approach embodied in SD principles impacts the entire mine to market life cycle and addresses the economic, environmental and social consequences of mining.

3 Industrial minerals

The world economy relies heavily on minerals; they are essential to economic prosperity and the quality of life. Industrial minerals are non-metallic, non-fuel minerals that provide the raw materials for a vast range of products used in most every aspect of daily life. They are mined and processed worldwide and they span the spectrum from relatively low value, high volume commodities (e.g., common clay, crushed stone) that are typically mined locally to high value, lower volume specialty materials that are sourced from unique one of a kind deposits and are often transported long distances to consuming markets (e.g., barite, talc, mica). High volume commodity mining operations are often located near the end use market which, in most cases, means areas of high population density where construction and other urban activities drive demand. In these situations the strict adherence to SD principles is particularly critical as these are highly visible operations that must meet the public's demand for good corporate citizenship. These operations are similar to chemical or other manufacturing facilities that operate near population centres. In contrast, some mining operations are located in remote but environmentally sensitive regions of the globe where the pressure to mine sustainably is driven by the need to preserve habitat and other natural resources that may be impacted by mining. Both situations require corporate sensitivity and strong commitment to SD principles.

4 Measuring sustainability in the industrial minerals industry

Sustainable development practices promote long-term economic prosperity for the company and community, minimise environmental impact and maximise the use of valuable non-renewable mineral resources (Shields et al., 2006). Many mining companies recognise that sustainable development principles are essential to their overall business strategy and that that they must be implemented in a transparent and consistent way. Consequently, mining firms have voluntarily launched SD programs that often include publicly available SD reports. For example Rio Tinto publishes an annual sustainable development report that includes specific targets for green house gas emissions (GHG), energy consumption and water consumption (Table 1). IMERYS provides a similar publication that highlights specific SD targets in the areas of environment, community, human resources, safety and innovation (Table 2). Vale's annual SD report is a comprehensive document detailing energy, water, green house gas emissions, biodiversity and the social impacts of their global operations. Additionally it includes an external audit of the report and an evaluation against standard reporting guidelines developed by the global reporting initiative (GRI). These are just a few examples of industry SD programs and SD reports. Many more examples can be found by searching company websites.

Table 1 Rio Tinto Minerals' (2008) sustainable development report

Metric	*Target*			*Performance*
Reductions per tonne product by 2008 (from 2003 baseline)	*GHG*	*Energy*	*Water*	
Borate operations	1.00%	0.40%	3.00%	On track
Talc operations – Americas	9.00%	12.10%	21.00%	On track
Talc operations – Europe and Asia Pacific	5.00%	5.00%	12.00%	Not on track
Salt operations	22.00%	12.00%	12.00%	On track
Climate change	Develop three-year climate action change plan			Completed
Energy consumption	Integrate priority sites into Rio Tinto Minerals' energy management plan			Completed
Regulatory violations	Zero violations affecting the community (annual target)			Met target
ISO 14001	Maintain certification of environmental management			Did not meet target in

Company generated reports provide a valuable tool for gauging a company's commitment to SD and these reports offer a benchmark for evaluating progress towards sustainability. However, companies have adopted different indicators and standards for reporting and, without a consistent set of indicators; it is difficult to compare individual corporate SD initiatives. Some companies choose to follow GRI guidelines but there is no requirement to adopt a particular standard. Adherence to GRI guidelines (GRI, 2005) helps by insuring that reports are balanced and unbiased and that accountability measures are in place. These guidelines also insure that all stakeholders have a role in the continuous improvement of the SD reporting process.

In addition to corporate driven measures, quantitative and independent third party SD evaluation tools have been developed and are gaining acceptance by mining companies seeking to apply a more rigorous and consistent measure of SD. Momentum has been building in this area because industry recognises the need for establishing best practices and for adopting a set of standard indicators that are accepted by all stakeholders. Groups that have led this development include government institutions, academia, NGO's and consulting companies often working in collaboration with industry. Agencies leading the way in setting SD standards for mining include International Council on Mining and

Metals, Mining Association of Canada, United Nations, ISO, the Minerals Council of Australia and the National Stone, Sand and Gravel Association (www.nssga.org/ sustainability).

Table 2 IMERYS' (2007) sustainable development indicators

Action area	*Indicator*	*2006*	*2007*
Health and safety	Frequency rate (No. of lost time accidents × 1,000,000/No. of work hours)	7.96	5.76
	Severity rate (No. of lost days × 1000/ No. of work hours)	0.24	0.18
Environment	Number of prosecutions	19	16
	Amount of fines (Euros)	€50,648.00	€64.483.00
	Water use (thousands of litres)	–	71,635,983
	Energy efficiency	–	3.4% increase
	Energy consumption (GJ)	38,620	39,500
	CO_2 emissions (Kt)	2909	2966
	Waste generation (tons)	–	272,068
	Waste recycling (tons)	–	202,270
	Number of ISO 14001 or EMAS certified sites	65	84
Human resources	Headcount by business group, geographic zone and functions	15,776	17,552
	Percentage of women	13.8	14.3
	Seniority	See report	
	Age	See report	
	Working hours lost through strikes	5155	12,065
	Employee shareholders	4108	3653

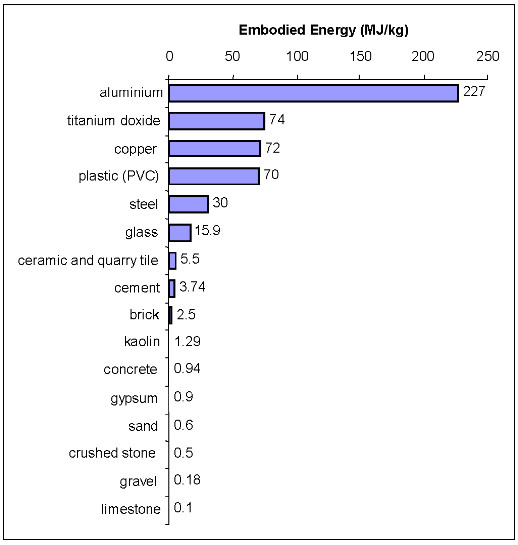
Life cycle assessment (LCA) studies using comprehensive models that simulate ore processing have been at the forefront of environmental assessment in the minerals industry. LCA evaluates the environmental impacts of a system by considering all aspects of a product's manufacture starting with mining (cradle) all the way through to final disposal (grave). These assessments have become increasingly important to the minerals sector and are gaining acceptance as a tool for understanding environmental burdens throughout the process from mining to production. There are many benefits to LCA. LCA integrates complex relationships within the system and allows for more informed decisions. When applied appropriately it is a powerful quantitative method for optimising mining operations while improving profitability and reducing environmental impacts.

In the past, LCA studies have focused on mineral processing and less attention has been given to mineral extraction (Durucan et al., 2006). These studies have also focused most commonly on metals (e.g., Nobuhiko et al., 2001) although in recent years there has been more focus on industrial minerals. Examples of recently published industrial minerals LCA studies include bauxite (Tan and Khoo, 2005) sand (Schuurmans et al., 2005) and clay (Bovea et al., 2007). IMA (Industrial Minerals Association) Europe in collaboration with the European Commission has recently launched a project to develop a

LCA database for industrial minerals. The purpose of the database is to provide policy makers with LCA information and to promote the integration of LCA concepts in policy decisions (http://lca.jrc.ec.europa.eu/lcainfohub/index.vm). This information is particularly important because many LCA studies of manufactured products do not consider the raw material used to make the product and, if they do consider the raw materials, mineral extraction is usually given a very cursory treatment. This is a serious short coming because mineral extraction, processing and transport may have significant environmental impacts on the overall environmental burden of a particular product. Recent work demonstrates that the combined impact of mining and processing exceeds the impact of the remaining stages of the product life cycle (Udo de Haes, 2006). One industry that has taken a leading role in considering the impact of minerals and mining on the sustainability of their products is the building industry. The industry actively engages in life-cycle assessment of construction products, many of which contain industrial minerals and rocks. For example, BRE Global, an independent group that publishes environmental profiles of common building materials, certifies products based on LCA studies that begin with mineral extraction (http://www.bre.co.uk/). The industry also uses the concept of embodied energy (the energy required to extract, process and transport materials) to compare the environmental footprint of various building materials. This is a very useful approach that allows architects, builders and other stakeholders to make informed decisions about the environmental impact of commonly used construction materials. Embodied energy is equivalent to life cycle energy use analysis in LCA.

Although there is not a standard method for calculating embodied energy there is general consensus about the relative ranking of materials (Figure 1). A survey of the literature consistently shows that aggregates, cement and brick have relatively low embodied energy compared to plastic (PVC), steel and aluminum. For these bulk materials, the embodied energy related to extraction and processing is low to moderate but transport to the construction site may substantially increase embodied energy depending on distance of transport.

Figure 1 Embodied energy of various building materials (includes extraction, production and transport) (see online version for colours)



5 Using the industrial minerals life cycle to measure SD impacts

The above discussion illustrates the importance of quantifying SD impact throughout the mining lifecycle. A survey of various publications shows that there are many approaches to measuring SD impact but that there is not a consistent or universally accepted metric or process. To bridge this gap a scoring system for the entire mine to market lifecycle has been developed. It includes 4 key stages:

- exploration and mining
- processing
- transportation/logistics
- marketing.

For each of these stages a set of goals and indicators has been proposed (Appendix 1). The goals are derived from and consistent with the 10 ICMM SD principles and although only 7 of the 10 principles are directly addressed with the goals, the remaining three principles are implied in the proposed framework to measuring SD. For example, although the principle of implementing and maintaining ethical business practices and sound systems of corporate governance is not specifically included in the goals, this principle underlies the entire process.

The objective is to provide a check list or set of standards against which to rate sustainability. The goals and indicators are tailored for industrial minerals which require indicators that may not be relevant or are less relevant to precious and base metals (Table 3). The proposed indicators are not intended as a comprehensive list but include the core activities that are common to most industrial minerals mining operations. Each site may find it necessary to modify the criteria by adding or dropping goals and indicators to better represent their specific situation. The analysis presented in Table 3 is based on subjective rankings of the various SD goals for a range of mineral categories. These range from low value commodities to high value precious metals. The results show that, regardless of the mineral category, the overall SD factor score (Total Score) falls between 1 and 2 indicating that the SD factors collectively rank as extremely important but the relative importance of individual goals varies across the mineral categories. For example, optimising customer value ranks from extremely important to not relevant in the case of industrial minerals, which are directly marketed to customers, vs. metals which are sold on open markets.

Although this metric offers a straight forward way to evaluate SD, caution must be exercised when applying the criteria. Because this approach is deliberately designed to be simple and easy to apply, complex systems may be misrepresented and oversimplified. It is therefore essential that the particular circumstances unique to each operation are understood and considered when applying the metric and interpreting the results. For example, to keep the scoring system from becoming needlessly bogged down in detail, the focus is on global goals that are widely held to be the core tenets of best SD practices. Each goal has only one and rarely two or three indicators. Again, this was done to simplify and focus on the most important criteria; and is by no means meant to be an inclusive and complete list.

Table 3 Relative ranking of SD goals for various mineral and metal categories

Goal	*Importance ranking factor**			
	Low-value IndMin	*High-value IndMin*	*Base metals*	*Precious metals*
Best waste management practices (minimise or eliminate waste)	1	2	2	3
Environmental, health and safety compliance (of products)	2	1	3	3
Increase process recovery	3	2	2	1
Manage water effectively	2	1	1	1
Mine safely and MSHA compliance	1	1	1	1
Optimise bulk handling	1	2	2	3
Optimise customer value	2	1	3	3
Recyclable/reusable	3	2	1	1
Reduce CO_2 emissions	3	2	1**	1**
Reduce energy consumption	1	1	2	2
Reduce H_2O consumption	2	1	1	1
Reduce mining footprint	1	2	1	1
Reduce packaging	2	1	3	3
Reduce raw material consumption (ore, process chemicals)	3	2	1	1
Restore habitat post mining	1	1	1	1
Transport finished product to customer	1	1	2	3
Transport raw materials to process plant	1	1	2	3
Utilise waste heat	1	1	1	1
	31	25	30	33
Total score	*1.72*	*1.39*	*1.67*	*1.83*

*(1) Extremely important; (2) Moderately important; (3) Not important or not relevant.

**If use pyrometallurical process instead of hyrometallurgical leaching and SX_EW processes.

5.1 Stage 1: Exploration and mining

This stage in the mining process involves

- prospecting for and proving the deposit through drilling and testing
- site preparation
- overburden removal
- mining
- transporting the ore or raw material to the plant or stockpiles

- water and dust management
- land reclamation and environmental restoration.

Because the majority of industrial minerals (on a volume basis) are extracted from open pit operations only surface mines are included.

Several questions must be considered when applying the metrics as outlined. Perhaps the most challenging question is one of scale and complexity. The metric is designed to work for single mine sites that feed a single process plant or it can be applied to multiple mines supplying a single plant which is a more common scenario for industrial minerals. In some cases a single mine may provide raw material for multiple process plants thus adding yet another layer of complexity.

A central mining issue addressed by the metric is the question of resource depletion. The utilisation of mineral reserves close to the processing plant meets the immediate goal of reducing CO_2 emissions today but may have negative consequences in the future. This is because as soon as local deposits are depleted, mining shifts to more distant deposits that drive up transportation costs and increase environmental impact by using more fossil fuels to deliver the raw material to the plant. Eventually the environmental and economic cost of mining becomes prohibitive and the operation is no longer profitable. What may appear environmentally responsible for today, has a negative impact on the long term sustainability of the overall mineral resource and the community that depends on the profitable utilisation of the resource. A metric for measuring mineral supply must be included to emphasise the important role that reserve life plays in long-term viability and sustainability.

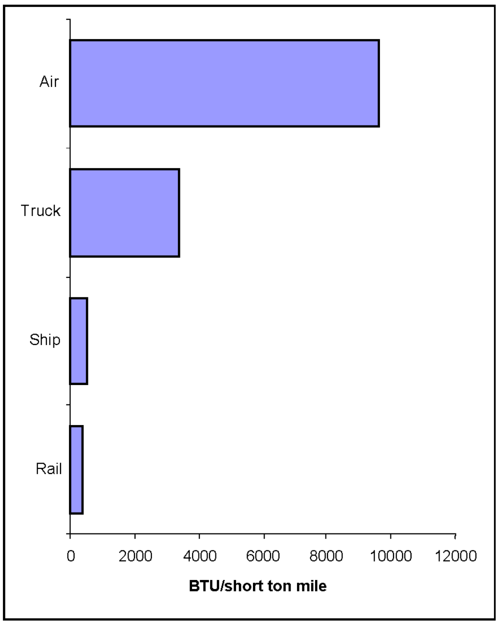
5.2 Stage 2: Processing

Industrial mineral processing may be as simple as dry screening and crushing to highly complex, multi-stage wet processes that involve sequential steps of mineral separation and particle size engineering. All processing consumes resources (mineral raw materials, chemicals, energy, water) and all generate outputs (waste water, dust, process waste, GHG). As a consequence a common set of goals can be applied across most industrial minerals processes. Many of the same themes used to evaluate mining are applicable to mineral processing as well, including reducing energy use, reducing waste and complying with health and safety standards. In addition, many companies focus on cost per ton produced rather than cost per ton processed. When the focus is on cost of product, the cost of waste generated during the extraction of that product is not considered in the metric. Therefore, in the discussion of SD, attention must be given to tons processed. This concept has been incorporated in some of the metrics listed in Appendix 1.

5.3 Stage 3: Transportation and logistics

Distribution is a critical aspect of industrial minerals marketing and is a key factor in the economic development of industrial minerals deposits. In most cases proximity to transportation infrastructure is a prerequisite for deposit development. Transportation plays a role in two points of the supply chain. The first is transportation from the mine to the mineral processing plant and the second is transportation from the mineral processing plant to the market. Transportation from the mine to the process facility may be by off-road truck, over road truck, rail, slurry pipeline or barge. Product may be transported to the market by rail, truck, barge, or ocean going vessel. Statistics reported by the US DOE show that rail is the most fuel efficient mode of transportation for freight (Figure 2).

Figure 2 Fuel efficiency for various modes of transportation (see online version for colours)



Source: US DOE, Transportation Energy Databook

Packaging (i.e., small bags, bulk bags) as well as the form of shipment (i.e., dry powder, slurry, granules) all play a role in the economics of transportation as well as in the environmental footprint associated with this key part of the mineral life cycle. Logistics chains that reduce storage and therefore the need to build and maintain warehouses are advantageous. Waste generated during handling and packaging should be avoided as well.

5.4 Stage 4: Markets

Industrial minerals have little to no value without markets to create demand. Therefore, businesses engaged in mining and processing industrial minerals are sustainable as long as they can sell products at a profit. This sounds simple enough but there are a number of complex and sometimes unpredictable factors that drive industrial minerals markets and pricing. This is particularly the case when it comes to global trade where markets tend to be fluid and dynamic and drivers include availability of mineral resources, needs of the population and economic stability (O'Driscoll, 2006). Superimposed on this fluctuating market situation is the fact that prices vary across markets, across market segments within a single market, and from customer to customer. This is because industrial minerals pricing is negotiated between the supplier and consumer. Factors such as end-use, mining costs, processing costs, product quality, exchange rates, volume, product form, length of contract and differentiation from competitive products determine price. This contrasts sharply with metals which are sold for standard prices set by global markets.

Industrial minerals suppliers therefore have the opportunity to play a significant role in not only sustaining markets and market share but in growing market share by developing new markets. Sustaining markets generally means meeting existing market demand by offering competitively priced products. On the other hand, developing value-added products for new and non-traditional markets requires a commitment to innovation and an ongoing investment in R&D. For example, our expanding dependence on fuel cell technology has created new market opportunities for high purity graphite, lithium, zeolites, and borates. To meet this demand companies are actively investing in exploration, process development and research. Nanotechnology is another area that has enjoyed significant government as well as private sector investment and several new markets have evolved. For example, the demand for food packaging that reduces waste while improving water and vapour barrier properties has created new markets for clay minerals.

6 Conclusions

Industrial minerals are mined and processed for a range of markets and products. They are essential to the world economy and to our standard of living. In 2007 in the USA alone non-metal mine production was estimated at $43.2 billion compared to $24.8 billion for metal mine production (USGS, 2008). Over the next decade the market for industrial minerals is expected to expand as the global population increases and the middle class in China and India continues to grow. As a result of this demographic shift the sustainable utilisation of non-renewable mineral resources will become even more critical. Companies will face complex decisions as they balance short term profits against long term viability and SD will be an important part of this process. Many companies have already demonstrated leadership in this area by instituting voluntary corporate SD programs. A critical aspect of these programs is that various metrics are used to measure sustainability, support decisions and make informed choices. However, each company establishes their own targets and indicators leading to an inconsistent approach to the application of SD principles. This paper presents an alternative metric that integrates commonly used indicators with a typical life cycle for industrial minerals. The advantage to this approach is that it is systematic but flexible and includes aspects of the life cycle that are unique to industrial minerals.

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References

Bovea, M.D., Saura, U., Ferrero, J.L. and Giner, J. (2007) 'Cradle-to-gate study of red clay for use in the ceramic industry', *International Journal of Life Cycle Assessment*, Vol. 12, No. 6, pp.439–447.

Durucan, S., Korre, A. and Munoz-Melendez, G. (2006) 'Mining life cycle modeling: a cradle-to gate approach to environmental management in the minerals industry', *Journal of Cleaner Production*, Vol. 14, pp.1057–1070.

Global Reporting Initiative (GRI) (2005) *GRI Mining and Metals Sector Supplement*, Pilot Version 1.0, Available at http://www.globalreporting.org (Accessed 28 December, 2011).

IMERYS (2011) *Sustainable Development Indicators*, Available at http://www.imerys.com (Accessed 28 December, 2011).

International Council on Mining and Metals (ICMM) (2003) *10 Sustainable Development Principles*, Available at http://www.icmm.com/our-work/sustainable-development-framework (Accessed 28 December, 2011).

Minerals Professional Community (2003) Available at http://www.sdimi.org/milos_decl_org.pdf (Accessed 28 December, 2011).

Nobuhiko, N.I., Koki, S., Masayuki, M., Tadao, I. and Atsushi, I. (2001) 'Life cycle inventory analysis of copper production system in Chile', *Journal of the Mining and Materials Processing Institute of Japan*, Vol. 117, pp.271–276.

O'Driscoll, M. (2006) 'International trade in industrial minerals', in Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T. (Eds.): *Industrial Minerals & Rocks: Commodities, Markets, and Uses*, Society for Mining, Metallurgy, and Exploration, USA, pp.49–60.

Rajaram, V., Dutta, S. and Parameswaran, K. (Eds.) (2005) *Sustainable Mining Practices A Global Perspective*, Taylor & Francis, Oxford.

Rio Tinto Minerals (2008) *Rio Tinto Minerals 2010 Sustainable Development Report*, Available at http://www.riotintominerals.com/ (Accessed 28 December, 2011).

Schuurmans, A., Rouwette, R., Vonk, N., Broers, J., Rijnsburger, H. and Pietersen, H. (2005) 'LCA of fine sand in concrete', *The International Journal of Life Cycle Assessment*, Vol. 10, pp.131–135.

Shields, D.J., Solar, S.V. and Langer, W.H. (2006) 'Sustainable development and industrial minerals in industrial minerals & rocks: commodities, markets, and uses', in Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T. (Eds.): *Society for Mining, Metallurgy, and Exploration*, USA, 1548 pages.

Tan, R.B.H. and Khoo, H.H. (2005) 'A LCA study of a primary aluminum supply chain', *Journal of Cleaner Production*, Vol. 13, pp.607–618.

Udo de Haes, H.A. (2006) 'Sustainable management of natural resources in a life-cycle perspective', *The International Journal of Life Cycle Assessment*, Vol. 11, No. 1, p.2.

United Nations (1987) *Report of the World Commission on Environment and Development, General Assembly Resolution 42/187*, 11 December, 1987, Available at http://www.un-documents.net/k-001303.htm (Accessed 28 December, 2011).

USGS (2008) *Mineral Commodity Summaries 2008*, Available at http://minerals.usgs.gov/minerals/pubs/mcs/2008/mcs2008.pdf (Accessed 28 December, 2011).

Walker, J. and Howard, S. (2002) *Finding the Way Forward How could Voluntary Action Move Mining Towards Sustainable Development?*, International Institute for Environment and Development and WBCSD, Russell Press Ltd., Nottingham, UK, 58 pages.

Appendix 1: Example of life cycle based sustainability indicators and scorecard (see online version for colours)

Life cycle stage	*ICMM goal**	*Goal*	*Indicator*	*Scorecard*				
				Target	*Did not meet*	*Met*	*Exceeded*	*No. points*
Mining and mine planning	6, 7	Reduce mining footprint	Tons of ore extracted/acre of disturbed land	20%	0			0
	6	Reduce energy consumption	Total miles transported	–10%		1		1
	6	Reduce CO_2 emissions	Tons CO_2 emitted/ton mined	–30%		1		1
	7, 9	Restore habitat post mining	Acres restored/acres disturbed	15%	0			0
	4, 5	Mine safety	No. of MSHA reportable accidents	0			2	2
	5	Environmental, health and safety compliance	No. of reportable incidents	0		1		1
	9	Extend life of reserve	Years of resource/reserve (current production)	20		1	2	3
	3, 9	Reduce visual impact	No. of complaints	0		1		1
Processing	6	Reduce energy consumption	KWH/Ton processed	–10%		1		1
	6	Reduce CO_2 emissions	Tons CO_2 emitted/Ton processed	–30%	0			0
	6	Reduce H_2O consumption	Gallons/Ton processed	–20%	0			0
	6	Reduce raw material consumption (ore, process chemicals)	Units/ton produced	–10%	0			0
	6	Increase process recovery	% yield	5%		1		1
	6	Best waste management practices	Tons waste/ton produced	–10%		1		1
	6	Utilise waste heat	BTU from waste as % of total BTU/ton processed	–5%		1		1
	8	Reduce waste	Tons of waste recycled	–3%	0			0
	5	Environmental, health and safety compliance	No. of reportable incidents	0	0			0

Appendix 1: Example of life cycle based sustainability indicators and scorecard (see online version for colours) (continued)

				Scorecard				
Life cycle stage	*ICMM goal**	*Goal*	*Indicator*	*Target*	*Did not meet*	*Met*	*Exceeded*	*No. points*
Transportation	6	Transport raw materials to process plant	Cost per mile transported (gal fuel consumed/mile)	–5%		1		1
	6	Transport finished product to customer	Cost per mile transported (gal fuel consumed/mile)	–5%			2	2
	8	Reduce packaging	Tons of product shipped as bulk	2%	0			0
	8	Optimise bulk handling	Tons of spill per ton processed	–2%		1		1
	8	Reduce warehousing	No. days stored	–3%		1		1
Markets	3	Optimise customer value	Pricing achieved per unit of product	10%		1		1
	8	Recyclable/reusable	Months of product life	3%		1		1
	5	Environmental, health and safety compliance	No. of reportable incidents	0	0			0
							TOTAL	*20*
							Score	*0.4*

*ICMM goals:

1. Implement and maintain ethical business practices and sound systems of corporate governance.
2. Integrate sustainable development considerations within the corporate decision-making process.
3. Uphold fundamental human rights and respect cultures, customs and values in dealings with employees and others who are affected by our activities.
4. Implement risk management strategies based on valid data and sound science.
5. Seek continual improvement of our health and safety performance.
6. Seek continual improvement of our environmental performance.
7. Contribute to conservation of biodiversity and integrated approaches to land use planning.
8. Facilitate and encourage responsible product design, use, re-use, recycling and disposal of our products.
9. Contribute to the social, economic and institutional development of the communities in which we operate.

Minerals are vital to sustainable development, as both providers of the material infrastructure of society and as an important sector of the economy in many resource-rich nations. Ben McLellan, of Kyoto University, Japan, examined the historical and future mineral requirements and implications for sustainable development in scenarios that aim to achieve the SDG`s targets. Genesys International is an industry leader in the development and manufacture of speciality antiscalant and cleaning chemicals for reverse osmosis, nano-filtration and ultra-filtration membrane systems. Membrane technol