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MMSD Life Cycle Assessment Workshop

The Application of Life Cycle Assessment to Mining, Minerals and Metals

New York, 9 and 10 August, 2001

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Mary Stewart

Executive Summary

In August 2001, the Mining, Minerals and Sustainable Development (MMSD) Project convened a two day workshop in New York to investigate the application of Life Cycle Assessment (LCA) in mining, minerals processing and metals. Thirty-five people, representing a broad range of stakeholders, attended the workshop. This final report represents a synthesis of the workshop proceedings and comments made, and highlights opportunities and constraints to advancing the Sustainable Development agenda within the industry. This report assumes a certain level of understanding of LCA methodology, but relevant background reading is highlighted.

Sustainable development is presented herein as a process in which techno-economic, environmental and social considerations are included in decision making to promote the goal of Sustainability of our bio-physical, economic and social environments. Life Cycle Thinking – the consideration of both material and project life cycles, promoting "cradle to grave" accountability, and its practical embodiment in LCA, were seen to be of particular value to the mining, minerals and metals industry in defining the scope of such decision making situations, and providing environmental information to support this decision making. The complexity of the metals value chain was highlighted. This raises significant challenges for the industry, including, amongst others, how to move the industry from its current focus on primary production, to one in which the focus is on service delivery coupled to maximum resource use efficiency. This report examines the role of structured approaches to decision making in this regard. Consideration should be given to ensuring meaningful stakeholder participation in decision making, with due regard to information detail and availability, as well as the temporal and spatial domains over which the mineral industry exerts influence.

The starting point for this report is the recognition that LCA delivers only an understanding of the potential environmental impacts of a product, process or service. To engage with the full Sustainable Development agenda requires that we have other tools available to us to deliver techno-economic information as well as an understanding of the socio-political climate within which the industry functions – both at a micro, and macro level. This goes beyond LCA. However, the philosophy of Life Cycle Thinking can be engaged to provide a decision support framework within which a suite of complementary tools and processes can be developed – and applied – to achieve this overall objective. Whilst this was recognized by workshop attendees, little time was devoted to identifying the complete "toolbox" which could be used. It was noted that other international LCA initiatives – specifically the proposed UNEP/SETAC Life Cycle Initiative – recognize this also, and it was recommended that both the minerals industry, and MMSD, develop active links with these other initiatives.

An opportunity was given to workshop attendees to recount their experiences with LCA, in particular where these were directed at the minerals industry. The stated advantages include its ability to support change towards improvement environmental performance of a system i.e., to focus on prospective decision making rather than retrospective assessment. It was recognized also that LCA supports improved communication with stakeholders (such as NGOs, consumers and the broader community). The educational value of LCA was also emphasized i.e. the exercise of conducting an LCA generally results in an improved awareness and understanding of the system being studied. It was recognized too that LCA offered significant opportunities for enhancing the quality of supply chain management. However, concerns were expressed about some aspects of LCA. Of major concern is the lack of understanding of what exactly LCA delivers – underscored by confusion about the quality of LCA-related information and the potential of this to be misinterpreted by third parties. Though the methodology of LCA has been standardized through the International Standards Organisation (ISO 14040 series), there remains considerable ambiguity about the various "optional" elements of the methodology, mostly related to the aggregation of information through value-based arguments. The most obvious of these is where weights are used to provide a statement of the relative importance of environmental impacts. It was felt that such value judgements have the potential to undermine the transparency of LCA. A number of methodological inconsistencies were also presented. These include problems related to scoping i.e. deciding on the appropriate system boundary definition, the inability of LCA to adequately address site-specific impacts, and the manner in which risk is interpreted by the methodology.

The experiences of the attendees in applying Life Cycle Thinking and LCA to systems within the metals value chain can be grouped into focus areas as follows:

- Process improvement and integration – in these examples LCA has been used to assist decision makers in determining how single processes or technologies should be improved, and how more complex processes (either on the same site, or on separate sites) can integrated to effect improved overall environmental performance for the system
- Product improvement – these cases highlighted the use of LCA in tracking the effect that the product has on the environment throughout its material life cycle; how LCA is used to focus efforts to decrease these effects; and improving communications with customers
- LCA and Material Flow Analysis (MFA) – MFA is presented as a tool which can enhance the value of LCA information as it makes it possible to differentiate between the effects associated with a product over the logistical chain required for product delivery

In the first two of these LCA has been combined with economic tools to support decision making. This facilitates a better understanding of the commonalities and differences between the different applications of LCA presented.

LCA was seen also to have value in informing policy development. In particular, the potential for LCA to support recycling initiatives, and to address the "North-South Divide", i.e. the development tension between minerals' producing economies and minerals' consuming economies, was explored. The workshop concluded that LCA is not the only tool to resolve these issues. However, it can be used to identify points of significant impact and highlight where discrepancies in existing economic models arise.
The major constraints to the development of policy for recycling were agreed to be institutional, regulatory and economic.

The EU's Integrated Product Policy (IPP) framework was identified as a major existing policy initiative which was supported by a commitment to Life Cycle Thinking and LCA. Once again, problems with inconsistent methodology and data quality were identified as major constraints to the more effective use of LCA as a policy instrument. The complexities of applying LCA to mining, minerals and metals can be summarized as:

- **Methodological,** with respect to definition of impact categories, with eco-toxicity and resource depletion impacts requiring considerable attention; selection of impact assessment models where results are demonstrated to differ markedly between models; different boundary definitions for some studies; allocation of impacts in multi-product systems; and varying approaches to aggregation of impacts over space and time
- **Life Cycle Inventory (LCI) data/information deficiencies** which are most notable for the mining, concentration and refining of minerals
- **Impact categories** included in LCA which are inadequate to reflect the performance of the industry adequately; concern was also expressed about the lack of metal-specific information for Life Cycle Impact Assessment

Recommendations on how best to address these are identified in the body of the report.

Additional LCA-related themes discussed at the workshop related to how the requisite information to support sustainable development-driven decision making could be defined, and the management of uncertainty within decision making constructs supported by LCA information. These are highlighted as requiring consideration in this document.

The potential for LCA to interface with other elements of MMSD was also addressed. It was identified that LCA could find value as a potential tool to address issues relating to future markets and consumption patterns for metals. MMSD has an important role in highlighting this. LCA also has a role in guiding the development of other initiatives, including their potential to deliver against stated objectives, and to maximize the potential for effective integration of all the regional research programs.

Overall, it was felt that the MMSD workshop was successful. The challenge remains for the industry to engage actively in the methodological development of tools to support decision making for sustainability. What this means for LCA specifically can be summarized by way of the following recommendations:

- Education programs be promoted to ensure that LCA information is well-understood and used to best effect by decision makers
- Outreach programmes be started to encourage secondary metal scrap recyclers to take a more proactive role in promoting their industry within a Life Cycle framework
- The methodological shortcomings of LCA, as well as other issues relating to data quality should be addressed in the short term, through a co-operative exercise between industrial associations, industry, research organizations and LCA proponents, amongst others. Of particular interest is the international workshop on LCA of metals co-organized by ICME[1] and Natural Resources Canada under the umbrella of the UNEP/SETAC Life Cycle Initiative to be held in North America in Spring 2002. Attendance at this workshop should be a priority for all parties involved in the application of LCA to mining, minerals processing and metals
- Developments within the UNEP/SETAC Life Cycle Initiative should be monitored closely, and active collaboration sought where appropriate
- The promotion of Life Cycle Thinking as a sound basis for a framework for Sustainable Development-driven decision making should be championed actively, and the industry should be encouraged to look at the development of complementary tools to LCA

Responsible parties have been identified for all the recommendations made in this report. These responsible parties include those organizations that may follow afterMMSD, industry, industry associations, academia and research organizations, NGOs, government, and consultants.

[1] *International Council on Metals and the Environment*. From October 2001, *International Council on Mining and Minerals (ICMM)*

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Glossary of Terms

LIFE CYCLE THINKING AND LIFE CYCLE ASSESSMENT

Background System	Processes that contribute to the environmental profile but over which the study/project proponent/decision process has not influence other than through the amount of material/energy that is considered
Boundary Definition	The artificial border between the system being assessed and other systems
Categorisation	Quantification of potential impacts associated with *LCI* elements using *Equivalency Factors* (*Categorisation* is part of *LCIA*)
Classification	Elements in the *LCI* are aggregated according to the impact categories to which they contribute (*Classification* is part of *LCIA*)
Data	Raw data
Equivalency Factor	A scientifically based weighting factor used to map the significance of *LCI* elements onto associated impact categories
Foreground System	Processes that are under the direct influence and control of the study/project proponent/decision process and where decisions made have a direct influence on the environmental profile of the system under study
Information	*Data* which has been transformed in order to enable decision making processes; in this document *LCA* can be seen to transform *Data* into *Information*
Life Cycle Assessment (LCA)	A systematic tool for evaluating the potential environmental impacts associated with a product, process or service; includes impacts associated with all inputs and outputs; extends over all stages of the *Metal Life Cycle*
Life Cycle Impact Assessment (LCIA)	The stage of *LCA* in which inputs and outputs are linked to the impacts which they embody
Life Cycle Inventory (LCI)	A complete listing of all inputs and outputs for the system being assessed in an *LCA*
Life Cycle Thinking	Assessing a system within the expanded boundary defined by *LCA*
Project Life Cycle	All elements in a project from Strategy and Planning, through Research and Development, Product/Process Design, Construction and Commissioning, Operation and Closure to Post-closure.
Valuation	The process in LCA in which impacts are weighted relative to each other

DECISION STRUCTURING AND DECISION SUPPORT

Decision Making	The **process** whereby decisions are made, used interchangeably with *Structured Decision Making*
Normalisation	A process in which results from an assessment are ratioed relative to another set of information in order to gain a better understanding of the significance of the results, e.g., dividing results for a single process by the performance for an industrial sector
Operational Decisions	Decisions relating to particular projects; typically have shorter time frames, limited spatial domains and fewer stakeholders with less diverse perspectives
Problem Analysis	An element of Structured Decision Making; includes Analysis of Alternatives, Comparison of Consequences, Uncertainty Analyses and Selection of Preferred Alternative(s)
Problem Structuring	An element of *Structured Decision Making*; includes Problem Definition, Identification of Objectives, Specification of Performance Measures, and Identification of Alternatives
Socio-economic	Social and macro-economic considerations for a system
Strategic Decision	Decisions relating to policies, plans and programmes; typically have longer time frames, large spatial domains and a significant number of stakeholders with diverse perspectives.
Structured Decision Making	The **process** of arriving at a decision; incorporates the generic elements of decision making in a systematic structure, includes *Problem Structuring*, *Problem Analysis* and Implementation and Monitoring; used interchangeably with *Decision Making*
Tactical Decision	Decisions relating to design and development of products, processes and technologies
Techno-economic	Technical and micro-economic (financial) considerations for a system

MINING, MINERALS AND METALS SYSTEM

Concentration	In *Minerals Processing*, processes which concentrate minerals contained in an ore body to concentrations which can be processed by *Refining*; usually physical separation processes
Envirosphere	All elements outside the Industrial Economy
Manufacturers	Processors that manufacture metal and metal-containing products
Material Chain	The life cycle of the material from resource extraction through processing, manufacture, and use to final disposal. Interchangeable with *Value Chain*, *Metals Value Chain*, *Metal Life Cycle*
Material Flow Analysis (MFA)	A tool used to describe material flows with respect to magnitude, composition and location; in the report is equivalent in meaning to Material Flux Analysis
Metal Life Cycle	The life cycle of the material from resource extraction through processing, manufacture, and use to final disposal. Interchangeable with *Value Chain*, *Metals Value Chain*
Metals Manufacture	The process whereby a metal commodity is turned into a final product, either one made purely of metal, or a product containing metal(s)
Metals Use	The use of metals as pure substances or as alloys, either independently or as part of a manufactured product
Metals Value Chain	The life cycle of the material from resource extraction through processing, manufacture, and use to final disposal.
Minerals Industry	The industry involved in *Mining*, *Concentrating* and *Refining* of mineral ores
Minerals Processing	The processing of ores from *Mining* to deliver a metal commodity product; includes *Concentration* and *Refining*
Mining	The process of removing a mineral resource from a deposit
Recyclers	Processors who re-process secondary scrap to deliver metal commodities
Refining	In *Minerals Processing*, processes which take concentrates from *Concentration* or ores and process them to deliver a metal commodity; usually chemical and physical processes, includes Pyro- and Hydro-metallurgy
Resource Dissipation	Resources leaving the Industrial Economy in such a diluted form that it is not energetically viable to recycle them back into the Industrial Economy
Resource Extraction	The removal of mineral-bearing ores from the earth's crust
Technosphere	The Industrial Economy
Value Chain	The life cycle of the material from resource extraction through processing, manufacture, and use to final disposal. Interchangeable with *Material Chain*, *Metals Value Chain*, *Metal Life Cycle*

1 Introduction

The intention of this document is to report on a workshop convened to place Life Cycle Assessment (LCA), and, in a broader sense, Life Cycle Thinking, in the context of sustainable development in the mining, minerals processing and metals production sectors, i.e., the entire value chain of metals.

A complete review of LCAs conducted for these industries is not included in this report. The workshop used a report previously commissioned by MMSD *The Life Cycle of Copper, its co-products and by-products* (Ayres *et al*, 2001) as a starting point. Information and data discrepancies in the work of Ayres *et al* (2001) as highlighted at the workshop will not be addressed in this document, this is left to the authors of that report.

As a preamble, the focus of much of the work contained in this document is on the ability of both Life Cycle Thinking, and Life Cycle Assessment to inform and support robust and defensible decision making for Sustainability. The recently formed UNEP/SETAC Life Cycle Initiative has this as a primary goal:

> *Consumers are increasingly interested in the world behind the product they buy. Life cycle thinking implies that everyone in the whole chain of a product's life cycle, from cradle to grave, has a responsibility and a role to play, taking into account all the relevant external effects. The impacts of all life cycle stages need to be considered comprehensively when taking informed decisions on production and consumption patterns, policies and management strategies.*
>
> Klaus Toepfer, Executive Director, UNEP (2001)

1.1 THE WORKSHOP PROCESS

The contents of this report are a summary of the discussions of the MMSD LCA workshop held in New York on 9 and 10 August, 2001. In all, thirty-five people attended the workshop. A list of these attendees, as well as the workshop Objectives and Programme are included in Appendix 1. Significant efforts were made to ensure that the workshop attendees represented all relevant MMSD stakeholder groups. Whilst these efforts were largely successful, there were significant deficiencies in stakeholder representation. The following groups were not represented (despite invitations being extended them):

- Metals manufacturing and use sectors
- Metals recyclers
- Decision analysts or management scientists involved in decision making

A number of MMSD telephone interviews are planned for later in 2001 to interact with the first of these. During the workshop, attention was drawn to the need to include metals recyclers in discussions, this is included in the outcomes of the workshop. As has been stated, in this report emphasis is placed on LCA and decision making, the potential remains to disseminate this workshop document to a broader community.

There were four discrete elements to the workshop:

- Review of the work of Ayres *et al* (2001) commissioned by MMSD.
- Perspectives on LCA in the minerals sector
- Lessons from existing LCA initiatives within the sector
- Focus groups on using LCA to support sustainable development

Care was taken to ensure that sufficient time was available for discussion, both in small working groups, and in a round table format.

Information additional to that presented and discussed at the workshop has been included in this report. This additional information has been included to illustrate arguments where possible and to clarify points where necessary. An initial draft report was prepared which was circulated to all workshop attendees for comment. Workshop attendees had two weeks to submit their responses to the first draft. Their comments have been included in this second version of the report. Thus, this report is the result of a two-stage process.

1.2 REPORT STRUCTURE

Upfront of any synthesis of the workshop results, LCA in the context of structured decision making is presented as a point of departure. LCA, and in a broader sense, Life Cycle Thinking, and their potential to support decision making for sustainable development is then discussed.

The following sections of the report are structured according to discrete themes of discussion which arose from the workshop. The main themes of the workshop discussions were:

- Current examples of, and approaches to, applying LCA to mining, minerals and metals
- The potential of LCA to support recycling initiatives within the industry
- LCA and policy development
- Shortcoming of LCA with respect to mining, minerals and metals, this includes both methodological shortcomings, as well as highlighting problems with information and data availability and quality

This is followed by a discussion of the potential for LCA, and Life Cycle Thinking, to support current and future initiatives within MMSD (both global and regional). Recommendations for future initiatives on LCA in the minerals sector are highlighted in order to ensure that the potential for LCA allow the mining, minerals and metals industries to fully capitalise on the use of LCA to support decision making towards sustainable development. These recommendations relate to MMSD (and those organisations that carry forward the work of this project), industry, consultants, NGOs, research communities and other stakeholders who can play a role in the development and application of LCA.

2 Background

This section explains the concepts of Life Cycle Thinking and LCA and relates these concepts to the value chain of metals. Attention is paid to LCA boundary definitions. Approaches to structured decision making are presented. This discussion includes a description of different decision contexts, and the information detail required to support decision making in these different contexts. The integration of LCA into decision making for sustainable development is discussed. LCA is presented as only one of a potential suite of tools to support decision making for sustainability.

2.1 SUSTAINABLE DEVELOPMENT AND LIFE CYCLE THINKING

Numerous definitions exist for the goal of sustainability and the process of sustainable development. Generic to all of these is the understanding that, in order to meet an overall sustainability objective it is necessary to incorporate three sets of criteria/considerations/objectives in the decision making process:

- Techno-economics (micro-scale economics)
- Environmental
- Socio-economics (macro-scale economics)

Furthermore, the pursuit of sustainability requires the simultaneous exploration, and ideally, the satisfaction of these objectives.

Life Cycle Thinking is the philosophical basis for the development of LCA, i.e., LCA is the practical embodiment of Life Cycle Thinking. Life Cycle Thinking places the study within meaningful temporal and spatial boundaries, relating the effects of a product, process and/or service provided to society from a cradle-to-grave perspective. This cradle-to-grave system is the material chain. A generic material chain for metals is included in Figure 1.

This figure illustrates the cyclical nature of the entire metals value chain. Optimising a single node in a network does not guarantee an optimal network. It must be recognised that, in order to move the minerals industry towards sustainable development, this entire value chain must be taken into account, focussing attention on any single element in the value chain will not guarantee sustainability of the entire value chain. It is this expanded system boundary that makes Life Cycle Thinking (and thus LCA) directly applicable to sustainability arguments. Life Cycle Thinking makes it possible to objectively view the environmental effects associated with the entire value chain of metals and to consider this value chain in the context of sustainability.

A further life cycle is included in Life Cycle Thinking, this is the Project Life Cycle. In mining, minerals processing and metals this Project Life Cycle spans initial decisions on exploration, project selection, through design, construction and commissioning, to closure and post-closure. **Figure 2** has been included to demonstrate the relationship between the Material Life Cycle with the Project Life Cycle. For each stage within the material life cycle, a complete project life cycle will exist. In decision making for sustainability it is necessary to incorporate an understanding of both of these cycles to ensure that the decisions taken through each support the move to sustainable development.

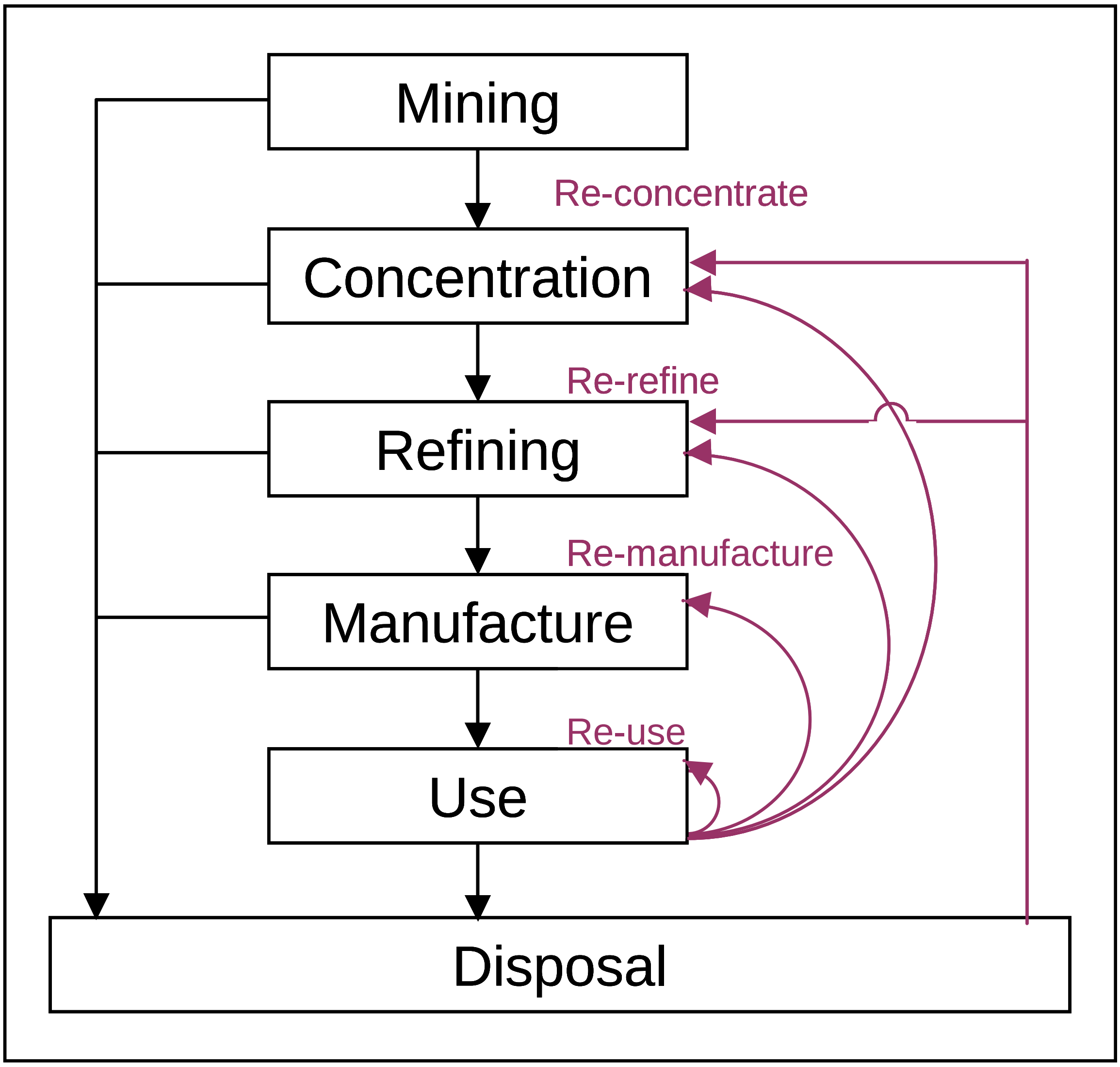


Figure 1 *Generic Metal Value Chain*[2]

It must be recognised that flow of materials, energy, capital and labour through the value chain are inherently complex. Understanding these flows requires particular skills, this understanding is aided both by LCA and by Material Flow Analysis. Interpreting these flows in order to support more effective decision making is crucial. Thus, a more structured approach to decision making is required. Structured decision making is presented in section 2.2.

[2] Note, the intention of this figure is to demonstrate generic technologies to which different metal containing streams can report, it is not to infer that all metals are recycled through primary concentration and refining technologies

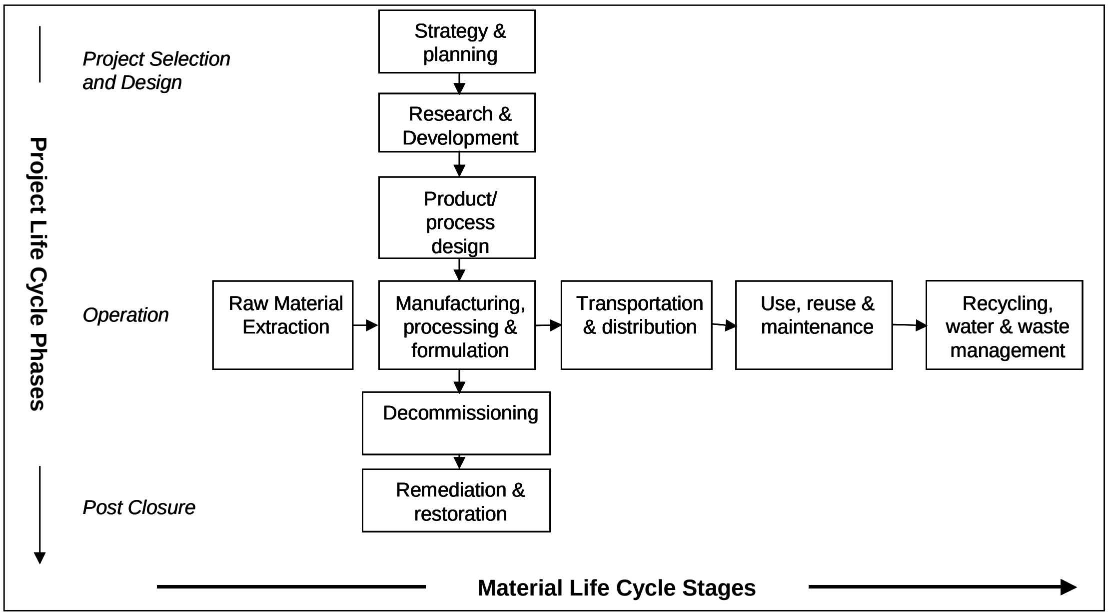


Figure 2 *Material and Project Life Cycles (after Allen* et al*, 1997)*

2.2 DECISION MAKING AND LCA

This section contains a brief introduction to structured decision making for sustainable development. This is followed by a discussion of the use of LCA in decision making to support sustainable development.

2.2.1 Structured Decision Making

While all decisions differ, there are generic elements associated with all decision making processes. Such a generic decision cycle is illustrated in Figure 3. This figure highlights the three main elements of decision making, i.e.:

- Problem structuring
- Problem analysis
- Implementation of preferred alternative(s) (decision outcome) and monitoring of effect of the decision

Note, this decision process is not linear, iterations occur within and between all elements in the cycle included in Figure 3.

While problem structuring will not be discussed in depth in this report, it must be noted that this element of the decision cycle is often regarded as the most valuable element (von Winterveldt and Edwards, 1986; Keeney and Raiffa, 1976). These authors highlight the value of problem structuring in cases involving significant multiple stakeholder input. A number of approaches to facilitate problem structuring exist, these range from simple questionnaires to complex conflict negotiation strategies (Basson and Petrie, 2001a and 2001b, Rosenhead, 1989). The elements of problem structuring include:

- Problem definition in which stakeholders are identified, and consensus is obtained from all stakeholders as to the decision to be taken
- Identification of objectives to be met by the decision outcome, this includes eliciting the preferences of stakeholders for different decision outcomes
- Specification of performance measures used to measure the satisfaction of these objectives
- Identification of alternative solutions for the decision at hand

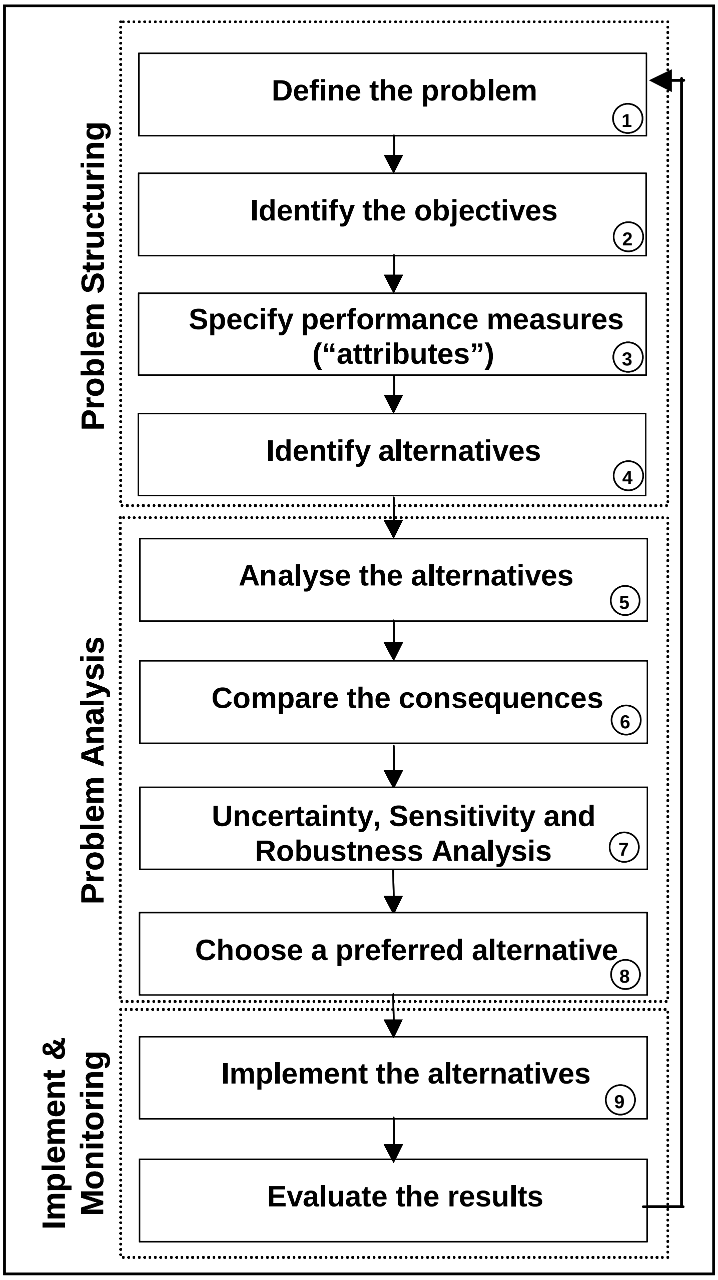


Figure 3 *Decision Cycle (after Anderson* et al*, 1991)*

This approach to taking decisions is predicated on the understanding that all participants in the decision process are willing to achieve rational outcomes. The usual outcome of the problem structuring exercise is an hierarchy of objectives used to measure the performance of the alternatives assessed in problem analysis. An example objectives hierarchy for decision making for sustainability is include in Figure 4. This figure contains an additional level of detail for environmental considerations. In reality objectives hierarchies can contain numerous levels, depending on the decision context, and the requirements of stakeholders. Note: Objectives are separate from attributes or performance measures which are used to determine how well the alternative perform relative to the stated objective.

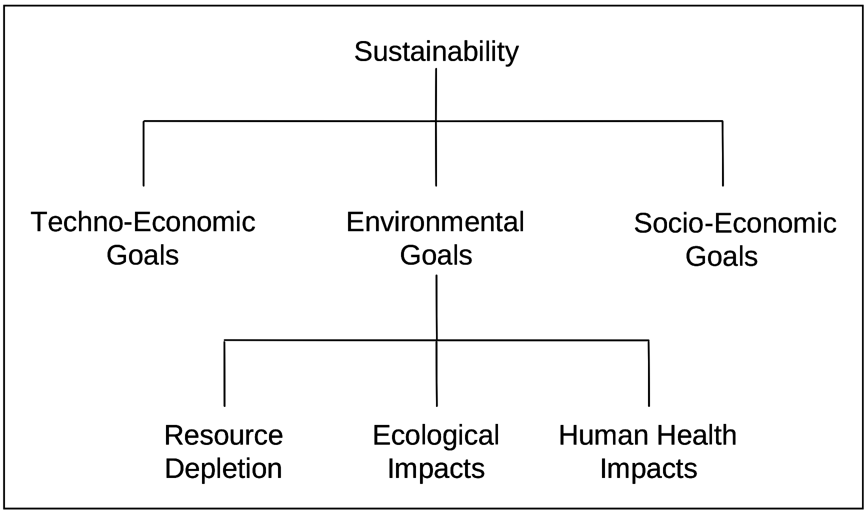


Figure 4 *Example Objectives Hierarchy*

Problem analysis comprises the following elements:

- Analysis of alternatives in which the performance of the alternatives in the objectives determined during the problem structuring stage
- Comparison of the relative performance of the alternative in the objectives
- Uncertainty and sensitivity analyses to ensure robustness of conclusions drawn
- Selection of preferred alternative(s) from the set of alternatives.

Selecting a preferred alternative in the context of multiple criteria and differing stakeholder preferences is not a trivial exercise. To this end the tools of Multiple Criteria Decision Analysis (MCDA) have been developed. The intention of these tools is not to reduce all criteria under consideration to a single index, but rather to determine what represents an acceptable trade-off between the different criteria in the context of stated stakeholder preferences; and to facilitate the selection of a preferred alternative in the context of these acceptable trade-offs. A complete discussion of MCDA tools is not necessary for this report. The interested reader is directed to the work of Stewart (1992) and Seppala *et al* (2001).

Once a preferred alternative is selected the decision is taken and the outcome of the decision process is implemented and monitored.

Although the process of making decisions is generic, elements within the decision process illustrated in Figure 3 are specific to the context for the specific decision to be taken. Decision contexts are discussed in section 2.3.

2.2.2 The Role of LCA in Structured Decision Making

It must be recognised that LCA is not a tool which can be used to deliver information relative to all elements of sustainability – LCA only delivers an indication of the potential **environmental** effects associated with the system being assessed. There are two important elements here, the first is that LCA looks solely at environmental effects; secondly that these effects are quantified as potential, and not actual, impacts. This being the case, in the context of sustainability initiatives LCA can only be expected to deliver an understanding of potential environmental outcomes. However, it should be recognised that LCA is a form of environmental systems analysis, which facilitates its integration with information from other systems-based tools such as those used in determining the economic performance of systems. Thus, LCA information has significant potential to be integrated with information from other tools (i.e., those used in assessing the techno- and socio-economic performance) to inform decision making for sustainability.

With respect to developing the other considerations (techno-economic and social) to the same level of detail as LCA delivers for environmental considerations, techno-economic tools are extremely well developed and do not need to be addressed further. It is not possible to make a recommendation on the selection of a "social assessment tool". The two main reasons here are:

- The tool needs to be fit for purpose and cannot be specified in isolation of the decision context
- Tools for assessing the social performance of a system are not well developed, or even understood

The main recommendation to be made here is that the work of the Life Cycle Management element of the UNEP/SETAC Life Cycle Initiative be followed closely as it is this body which represents the greatest potential for addressing this deficiency.

Significant work has been invested recently by the LCA community in determining and evaluating the integration of LCA into decision making (SETAC W/G on LCA and Decision Making, 2001). Originally LCA served as a generic resource of information around the environmental performance of products. Little clear guidance was given on how this resource should be used. LCA supplies an understanding of the environmental performance of a system to a decision process. The LCA methodology will not be described in detail in this report. For background information on LCA methodology see the work of SETAC (2001, 2000, 1999,1993a and b) and the ISO standards (2001, 2000, 1999).

However, there is value in highlighting the mapping of LCA onto the decision cycle presented in Figure 3, this mapping is included in Figure 5. This figure demonstrates that LCA contains the significant elements of decision structuring, with the exception of the requirement for a rigorous uncertainty analysis. This highlights both its intended use as a decision support tool, and the potential for it to be used in situations which are characterised by multiple objectives. The application of MCDA tools to LCA has been explored by a number of authors (Basson and Petrie, 2001a; Cowell, 2001; Seppala *et al*, 2001; Seppala, 1998; Meittinen and Hamalainen, 1997). This work has highlighted the potential for LCA to be used in developing environmental criteria and providing environmental performance information to decision making. However, as has already been stated, it is not the intention of LCA to evaluate the techno-economic and/or socio-economic performance of alternatives required for decision making for sustainable development. Thus additional tools are required to determine the performance of the alternatives in these other criteria before it is possible to facilitate decision making for sustainability.

2.3 DECISION CONTEXTS AND BOUNDARY DEFINITIONS

In the discussions included above, reference has been made to decision contexts. These contexts are usually delimited as strategic, tactical and operational. Generic characteristics of these decision contexts have been described by Wrisberg and Triebswetter (1999). Essentially strategic decisions are typified by large temporal and spatial boundaries for the decision. They are often made under significant uncertainty, there are a significant number of alternatives under consideration, and stakeholder preferences are diverse. Examples of strategic decisions include policy formulation in government as well as industry, and planning decisions.

In the case of operational decision making, the number of alternatives included in the decision making processes is limited, as is the uncertainty inherent in available data. Temporal and spatial boundaries are limited and better defined and stakeholder involvement is usually direct.

In the context of the Project Life Cycle (included in Figure 2) decisions are taken which span the entire range of decision contexts from strategic to operational. As these decisions are taken the data and thus the information available to support decision making becomes more detailed, and better

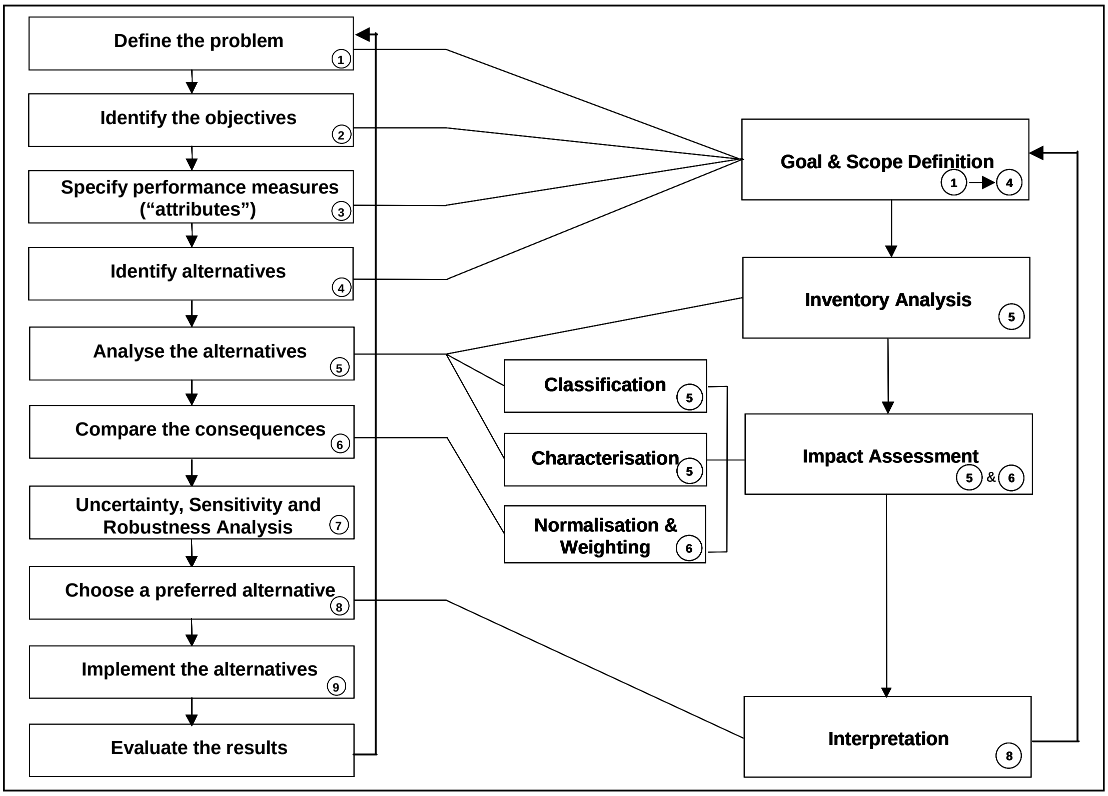


Figure 5 *Mapping of LCA onto Decision Cycle (Basson and Stewart, 2001)*

defined. At the same time, each time a decision is taken potential alternatives are eliminated from the set of alternatives under consideration. Stewart and Petrie (2000) highlight the significance of decisions taken early in the project life cycle. They conclude that initial decisions (for example the selection of an ore body and associated technology) to a great extent set the performance of the alternatives selected. Decisions taken later in the project life cycle (for example recycle structures within a process) have less of an effect on the overall performance of the project. The challenge is to ensure that sufficient information on the environmental, social and economic performance of the alternatives is available at these early stages of the project life cycle to ensure the project is developed within the context of sustainability.

It should be recognised that making this information available is not a trivial exercise. Data available at early stage of the project life cycle are not necessarily detailed nor of high quality. This makes the task of incorporating multiple criteria in the decision making process all the more complex. The decision context sets the information detail included in the development of:

- Objectives to be met by the decision outcome
- Performance measures used to compare the alternatives included in the assessment
- Quantification of the performance of the different alternatives in the criteria selected

In addition, different MCDA tools are applicable to different qualities of information. Thus, different MCDA tools are suited to different decision contexts. It is important to ensure that the MCDA tool selected suits the decision situation to which it is applied. For a detailed description of tools which are applicable in different decision contexts see the work of Basson and Petrie (2001b).

At this point it is worth highlighting the potential for LCA to support decisions in different contexts. As was stated in 2.1, LCA gives an indication of the potential environmental impact associated with a specific process, product or service. LCA information is generic and often aggregated over space and time. There can be significant uncertainty associated with LCA information. Understanding these attributes of LCA-based information it can be stated that LCA is more applicable to strategic and tactical decision making where information uncertainty is inherent in the entire information set (not only the environmental information set) on which the decision is based. There are other environmental assessment tools such as Environmental Impact Assessment and Environmental Risk Assessment which are better suited to less system-wide decision contexts, for example decisions taken at operating plants. However, there is increasingly a potential to use LCA in more detailed assessments. However, the limitations of the information LCA provides must be recognised. A complex problem which remains to be solved in the question of how to integrate the use of different decision support tools in a structured manner. This presents a significant challenge, and has been taken up explicitly by the Life Cycle Management component of the UNEP/SETAC Life Cycle Initiative.

The discussion included above highlights a number of points, these relate to:

- The importance of decisions taken early in a project life cycle
- Boundaries defined for the decision
- Information detail available for decision making
- The management of uncertainty

With respect to the defining decision boundaries, existing LCA studies and initiatives within the minerals industry are discussed in section 4 relative to their coverage of both material and project life cycles. The potential of these initiatives to support decision making in different decision contexts is also discussed. Changes in system boundary definition with changing decision context are illustrated in Figure 6 overleaf. In this figure only three of an almost infinite number of potential boundaries have been demonstrated. These are illustrative and not prescriptive. The first boundary illustrated is that over which an industry association might operate when trying to place its commodity in the context of a global scenario, or measuring the performance of one commodity against another. These are strategic decisions. The second boundary illustrates the domain over which mining industry decisions might be taken. The third boundary defined is that of the operating plant, this is usually the boundary defined for operational decisions.

2.4 CONCLUSIONS

Life Cycle Thinking can be used to support decision making for sustainable development because of its extended system boundary, for both the material and the project life cycles. The life cycles are complex and require structured approaches to decision making to facilitate decision making processes. Decisions occur in different contexts, these contexts are affect by, and also affect, the amount of information required to support them. LCA has been integrated into structured approaches to decision making. However, LCA can only deliver a consideration of the environmental aspects of a decision. In decision making for sustainable development additional tools are required to deliver information on the techno-economic and social performance of the alternatives being assessed.

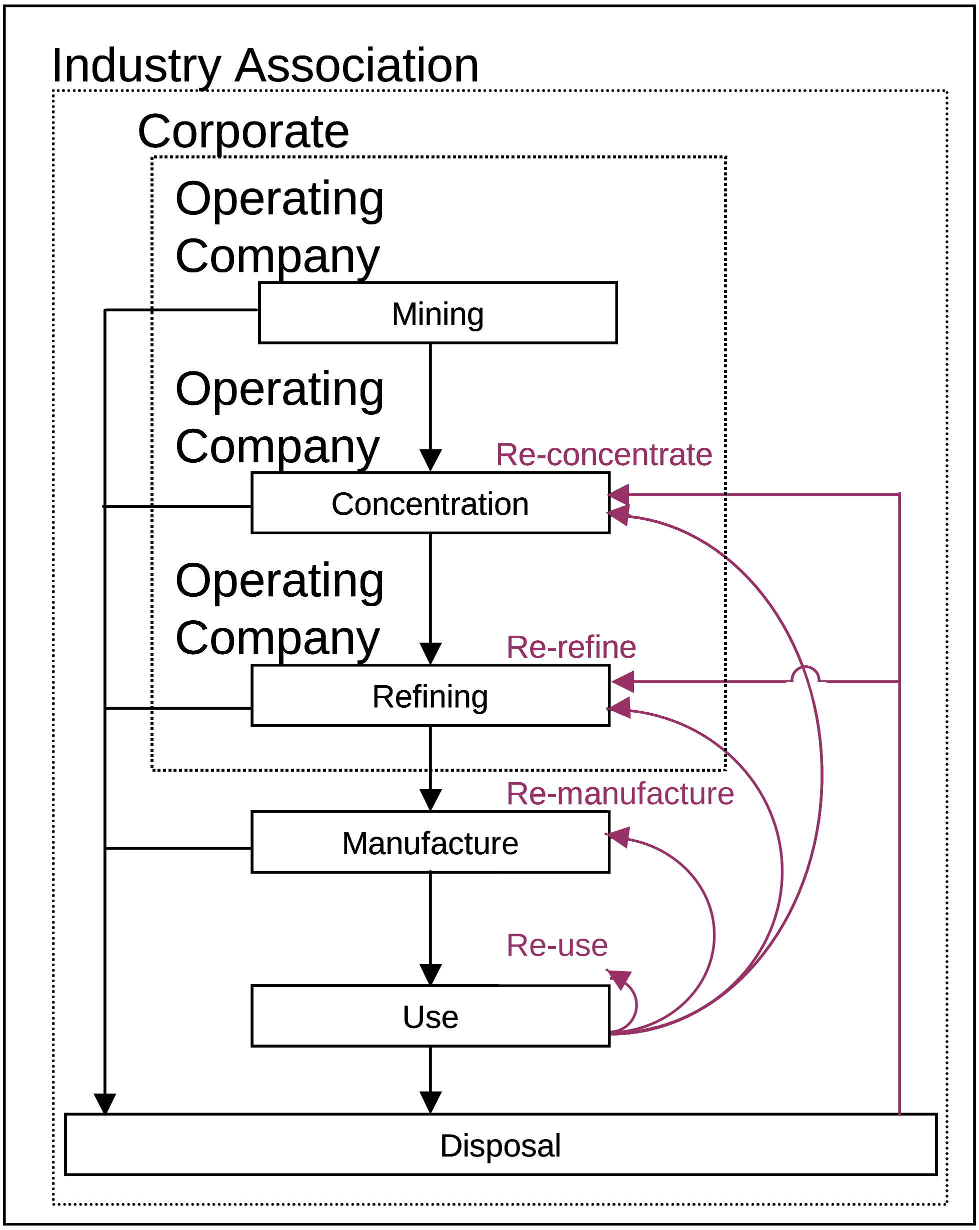


Figure 6 *Decision Boundaries*

3 Workshop Perspectives on LCA

The commentary in Section 2 suggests the significance of LCA in decision making, with a particular focus on decision making with limited data, i.e., strategic decision making, and decision making for policy development. LCA is applicable to these purposes due to the generic nature of the information, and the ready availability of existing data sets. Lack of LCA data and information for mining, minerals and metals is discussed in Section 6.6 of this report.

A number of different perspectives on the application of LCA in the minerals sector were presented at the workshop. The views expressed can be aggregated into discussions around the advantages of LCA (section 3.1), constraints with respect to its application (section 3.2), and potential future opportunities (section 3.3). The opinions summarised in this section represent the views of the workshop attendees, for this reason many assertions are made without reference to the literature.

3.1 THE ADVANTAGES OF USING LCA

The advantages of LCA presented at the workshop can be grouped into:

- Effecting change for improved environmental performance of a system (section 3.1.1)
- Improved communications with stakeholders (section 3.1.2)

3.1.1 LCA to support Change

LCA was highlighted as a tool which presents the “bigger picture”; due both to the application of Life Cycle Thinking perspectives; and its extended system boundary. This extended system boundary makes it possible to explore the potential environmental impact associated with different elements within the value chain of metal. LCA focuses solely on environmental impacts. It does not deliver an absolute quantification of these impacts, but rather a potential effect. The extended boundary defined by LCA highlights potential points of intervention within a material chain in order to effect improved environmental performance, leading often to outcomes which are counter-intuitive, and which arise only through the systematic exploration of expanded system boundaries typical of LCA studies. Often there are more lessons learnt from conducting the assessment, than from the results of the assessment. LCA highlights points of intervention where change can be brought about to best environmental effect.

LCA can be used to identify opportunities for process and product improvement. These are usually formulated in the context of a relative assessment. The results of relative assessments are useful in that they tie all processes under assessment together in a comprehensive picture.

In LCA methodology, inventories which contain significant amounts of data are aggregated into a greatly reduced number of impact categories (or environmental interventions) according to a relatively objective set of mainly science-based or agreed to rules (classification and characterisation). There is a final stage to LCA which uses weighting factors based on non-scientific value choices in order to achieve a single score for the alternatives being assessed. However, due to the subjective basis of these weights ISO 14 000 standards require that this stage not be conducted if a relative assessment it being conducted. The tools of multi-criteria decision making are suitable to this application as they make explicit the trade-offs accepted between different impact categories when a decision is taken. In addition, decisions have also been taken on inventory data alone.

LCA as a tool which is suited to the comparison and benchmarking of alternatives with respect to relative performance, as opposed to the evaluation of absolute impact was highlighted. In this context the value of LCA in supporting the development of Environmental Management Systems was discussed. LCA has the potential to improve and integrate the development of environmental indicators within the mining and minerals industry as a whole. A significant advantage of LCA is its standardisation under the ISO 14 000 set of Environmental Management Standards. LCA is also cyclical in nature, it should not been seen as a single process with one outcome, but rather as a tool to enable continued improvement. The relationship between LCA and Environmental Management Systems is being explored as part of the Life Cycle Management element of the UNEP/SETAC Life Cycle Initiative.

3.1.2 LCA and Communication

LCA also has the potential to structure quantitative information flow between stakeholders, be these industry, customers, researchers, government agents, local communities and other groups. LCA is used internally within industry for process improvement, technology selection and reporting, and externally to support marketing, and to inform different stakeholder groups (including NGOs).

As is it based in objective argument, the results of LCA studies can be used for trust building and in better communication with the broader community. Transparency and accountability form the basis of such trust building exercises, thus care should be taken to ensure that transparency and accountability form part of the goals set for the LCA.

LCA was presented as a tool which is suitable to the NGO view of the world. LCA information is accessible and allows NGOs to determine where to concentrate their energies to best effect.

In addition, NGO input is required to ensure that efforts expended on the development of LCA in the mining and minerals sector is expended for most impact.

3.2 CONSTRAINTS IN THE APPLICATION OF LCA

Constraints on the application of LCA presented at the workshop included:

- Concerns about methodology (section 3.2.1)
- Value Judgements in LCA (section 3.2.2)
- Misinterpretation of LCA information (section 3.2.3)

Data availability was highlighted as a significant constraint on the application of LCA in mining and minerals processing. This is discussed further in Section 6.6.

3.2.1 Methodology

In spite of the standardisation of the tool under ISO 14 000, methodologies applied are different. This observation is for the application of LCA in general. An analysis of peer reviewed LCAs of metals conducted by Ecobalance showed significant compatibility between both methodologies and boundary definition applied. This study in not available in published literature. However, as more LCA practitioners become involved in conducting assessments for the mining, minerals processing and metals industries, the potential for differences to occur increases. Differences in LCA studies can be addressed to some extent by building consensus within the industry (including stakeholder input) on which flows to report, how to report flows, allocation choices, modelling considerations, etc. ISO 14 048 (Data Quality) has the potential to address some of these issues.

The inability of LCA to adequately address site-specific impacts was highlighted. The manner in which risk is managed within LCA methodology was also presented as a potential limitation in that LCA provides information about a set of prescribed impacts, these impacts may not be the only ones important to a particular study. This quantification has the potential to magnify known effects, to the detriment of other potential risks associated with the project or process under review. Within reason, additional tools may be required to augment LCA information in the context of decision making for sustainable development.

The choice of differing boundary definitions for different projects was seen as a significant problem for a number of reasons:

- Boundaries can be defined to reflect the interests of the project proponent and can be manipulated in order to deliver a required outcome from the assessment
- Different boundary definitions render existing LCA studies not comparable undermining the value of the information and/or data contained therein

Boundaries of existing studies are discussed further in Section 4.

3.2.2 Value Judgements

There are a number of places within LCA in which value judgments are made. The discussion on boundary definition above highlights one of these. Other places where value judgements may be made are:

- Goal and scope definition: Definition of goal, boundary definition, selection of impact categories to be included
- Inventory: Modelling methodology selected, determination of what represents a complete inventory
- Impact Assessment: Selection of categorisation models, normalisation regime and weightings used

Care should be taken in ensuring that these (and any other value judgements) made are adequately justified and effectively communicated. Life Cycle Impact Assessment is, wherever possible a technical and scientific procedure. However, value choices are used in the selection of the impact categories, indicators and models, and in grouping, weighting and other procedures. This is detailed in ISO 14042.

Care must be taken when trading-off between different impact categories as units are not always commensurate, e.g., 1kg SO_2 equivalent is not equal to 1kg CO_2 equivalent, in spite of units of measure being the same (kg). This can be solved to a certain extent by the correct selection of normalistion regime. In the context of rigorous LCA methodology the weighting (or trading-off between different impact categories) is an optional element of life cycle impact assessment based on value choices and not on pure sciences. The experience and tools of the MCDA community as discussed in Section 2.2.1 are particularly relevant in this context and address many shortcomings associated with the weighting methodology used in rigorous LCA methodology.

3.2.3 Misinterpretation of LCA Information

Concerns that users of LCA information may not be familiar with the methodology and thus may misuse the information were expressed. Transparency with respect to all elements of LCA (generation of inventories, impact assessment and valuation) was highlighted as key in overcoming some of this misuse of the information. At the same time users of LCA information need to be educated, and the limitations of the tool highlighted.

In addition, the standardisation of LCA within the ISO 14 000 series, while being a perceived advantage of the tool, was also presented as a constraint. The fact that the tool has been standardised does not guarantee that the results of LCA studies will be used to best effect. There is the potential that LCA studies, conducted as part of an ISO 14 000 certified environmental management system, might carry more weight than they deserve.

3.3 FURTHER OPPORTUNITIES OFFERED BY THE APPLICATION OF LCA

This section highlights future opportunities for the application of LCA. These include:

- Improved supply-chain management (section 3.3.1)
- Scenario development and assessment (section 3.3.2)

In addition, the application of LCA to policy development was seen as a significant future role for the tool, this is discussed in Section 5.

3.3.1 Improved Supply-Chain Management

LCA is useful for unpacking supply chain information. In addition, positive aspects of products can be articulated adequately. With specific reference to metals these aspects relate to recyclability, durability etc. These positive aspects can be promoted quantitatively. Through its extended boundary, LCA also provides a direct link into the product stewardship debate and can be used to develop the fundamental underpinnings of stewardship concepts.

3.3.2 Scenario Development

The focus of LCA on the functionality of a product, and not on the product alone facilitates comparisons with different systems that provide the same functionality than those which only look at product flows. An example here is the assessment of washing machines. Recognising that the functionality of a washing machine is not the product itself but rather the provision of a service – people do not necessarily want to own a washing machine, they require the delivery of clean clothes – has the potential to change the emphasis of the assessment being conducted, from designing an efficient washing machine, to developing a system which delivers the clean clothes which society desires. LCA thus allows companies to view their place in society differently, as suppliers of the services provided to society by products and not necessarily suppliers of the products themselves.

The systems structure of LCA facilitates the development of scenarios related to product selection, design, manufacture, future world, etc., and enables these to be explored with relative ease. Because of its comprehensive boundary definition as illustrated in Figure 1, Life Cycle Thinking can guide scenario development in directions not initially thought of.

Note was taken of the point that LCA results highlight current macro-economic systems as not environmentally sustainable. LCA has the potential to assist policy in moving economic drivers closer to supporting sustainable development by demonstrating the environmental effects associated with shifting economic drivers and systems. LCA is a valuable tool for assessing the numerous credit and incentive based policies under development at the moment. This with the understanding that it is better to get policies in place that work from the outset, as opposed to having to change these policies after they have been development and institutionalised. LCA is not the only tool which needs to be included here, economic and socio-centric considerations need to be included in these assessments. The potential exists to align LCA with other mappings (institutional, policy, etc.) in order to develop better tools to guide change. The systems nature of LCA facilitates this alignment.

3.4 CONCLUSIONS

The advantages of applying LCA to mining, minerals processing and metals were seen to be:

- improved communication with stakeholders, and,
- the potential to effect change to improve the environmental performance of the system being assessed.

Constraints on the application of LCA relate to methodological considerations, the value judgements inherent in conducting and LCA, and potential misinterpretation of LCA information by stakeholders. Further opportunities for LCA discussed included the facilitation of better supply chain management, and imaginative scenario development.

4 Application of LCA in Mining, Minerals and Metals

Work on the application of LCA to mining, minerals and metals presented at the workshop can be grouped into three main themes:

- LCA of processes and integration of processes (section 4.1)
- LCA to ensure market access and to improve products (section 4.2)
- LCA combined with Material Flow Analysis for long term planning and strategy development in the industry (section 4.3)

These are discussed in turn in this section. While the content of this section is not in anyway a complete listing of all projects in which LCA has been applied in mining, minerals processing and metals, the coverage of the different themes as listed above is adequate and thus the conclusions drawn are substantive.

At this point it is worth noting the difference between foreground and background systems defined for different projects. While assessment boundaries may be defined to range from cradle-to-grave over an entire metal value chain, the focus of the study is often only one element of this metal life cycle. The foreground system is defined as the element(s) of the value chain which are being considered with the aim to change/improve it(them) through the results of the assessment. The background system includes all elements which supply materials and energy to the process, as well as the balance of the material chain that does not fall into the foreground system. To clarify this distinction with an example, in process improvement studies only the process falls in the foreground system, whereas provision of electricity and other utilities, transportation, manufacture, use and waste disposal together make-up the background system. In this section the foreground system is defined as those elements on which the assessment focuses.

4.1 LCA OF MINING AND MINERALS PROCESSING FOR PROCESS IMPROVEMENT AND INTEGRATION

LCA for technology selection and integration has been conducted within minerals processing by companies, industry associations and in academia (International Iron and Steel Institute, 2001; International Aluminium Institute, 2001; Ecobalance, 2000b; Norgate and Rankin, 2000; Stewart, 1999; Stewart and Petrie, 1996; Azapagic, 1996). Other industry associations have conducted LCA studies, but these are not published in open literature. Notable among companies applying the tool to process performance improvement and integration is BHP Billiton (with most of the work being conducted by the then BHP Laboratories in Newcastle, New South Wales, Australia). Their experience of the tool suggests that there is significant value to be gained from the process of conducting an LCA as well as from the results generated by the assessment even if information detail contained in the studies is limited. In general in the BHP Billiton work, LCA environmental information has been combined with additional techno-economic information to inform decision making.

The focus of industry's work in minerals processing has been on technology, covering such aspects as:

- Technology Selection (e.g., BHP Billiton comparison of steel production technologies)
- Technology Integration (e.g., BHP Billiton Inter-business integration between Olympic Dam and Wyalla Steelworks where it is proposed to transport a slag from Wyalla to Olympic Dam to combine with flyash at Olympic Dam to replace Portland cement in mine backfill; BHP Billiton comparison of a number of alternatives for steel production

with integration of technologies delivering the best outcome with respect to environmental and techno-economic considerations)
- Process Improvement (e.g., Aluminium Institute have proposed improvements to Alumina Smelters to decrease carbon consumption)

The boundary definition chosen for these assessments has been one of cradle-to-gate. Practitioners explain this selection of boundary by stating that the impact associated with the use of the metal is independent of the technology used to deliver the metal to the market.

With respect to the value chain of metals, these studies have generally been limited to consideration of Mining, Concentration and Refining alone. Within this system, complete LCAs of mining with a focus on assessment and improvement have generally not been conducted. Mining LCAs have been in the generation of Life Cycle Inventories to be included in LCA databases (Frischknecht, 1996). The application of LCA to mining is not trivial and is discussed, to a limited extent, in Section 6.1. In addition, very little LCA work has been conducted on Concentration processes (i.e., the concentrating of run-of-mine ore to a metal-in-concentrate), most industrial LCAs have focused on Refining technologies. Thus the foreground system for these assessments is usually only the Refining element of the metal life cycle.

Considering the project life cycle the work is relatively easy to classify. Technology Selection has usually taken place during the Design element of the project life cycle. This is the case for some of the Technology Integration case studies. In other cases Technology Integration has been assessed during the Operational cycle of the project, where technologies on different sites have been integrated to deliver better overall performance. Process Improvement assessments have been conducted during the Operating element of the project life cycle. Technology Selection decisions are usually Tactical in nature. Technology Integration between processes are also Tactical, Technology Integration within processes are operational decisions. Technology Improvement decisions are operational in nature. This discussion in summarised in Table 1. This table also details which of the value chain elements fall into the foreground system.

Table 1 *LCA in Minerals Processing Decision Contexts*

LCA Application	Material Life Cycle Elements	Foreground System	Project Life Cycle Element	Decision Context
Technology Selection	Mining, Concentration, Refining	Concentrating and/or Refining (Refining is most common)	Design	Tactical
Technology Integration between Processes	Mining, Concentration, Refining, Transport, Use	Refining, Transport, Use	Design	Tactical
Technology Integration within Processes	Mining, Concentration, Refining	Refining	Operation	Operational
Process Improvement	Mining, Concentration, Refining	Concentrating or Refining	Operation	Operational

In summary, LCA has been used meaningfully within minerals processing industries. However, deficiencies in LCA have been noted. These are discussed in detail in Section 6 of this report.

4.2 LCA OF METALS AND FOR PRODUCT IMPROVEMENT

Here the assessments can be classed as:
- LCA of metals (International Copper Association, Nickel Development Institute, Aluminium Institute, International Iron and Steel Institute)
- LCA of products containing metals (Electrolux, Nokia, etc.)

With respect to the former, a number of study aims can be identified, these include:

- Determining the effect that the product has on the environment throughout its material life cycle
- Determining where it is best to focus efforts to decrease these effects
- Improving communication with customers

Most of these assessments have included both the environmental and the economic performance of the metal being studied. These studies are extremely comprehensive with respect to coverage of the industry. They represent significant information gathering and data reconciliation exercises. All of the studies have been peer reviewed by external peer review panels. Not all of the studies are readily available to the public. As with the industrial application of LCA these studies have proven valuable just from the lessons learnt in conducting them.

Outcomes of the studies have not always been intuitive. In some cases the most significant impact associated with the metal over its life cycle has been in the provision of electricity to primary refining. In other cases the most significant impact is associated with the metal's use phase. This highlights the fact that it is not only the minerals industry that must take responsibility for the impacts associated with its products. Designers and consumers determine the impacts associated with the manner in which a metal is used, this can often be the source of highest impact over the life cycle of the metal. An example here is an LCA of a kettle where the most significant impact is associated with the manner in which the kettle is used. Kettle users mostly fill the kettle far fuller that they require. The extra energy used in boiling the additional water dominates the impacts associated with the manufacture, use and disposal of the kettle. This highlights the need for education around metals and the part they play in society, as well as the role that society plays in ensuring that metals are used efficiently.

The assessments carried out by the institutes/industry associations have also considered a cradle-to-cradle boundary which looks at replacing primary material with secondary, or recycled, metals. The case of the aluminium industry is significant here as the energy associated with recycling aluminium is 5% of that required in primary refining. LCA studies have been used to support recycling initiative. Recycling is discussed in more detail in Section 5.2.

While decisions have been taken using the information delivered by the institutional LCA studies, most of these have been in the context of process improvement as discussed in Section 4.1. The role of these assessments is far more long term as they have the potential to support strategic decision making for the industry. The boundary definition invoked (cradle-to-cradle) means that they include all elements of the material life cycle. They have the potential to inform decisions in the Strategy and Planning, and Research and Development elements of the project life cycle. This discussion in summarised in Table 2.

With respect to the application of LCA to metal-containing products, it was suggested that this is the element of the metal value chain in which the application of LCA is most mature. Consumer pressure, motivated by concerns about the environmental performance of products across their life cycle, has driven LCI/LCIA data collection within the resource intensive industries, and specifically metals. Thus initiatives in the resource consumption economies has driven data collection from the resource extraction economies. There is a recognised shortage of LCA data for the initial stages of the material life cycle. This is discussed in more detail in Section 6.6 of this report.

Initiatives in product development have been to minimise the impact associated with both the use and the disposal of products, for example mobile phones. Thus the focus in this area has been on decreasing the amount of metal used in products, improving the manner in which products are used, design for recycling (e.g., ease of dismantling) and to minimise impacts associated with final disposal. In this context it can be seen that all these aspects relate to decisions taken during the product design phase. The boundary defined is usually cradle-to-grave.

In addition, product manufacturers have used LCA, together with other environmental tools, to improve the performance of their own operations (e.g., Nokia and Alcatel). These are operational decisions which have also included supply chain management. In these cases the foreground system comprises only the manufacturing plant.

The decision contexts, material and project life cycle elements, and foreground system elements discussed above are included in Table 2.

Table 2 *LCA in Metals and Metals Products Decision Contexts*

LCA Application	Material Life Cycle Elements	Foreground System	Project Life Cycle Element	Decision Context
Product Defense (Metals Specific)	Mining, Concentration, Refining, Manufacture, Transportation, Use, Reuse, Disposal	Material Life Cycle	Strategy and Planning, Research and Development	Strategic
Product Design	Mining, Concentration, Refining, Manufacture, Transportation, Use, Reuse, Disposal	Manufacture, Transportation, Use, Reuse, Disposal	Research and Development	Strategic
Product Design	Mining, Concentration, Refining, Manufacture, Transportation, Use, Reuse, Disposal	Manufacture, Transportation, Use, Reuse, Disposal	Design	Tactical
Process Improvement	Mining, Concentration, Refining, Manufacture, Transportation, Use, Reuse, Disposal	Manufacture	Operation	Operational

In summary, LCA has been used to a significant extent in the assessment, design and development of consumer goods containing metals. This is the most mature use of LCA in mining, minerals and metals.

4.3 LCA AND MATERIAL FLOW ANALYSIS

One of the characteristics of LCA is that it aggregates effects over space and time. This requires a number of inherent value judgements, the most notable of which are

- Environmental effects experienced in the future are assumed to be equivalent in significance to environmental effects experienced in the past and the present. Attempts to address this have invariably required some form of discount rate analysis
- Environmental effects are assumed to be equivalent independently of the location of the effect

It is in the context of the latter that some practitioners are integrating LCA with Material Flow Analysis (MFA). The intention of MFA is to describe material flows with respect to magnitude, composition and location, i.e., where the material originates, and where it reports to. LCA is then used to determine the potential environmental impacts associated with all elements within the MFA. The value in integrating MFA with LCA is that it makes it possible to differentiate between the effects associated with a product over the extent of the logistical chain required to deliver that product. Researchers in this field argue that this facilitates more explicit consideration of trade-offs in decision making.

In addition, the location and quality of material available for recycling in better known and understood, supporting the development of recycling initiatives.

A number of MFAs for metals have been developed. Most of the work in this area has focussed on Aluminium and Copper. The work of Ayres *et al* (2001) describes material flows of copper. The work of RWTH Aachen (Rombach *et al*, 2001) has focussed on Aluminium and work on Copper is starting. The work of Giurco *et al* (2001) has also focussed on copper. It should be noted that none of these works are classically (or entirely) MFAs The value of integrating MFA and LCA is to support strategic development of the minerals industry. It will provide guidance to the industry as it strives to meet its sustainable development goals. Researchers in the field suggest that the integration of MFA and LCA can support the development of strategies with respect to, for example:

- Which ore body to exploit using which technology(ies)
- Where to focus recycling initiatives
- Where to place recycling technologies

While it must be recognised that LCA can supply information about the environmental consequences of these different scenarios, other tools will be required to ensure that all sustainability considerations are included.

4.4 CONCLUSIONS

LCA has been used in mining and minerals processing to effect process integration and change. Lessons learnt from conducting the assessments were often more valuable than the results of these assessments. LCA has been widely applied to the production of metals and in product improvement. These assessments include determining the effect that the product has on the environment throughout its material life cycle, determining where it is best to focus efforts to decrease these effects and improving communication with customers.

The integration of LCA and MFA is seen as having potential to inform industry-wide decision making.

5 LCA to Support Policy Development

LCA has been discussed as a tool to support multiple criteria decision making for sustainable development in that LCA, including decisions relating to policy development.

In this section, an existing policy initiative which utilises LCA is discussed with respect to the benefits and weaknesses of the approach. The potential for LCA to support policy development in Recycling, and in addressing the differences in impacts between Resource Extraction economies and Resource Consumption economies, is also discussed. Again this section reflects the opinions of workshop attendees and substantive references are not cited.

5.1 LCA IN EXISTING POLICY INITIATIVES

The policy initiative discussed at the workshop was the European Union's Integrated Product Policy (IPP). The aim of the IPP is to apply Sustainable Development objectives to the design, production, use and disposal of products, i.e., guided by Life Cycle Thinking.

There are three potential action routes within the IPP:

- Pricing mechanisms
- Producer side management
- Consumer side management

In this context LCA is seen to belong to producer side management as illustrated in Table 3.

Table 3 *Tools for Production and Consumption Side Management (after Thiran, 2001)*

Production Side Management	Consumption Side Management
Eco-product Development	Economic Instruments
Extended Producer Responsibility	Green Procurement
Grants/funding projects	Eco-efficiency
Environmental Management and Auditing Systems	Eco-marketing
Eco-design	Consumer Information
LCA	End-of-Life Measures

At the workshop, it was recognised that there is potential for LCA not only to inform policy development, but also to become part of the regulatory process. Using life cycle thinking and LCA the development of this policy has shifted the focus from wastes to impacts. It has changed the quality of information available for decision making, and facilitates the evaluation of environmental objectives for decision making for sustainability. It has also made it possible to incorporate considerations such as the durability and recycleability of products into the decision making process.

Reservations on the application of LCA to the development of policy relate to lack of consistent methodologies and data sets as discussed in Section 6. Other issues include the complexity of defining sustainability indicators and thus defining a green product, and problems with integrating socio-economic indicators into the assessment. There was general agreement at the workshop that this is not the function of LCA and required integration of LCA with other tools. Indicators are best developed during problem structuring exercises as discussed in Section 2.2.

However, it was noted that LCA is beginning to play a greater role internationally in policy development as well as regulation. Again significant emphasis is being placed on data gathering in the short term. There is a role here for industry as well as industry associations. Intervention should take place to ensure that data is gathered relative to equivalent bases. In addition, policy development is focussed on resource consumption economies, there is no guarantee that sufficient attention will be paid to resource extraction economies and the impacts associated with the provision of materials to resource consumption economies. Again the mining and minerals industry has a role to play here to ensure that policy developed is balanced and fair.

5.2 POLICY FOR RECYCLING

The role for recycling of metals in Sustainable Development was debated actively at the workshop. The opinion of workshop attendees was that LCA is not necessarily the primary tool to driving recycling initiatives, these are being driven more by economics and legislation. LCA has value in supporting policy development for better recycling of metals. In this context LCA has the potential to assist in the unpacking of the supply side system required to:

- Compare the environmental performance of different recycling scenarios, including all considerations such as transport and energy provision
- Compare the environmental performance of different recycling technologies
- Develop products with increased recycleability
- Determine appropriate and effective collection mechanisms
- Assist in developing better routes for access to financing

Most significant constraints on recycling were identified as being functions of institutional, economic and regulatory structures. These relate to the structure and ownership of the scrap industry; the part that the Basel Convention plays in either stopping scrap or waste materials from being transported to locations where they could be re-processed, or increasing the administrative burden associated with recycling; and direct or indirect subsidisation of landfills which is not available to recyclers. These constraints cannot be addressed using LCA.

There are a number of constraints on the application of LCA to developing and supporting recycling policies. Some of these relate to nomenclature and definitions. Wastes are now being called by-products which is changing the manner in which these streams are viewed by decision makers. Consensus needs to be reached on a definition for “recycling efficiency” so that the term can be used in a standard fashion for all assessments. In addition, care should be taken to ensure that the focus of assessments is on maximising resource use efficiency over all material life cycles. Concerns relating to the manner in which LCA allocates credits to recycled materials have already been discussed in Section 6.7.

A number of recommendations were made as to how to address these constraints. These are summarised in Table 4.

A further issue to be addressed in the development of recycling policy is for designers and regulators to consider the properties of the metals <u>after</u> the use phase of the products. Requesting recycling data for long life products can stifle innovation due to the significant amount of time that these products spend in the industrial economy.

Table 4 *Recommendations for applying LCA to Recycling Policy Development*

	Metals Industry	National Governments	Local Authorities	Communities	NGOs	LCA Practitioners
Internal education	X					
Intra-metal collaboration	X					
Downstream communication and collaboration	X					
Outreach to recyclers	X	X			X	X
Better definition of Nomenclature	X	X			X	X
Data development/gathering/propogation/incentives	X	X				X
In regulatory regimes for End Of Life products/hazardous wastes etc. (their classification, movement, liability regimes) consider consequences for recycling		X				
Work to level the playing field for recycling vs. waste industry/landfill business		X	X	X	X	

5.3 ADDRESSING THE NORTH-SOUTH DIVIDE

As has been stated already, LCA was developed in Northern Hemisphere countries to address environmental concerns specific to those regions. This has resulted in a number of deficiencies in LCA information and methodology as discussed in Section 6. At the same time, as Life Cycle Thinking incorporates a consideration of the entire life cycle of a metal, it does have the ability to highlight differences in the impacts borne by the environment, as a function of where these impacts arise within the material life cycle. Thus LCA makes it possible to differentiate between impacts borne by resource extraction economies, and those borne by resource consumption economies. This is only possible if LCA results are combined with MFA-type approaches so that the location of environmental burdens can be highlighted.

Workshop participants engaged with this question on two levels; determining the applicability of LCA to policy development in the context of the North-South divide; and defining the nature of this 'divide" to assess its significance.

As a first order assessment workshop attendees proposed that the North-South divide could be defined in different ways with respect to a number of generic attributes:

- South is a combination of the G77 countries, the non OECD countries and the non ex-USSR countries
- South represents the minerals production economies, whereas the North are the minerals consumption economies
- South countries are dependant on exports, North countries have a combination of imports and exports
- Perhaps the divide is as simple as rich versus poor countries

Irrespective of how the North-South divide is articulated it must be recognised that resource extraction economies bear a significant environmental burden associated with their provision of metals to the consumption economies. This is best illustrated in a figure drawn from the work of Clift and Wright (2000) which highlights the value added relative to environmental burden associated with different material life cycle stages. This figure is included as Figure 7. This figure demonstrates that economies which focus on Resource Extraction and Refining generate less income to be used in remediating the effects of these processes.

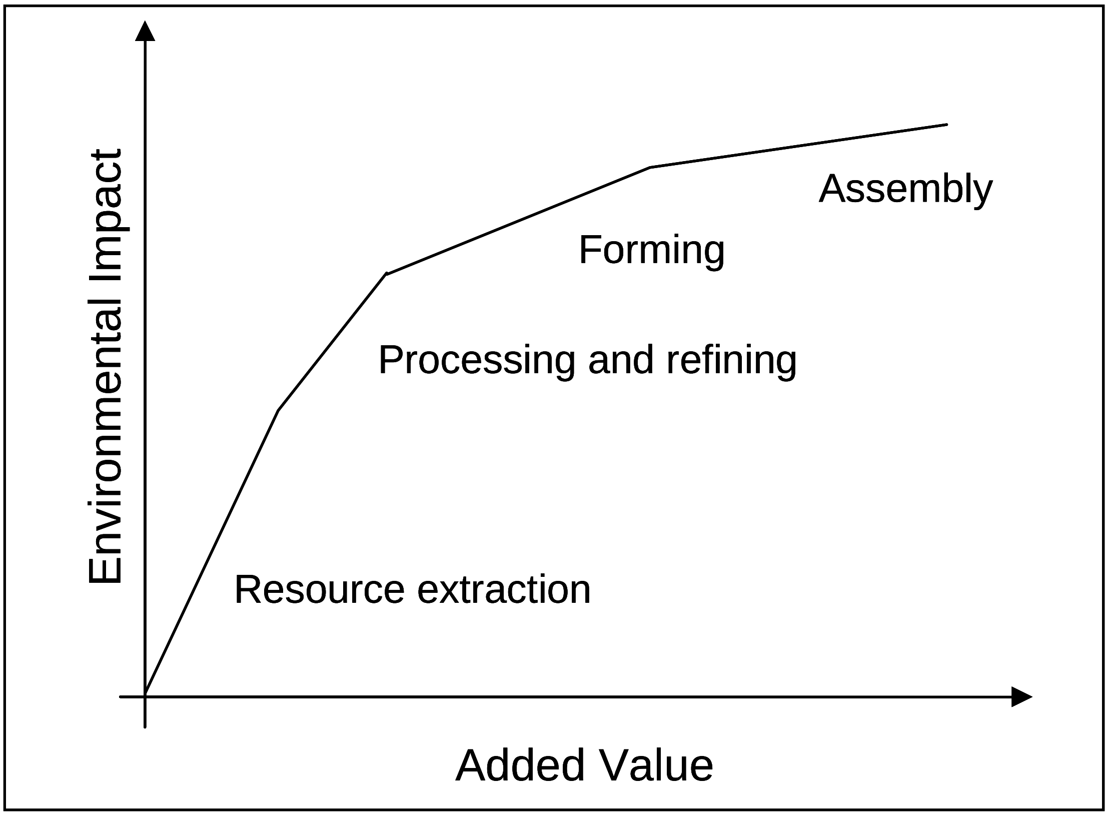


Figure 7 *Environmental Impact and Added Value along the Material Chain (after Clift and Wright, 2000)*

Workshop participants felt comfortable defining the issues which separate the North and the South with respect to their attitudes to metals and the environment. These are summarised in Table 5.

Table 5 *Issues for Metals in the North and the South*

North	South
Limit exposure to metals	Insure access of metals to market Primary metals sector growth
Focus on environment	Focus on development
Environmental problems are a result of development	Environmental problems are often related to poverty

Another perspective on this is the fact that it needs to be recognised that the economies of the "North" rely on significant inputs from the "South". Notable in this context is the provision of minerals and metals which create valuable stocks in the economies of the "North". However, the natural sinks in the "North" are limited, while there are still large natural sinks and significant resource availability in the "South". Extending this argument, there is the potential for northern economies to exceed the carrying capacities of their natural environments a long time before this is the case for the southern economies. The constraints on the "North" continuing to function at existing levels of consumption are significant, constraints on the "South" are far less stringent. While this is not necessarily an issue that can be addressed using LCA, or even Life Cycle Thinking, it is the reality of existing systems and is highlighted as such.

The workshop concluded that LCA is not the correct tool to resolve these issues. It can however be used to identify points of significant impact and highlight where discrepancies in existing economic models arise. It was noted that LCA is negative impact focused as was discussed in Section 6.8 and that LCA does not necessarily incorporate all environmental impact categories which are priorities in the South as discussed in Section 6.4. Furthermore, LCA measures a small number of variables with some precision, this may exaggerate the importance of these variables relative to others which cannot be quantified as was discussed in Section 3.2.

Although Life Cycle Thinking can be used to guide the debate to some extent, LCA is not the only tool to be used in developing policies to address the North-South divide. Additional tools are required in order for policy development to be adequate.

5.4 CONCLUSIONS

While Life Cycle Thinking can be used to guide development of policy to support sustainable development, LCA is not the only tool which should be applied in this context. Additional tools are required to ensure that techno-economic and socio-economic considerations are included in the development of policies and in decision making. In addition, LCA may not be adequate for informing the set of environmental considerations as the indicators within LCA are damage focused and not benefits or outcomes focused. In developing policy for sustainable development, it is best that the indicators of performance be defined by comprehensive discussions with stakeholder groups. The quantification of these indicators can then be achieved by integrating assessment tools where necessary.

6 Complexities in applying LCA to Mining, Minerals Processing and Metals

There are a number of deficiencies in LCA methodology, data and information which have been mentioned throughout this document. In addition, some of the complexities associated with applying LCA to the metals value chain are highlighted. These are discussed in detail in this section. The level of detail of discussion in this section is in order to state explicitly what is required of LCA methodological development in order that LCA be fit for purpose in applications as discussed in sections 3, 4 and 5.

6.1 BOUNDARY DEFINITIONS

In this section two issues are discussed:

- Boundary defined for the mining process
- Boundaries for recycling systems.

Defining the boundary around **the mining process** itself is not a trivial matter. Difficulties here can be likened to those experienced when applying LCA to agriculture, another primary industry. In the case of agriculture boundary definition is complicated by the fact that the farming process takes place in the natural environment. The challenge is to determine where the technosphere (the farming process) stops, and where the envirosphere (the natural environment starts). This is also the case with underground mining where processes take place deep within the earth's crust and are completely integrated into the envirosphere. It is easier to define a boundary for open cast (or open cut) mining where the extent of the ore body is known and the boundary can be drawn to fall outside the ore body. However, complexities may still arise in the case of open case mining as well.

With respect to **recycling systems**, the issue is related to the recyclability of various metals. According to ISO 14041 and ISO TR 14049, the boundary of the system needs to be expanded when the properties of the material are not degraded after the use phase. According to ISO LCA standards, for materials such as metals, the global aspects such as primary and secondary production needs to be considered in order to characterise the system properly.

In a generic sense, any given metal can have numerous applications (product systems). If the inherent properties of the metal are not changed by the recycling stage, it can be reused in the same or a different product system. In that case, a closed loop allocation procedure is applicable. Recovery of 1 kg of metal through recycling will displace an equivalent production (1 kg) of virgin (primary) metal. If the inherent properties of the material are not maintained, the open loop allocation procedure will consider this extra burden.

If a metal is used in a large number of product systems (Figure 8), the composition of the primary and secondary metal in the production system is not relevant. Taking aluminium scrap as an example, if the recovered scrap is used, for example, in building material production, the ratio of virgin to secondary aluminium will increase in the packaging material. According to the Figure 8, the recycling rate after the use phase is the important parameter. Any losses of aluminium at the disposal stage need to be compensated for by an equivalent quantity of primary aluminium production. The assumption made here is that all the aluminium not recycled after the use phase will be ultimately replaced by primary production as less scrap will be available for packaging material production and for aluminium building material production.

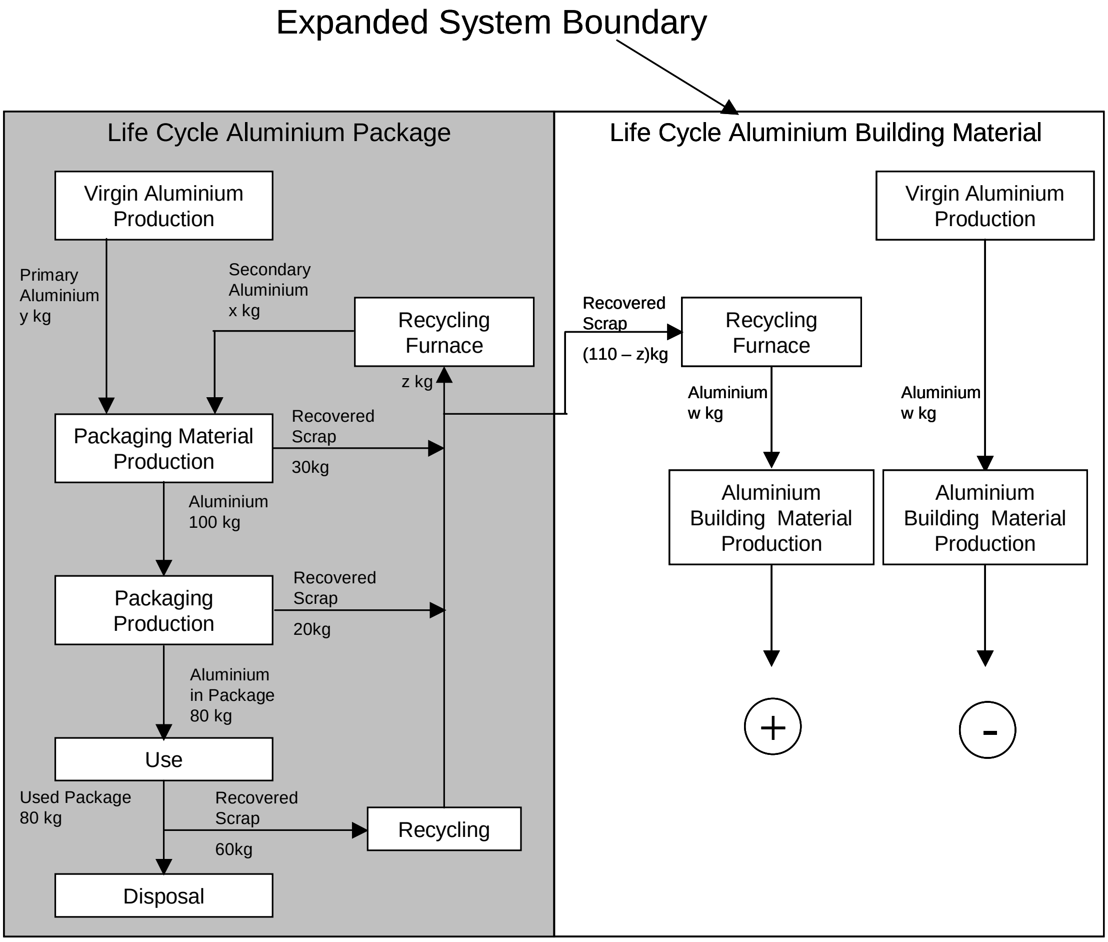


Figure 8 *Recycling procedure with expanded system boundaries (ISO/TR 14049, 2000(E))*

A potential mechanism for the industry to have input to the development of this process is through the international workshop on LCA of metals co-organized by ICME and Natural Resources Canada under the umbrella of the UNEP/SETAC Life Cycle Initiative.

6.2 DEFINITION OF IMPACT CATEGORIES

Two impact categories currently used in LCA have been highlighted as causing problems in their articulation. Their definitions are misleading, and it is difficult to express their significance unambiguously, whether one is concerned with metals-containing emissions to air, water, or directly to land.

6.2.1 Eco-toxicity

In response to well-founded concerns arising from environmental damage caused by pesticides and herbicides, the concepts of persistence (P) and bioaccumulation (B) were developed in the early 1970's for application with environmental toxicity (T) data in the hazard identification of highly toxic synthetic organic substances with distinct and exact chemical formulae. While strictly applicable only to synthetic organic substances, the criterion of persistence or biodegradability has been extended by domestic and international regulators and modellers to all substances, including metals and metalloids.

However, metals do not degrade and thus expressing their eco-toxicity in terms of persistence is not an adequate mechanism. Furthermore, LCIA models considered that metals are presented in a bio-available form. With rare exceptions, there is no speciation. This has been recognised by the LCA community and work is underway to formulate eco-toxicity in terms of bio-availability (Huijbrechts *et al*, 2001; Heijungs, 1999; Guinee *et al*, 1996; SETAC, 1994). Unfortunately, this work has proceeded largely independently of the wealth of knowledge within the mining and minerals processing industry itself as to the stability and bio-availability of its wastes. The industry needs to work with the LCA community to ensure that this impact category is developed correctly so that a better indication of the potential effects of their processes is included in LCA studies. A potential mechanism for the industry to have input to this process is through the international workshop on LCA of metals co-organized by ICME and Natural Resources Canada under the umbrella of the UNEP/SETAC Life Cycle Initiative, as well as through other elements of the UNEP/SETAC Life Cycle Initiative.

6.2.2 Resource Depletion

While it is possible to deplete the carbon-based energy minerals, it needs to be recognised that metals cannot be depleted, they can only be dissipated. This fact was highlighted in the work of Ayres *et al* (2001). Thus, in the context of metals utilisation, the name of this impact category is incorrect.

At the same time is it worth looking more closely at the material chain of metals to see at which points this “depletion” takes place. For convenience two further terms are defined, resource extraction and resource dissipation, where:

- Resource Extraction occurs during the mining process where metals are mined from the earth’s crust and supplied to a “pool” of metals in the material economy; as such, resource extraction essentially adds value to the metals naturally present in the earth’s crust by concentrating them to the point that they represents useful materials within the material economy
- Resource Dissipation occurs when metals leave this pool of metals in such a diluted form that it is not possible to recycle them back into the material economy, an example here is the copper used in the chromium-copper-arsenic (CCA) treatment of woods as highlighted in the work of Ayres *et al* (2001).

Within the current definition of Resource Depletion it is not possible to differentiate between the actions of resource extraction which do deplete ores as unique concentrate from the earth’s crust while making them available to the industrial economy, and resource dissipation which is the loss of these metals from industrial systems. As such the current articulation of the resource depletion impact category appears to place the emphasis of this impact at the mining end of the material chain, as opposed to emphasising the fact that product use and disposal are responsible for depleting resources. In the context of Sustainability, where provision must be made for future generations to meet their own needs, resource extraction plays a significant role in concentrating metals to the point that they are useful. Both current and future generations will bear the burdens associated with this provision of metals. However, it is the loss of these metals from the industrial economy which undermines the potential of future generations to meet the needs that that have of these materials.

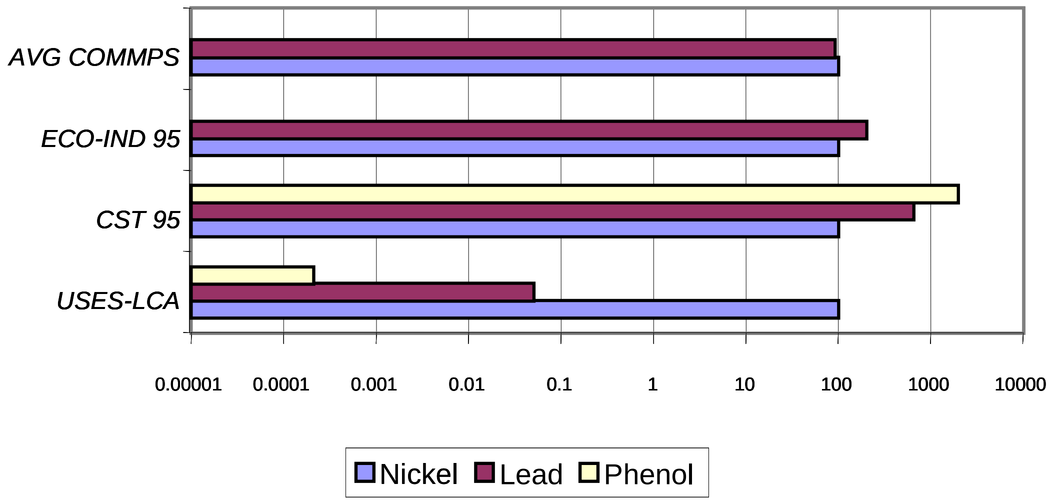
Again there is value in the minerals industry having input to the development of LCA to ensure that the effects of Resource Extraction and Resource Depletion are counted separately so that the value of the minerals industry to society is better understood, and in order to better reflect the performance of the industry. In addition, breaking Resource Depletion into two categories makes it easier to determine to whom responsibility for the loss of metals from the material economy can be attributed.

6.2.3 Other Impact Categories

Other impact categories that were not addressed directly at the workshop but are worthy of mentioning in that they are potentially ill-defined with respect to their application in mining and minerals processing LCAs are impact categories dealing with water use explicitly, as well as land use impacts. These are also mentioned in Section 6.4.

6.3 SELECTION OF IMPACT ASSESSMENT MODELS

One of the impact categories which has proven extremely difficult to quantify for metals is eco-toxicity. This is mentioned in Section 6.2 with respect to the definition of the impact category. To further complicate the issue, there are a number of models available for determining a systems contribution to this impact category. The matter is further complicated by the fact that each model presents different results and results with order of magnitude differences. This is illustrated in Figure 9, which contrasts four different models for evaluating the contribution of a process to eco-toxicity. Note: the y-axis of this figure is a logarithmic scale. The main reason for difficulties in quantifying eco-toxicity within an LCA framework is that eco-toxicity is a site specific impact and LCA does not reflect site specificity in its evaluation of impact assessments. This is discussed further in Section 6.5.



Key:
COMMPS - Combined Monitoring-based and Modelling-based Priority Setting
ECO-IND 95 - Eco-Indicator 95
CST - Critical Surface Time
USES LCA - Uniform System for the Evaluation of Substances

Figure 9 *Comparison of Different Aquatic Eco-Toxicity Characterisation Models (Ecobalance, 2000a)*

As a first estimate many minerals based assessments have not included eco-toxicity in their list of impact categories. A case in point is the LCA of Nickel recently published by the Nickel Development Institute (Ecobalance, 2000b). While it must be recognised that the methodologies used to quantify eco-toxicity may have significant inherent uncertainty associated with them, eliminating impact categories from assessments because they are not adequately quantified will deliver only a partial assessment. Eliminating eco-toxicity from LCAs is not necessarily the best approach, there is more value in including the impact category in the assessment and conducting a rigorous uncertainty analysis on the results.

6.4 REQUIREMENT FOR ADDITIONAL IMPACT CATEGORIES

As has been mentioned before, LCIA has been developed largely from a European perspective. Thus the impact categories included in the original formulation of LCA reflect environmental concerns in those regions. However, most mining activity occurs outside Europe in areas which have significantly different environmental conditions and concerns. It is necessary for LCA to be able to address these differences. A case in point here is the issue of water resources, and the effect of increasing salinity of these resources associated with mining and minerals processing operations. Salinity is regulated under water quality legislation and forms one of the considerations managed by Environmental Management Systems on-site. However, there is no potential to include a consideration of salinity effects in LCA methodology.

Impact categories other than Salinity that are under consideration for development, or in the initial stages of construction, include Land Use, Reclamation and Water Management. These impact categories are directly attributable to mining and minerals processing operations. The mining and minerals industry needs to be involved in debates on the development of these impact categories, as well as the definition and construction of other necessary impact categories. The following sections consider some of these issues, and explore the way forward to address the limitations of LCA in this regard.

The minerals industry together with an initiative such as the UNEP/SETAC Life Cycle Initiative needs to take steps to address these shortcomings in LCA. At the very least LCA should include consideration of all environmental effects which are regulated on mine sites. This can address, to some extent, the concerns expressed in Section 3.2 about LCA focussing too much attention on those system's performance aspects which can be quantified using the tool.

6.5 AGGREGATION OVER SPACE AND TIME

LCA aggregates environmental interventions over space and time. This has been mentioned in Section 4.3. This is one of the reasons why the quantification of global effects (e.g., Global Warming Potential) is more accurate than similar aggregation for local / regional effects (e.g., Eco-toxicity). While this spatial and temporal aggregation is attractive in that it makes it possible to compare disparate systems according to consistent boundary definitions, it does obscure significant effects associated with mining and minerals processing.

Of particular concern here are:

- Post-closure effects associated with solid waste management practises – these have the potential to last for time periods significantly greater than the operating phase of the mining/refining process
- The residence time of products in the material economy (or the useful life expectancy of a product) – this was highlighted as a deficiency in understanding/quantification in the work of Ayres *et al* (2001)
- The time involved in exploration for reserves – the complexity here is that mining companies with explore for significant time periods and over significant distances before proving a deposit. This deposit can remain unexploited for a significant period of time, whilst still accumulating the impacts associated with such exploration. Allocation of impacts associated with the exploration phase of the metals life cycle to a specific product is not trivial. This complexity also relates to the boundary definition adopted for projects. Exploration has been included in some existing LCA studies and databases (Frischknecht

et al, 1996). However, significant complexities exist in this boundary definition, the minerals industry should define this debate and assist in developing a uniform approach to including exploration in LCA studies. In addition, exploration has often been omitted LCAs conducted to date (see Table 1and Table 2 in Section 4).

- Consideration of other "resource drivers" required for minerals' development for example, the significant use of "background" energy

Care should be taken to ensure that these effects are adequately reflected in any LCA study conducted to ensure transparency and comparability of results. Again the minerals industry (together with other agencies) should be directly involved in this methodological development.

6.6 INFORMATION AND DATA DEFICIENCIES

At the workshop data and information availability was highlighted as one of the major problems associated with conducting LCAs for mining, minerals and metals. This was also one of the findings of the work of Ayres *et al* (2001). There is a deficiency in the information available to inform impact categories (equivalency factors) within LCA databases. In addition, it was felt by workshop participants that this lack of information relates mainly to the operation of technologies within the industry. Concern was also expressed about the ability of existing information sets to quantify flows within existing value chains, this with a particular focus on recycle rates and quantities. Once this information is available it may be possible to quantify the complex linkages within the value chain. These aspects are discussed below.

6.6.1 Impact Category Equivalency Factors

The impact categories of concern discussed at the workshop are Resource Depletion and Eco-toxicity. They are discussed separately below.

Work attendees have expressed concern about other impact categories after the workshop. These impact categories include Land use, Water Management and Land Reclamation. These are deserving of attention and should be addressed in future LCIA methodological development. They are not discussed in any further detail in this section.

Resource Depletion

The most recent SETAC publication on the Resource Depletion impact category is the SETAC WIA-2 Task Group Report *LCIA Framework for Resources and Land use* (Lindeijer *et al*, 2001). This work makes a distinction between biotic and abiotic resources with minerals resources falling into the latter. In this work they describe the four main approaches to quantifying resource depletion available to LCA practitioners as discussed by Finnveden (1996) and expand upon these to incorporate more recent work. The four broad categories for determining resource depletion as proposed by Finnveden (1996) are still sufficiently generic to apply to this more recent work. These categories are summarised in Table 6. A more complete description of these methodologies are included in Appendix 2.

Table 6 *Resource Depletion Characterisation Types (after Lindeijer* et al*, 2001)*

Characterisation Type	Aggregation Method
Type 1	Aggregation of energy and materials on energy and mass basis, relative to mass of metals produced, not nature of ore body
Type 2	Aggregation (Q) according to measure of Deposits (D) and current consumption (U) 2a: Q = 1/D (Fava *et al*, 1993) 2b: Q = U/D (Guinée and Heijungs, 1995) 2c: Q = 1/D*U/D (Heijungs et. al, 1992, Guinée, 1995, Mueller-Wenk 1978)
Type 3	Aggregation based on future scenarios, e.g., impacts associated with recovery to initial state (Pedersen, 1991)
Type 4	Aggregation relative to exergy or entropy impacts, e.g., Finnveden proposes an exery approach (1996)

The conclusions of this SETAC working group highlight the significance of uncertainty in information and its interpretation in connection with this impact category. They propose that the three aspects to be incorporated in the category are:

- Competition or Present availability
- Future availability
- Life support functions including bio-diversity

They note that type two focuses on competition for resources, while type three looks at future resource availability and highlights resource extraction. This highlights potential problems with the definition of the impact category, and the potential to disaggregate it into two elements, resource extraction and resource consumption as proposed in Section 6.2.

A further peculiarity associated with this impact category is that available reserves are defined by the technologies available to exploit them. As technologies advance and are better able to process ores of lower grades the reserve base grows. Thus a static statement of known reserves in LCA databases is not adequate. The minerals industry has significant expertise to bring to this debate to ensure that the development of this impact category is adequate, and to ensure that it is useful to the industry. Significant work on resource economics has been conducted by the industry (example references include AusIMM, 2001; JORC, 1999). This debate would be strengthened by consideration of such information.

Eco-toxicity

One of the characteristics of minerals processing operations is that there are a significant number of elements in input streams to various processes. For example, a feed stream to a copper refinery may contain more than 60 elements which occur in thousands of combinations as minerals. The deportment of these minerals to the environment, through a given combination of technologies, is a challenging exercise to quantify. It is also a necessary one if we are to have some understanding of the exposure and uptake paths of mineral-containing compounds within the environment, and the consequence of this for eco-toxicity. When reviewing equivalency factors available for metals, it is obvious that little information is available on either exposure or uptake mechanisms for the majority of the metals processed by the industry.

In addition, detail on mineral forms of metals (as opposed to pure metals) is not available at all. This is a particularly acute deficiency when considering impacts associated with solid waste management. This is best explained by way of example. Consider hydrometallurgical metals refining technologies. A specific focus is placed on iron as the mineralogy of iron the solid residues is easiest to describe. However, it should be recognised that iron is a minor source of eco-toxicity within the most hydrometallurgically produced solid residues. Iron has the potential to leave metals refining processes in different forms depending on the selected operating conditions. For simplicity only the three major minerals forms of iron are used to illustrate this point. These major minerals forms are jarosite, hematite and goethite. Figure 10 contains details of chemical compounds and stability of these wastes.

Hematite	(Fe_2O_3)	Iron Oxide	Stability	Completely Stable
Goethite	$(FeO(OH))$	Hydrated Iron Oxide		
Jarosite	$XFe_3(SO_4)_2(OH)_6$	Metal Iron Sulfate Hydroxide		Hazardous Waste

Figure 10 *Different forms of Iron in Solid Wastes from Metals Refining*

It is obvious that there is a significant difference in the impacts associated with these wastes. However, it is not possible to reflect this difference using standard LCA methodologies. Research work is underway in several countries to address this, but results to date are tentative only (Huijbrechts *et al*, 2001; Giurco *et al*, 2000; Heijungs, 1999; Guinee *et al*, 1996; SETAC, 1994). This impact category requires significant work with respect both definition and information available. Again, the minerals industry has a role to play here to ensure that LCA as a tool can be used to best effect.

6.6.2 Life Cycle Inventory Information/Data

Inventory data availability was highlighted as a significant issue. Most obvious here has been the call for better quality data from practitioners who are conducting LCAs for the Manufacturing and Use elements of the material life cycle. They highlight the fact that there is limited information/data available for the mining and minerals processing stages of the life cycle.

There were differing opinions from workshop attendees on the information/data available from existing studies. On the one hand practitioners present aver that LCA studies sponsored by commodity associations have both strong agreement in the methodologies and that LCI results are comparable. However, in the context of other studies information/data is available it is often defined relative to a different basis than that of the current study and not sufficiently transparent to facilitate comparison between different LCA studies. Reservations have also been expressed as to the accuracy of information on mining processes available in commercial LCA databases (Stewart *et al*, 2001; Brent, 2001).

The proposed SETAC/UNEP Life Cycle Initiative has, as one of its key focus areas, improvement in Life Cycle Inventories – from a methodological, management and communication perspective (Udo de Haes *et al*, 2001). The mining and minerals industry has much to add to this initiative with respect to:

- Process Modelling
- Data Supply

Process Modelling

It is possible to define boundaries of unit processes in such a manner as to both limit data gathering (or modelling) required in establishing an LCI, and to protect company-specific confidentialities relating to the performance of specific unit operations. Stewart and Petrie (1996) propose a set of heuristics for determining unit process boundaries which deliver the minimum amount of data required to inform a complete LCA for minerals processing. This minimum set of data is important as there are no overall modelling tools for modelling the performance of minerals processing plants (as there are for chemicals processing). Modelling of minerals processing technologies is often a rule-based exercise grounded in operator experience. Much minerals process modelling expertise lies with the industry and they have a role to play here. Additional expertise can be garnered from academia, minerals processing research organisations and the industry associations.

Data Supply

The minerals industry routinely collects most of the data required to support, at the very least, a first order LCA of their processes. However, the usefulness of this data is limited by:

- Collection relative to different bases (boundary definitions), or basis of collection not made clear
- Inaccessibility
- Confidentiality concerns
- Uncertainty associated with the data sets not being clarified
- Lack of transparency

This presents the mining and minerals industry with a number of challenges including:

- Meeting the data and information requirements of their stakeholders
- Defining information requirements for LCA studies
- Ensuring that information is collected

In this context attention should be paid to the SETAC LCA working group "Data Availability and Data Quality" which has worked to provide guidance and structure for data collection. The work of this group will be of value to the industry (Hischier *et al*, 2001; van Hoof *et al*, 2001). In addition, the recently completed ISO 14 048 on LCA data quality also provides guidance.

In addition, there is the potential for the industry to exploit better alignment of their existing information management systems (such as SAP®, PeopleSoft® etc) with their own environmental data requirements, as well as those of stakeholder groups.

6.7 ALLOCATION ISSUES

LCA allows for the allocation of impacts to all co-products and by-products of a system. The minerals industry as a whole is extremely complex in its technologies and processes, and generates a large number of different co-products. For example, in non-ferrous metals refining, there can be in excess of five co-products from the system. The challenge is to determine how impacts should be allocated to these different products. Different allocation regimes exist, some are relative to a mass basis; some to a volume basis; others to an energy basis; some allocation regimes use marginal changes in impacts relative to changes in feed. A clear definition of how best to allocate impacts to products in mining and minerals processing needs to be developed.

An additional complexity occurs when recycling initiatives and procedures are reviewed. This has been discussed in Section 6.1. If ISO 14 041 and ISO TR 14 049 are followed adequately confusion should be avoided.

6.8 LCA INFORMATION IN DECISION MAKING FOR SUSTAINABLE DEVELOPMENT

LCA has been highlighted as a tool which has the potential to supply the environmental information required to support multi-criteria decision making for sustainable development. However, it should be stressed that LCA will not necessarily deliver information on all aspects of environmental performance required by the decision context. The caveat here is that the decision making process should guide the definition of the requisite set of indicators, and not the tool.

Environmental information additional to that available from an LCA may be required in order for the decision to include all relevant consideration and be robust.

There is also much discussion in the LCA community regarding the difference between mid- and end-point indicators. Some practitioners strive to aggregate all the impacts associated with a system into a very limited set of areas of protection. These areas of protection include damage Biodiversity and natural Landscapes, and Human Welfare. While it is often easier to elicit societal preferences on these "endpoint indicators", significant uncertainty is associated with extending Life Cycle Impact Assessments this far. Note should be taken of this debate as it unfolds, specifically with reference to the impact categories highlighted as being of concern in the application of LCA to mining and minerals processing.

6.9 CONCLUSIONS

This section contains detailed discussion on the complexities of applying LCA to mining, minerals and metals. There is value in this level of discussion as it is only when these (and other) complexities are resolved, that LCA will be a tool that is "fit for purpose". Complexities in boundary definition; and selection of impact categories, allocation regimes and impact assessment models have been presented. Methodological deficiencies with respect to existing impact assessment categories and aggregation methodologies are discussed. Information deficiencies with respect to impact categories and inventory information are described. Recommendations on how these should be best addressed are made.

7 Additional Considerations

A number of themes that ran through the workshop have still to be highlighted within this document. Notable among these are information detail required to support decision making, and uncertainty analyses.

7.1 INFORMATION DETAIL

It should be noted that data available should not dictate the decision making process. Rather the objectives for the study and the indicators that will be used to measure their achievement should be set during the problem structuring stage of the decision making process (see Section 2.2.1). The level of detail to which data is collected is then set by the decision context. In other words, data gathering should be on a fit for purpose basis. Gathering data, and its transformation into information, can be considered an iterative process. Initial stages of data gathering should focus on readily available data and information sets. This then needs to be measured against what is required for the decision making process and augmented accordingly. In places where it is not possible to address information gaps directly, these should be explored using rigorous sensitivity analyses.

It has been noted that strategic decision making takes place with limited information detail while operational decisions have far more data/information readily available. This is the nature of the decision contexts. Rigorous uncertainty analyses may have the potential to add more value to the assessment than continued data gathering. These analyses can then be used to direct further data/information gathering to best effect.

In this context attention should be paid to the outputs of the SETAC LCA working group on Data Availability and Data Quality (Hischier *et al*, 2001).

7.2 UNCERTAINTY

Recently there has been growth in research into both the identification of key uncertainties in LCA (Huijbrechts, 1998a; Huijbrechts, 1998b), and the propagation of uncertainty through LCA type assessments (Notten, 2001; Huijbrechts et al, 2001; Basson and Petrie, 2001a; Basson, 1999; Le Téno, 1999). ISO/TR 14 048 (LCA Data Documentation Format) is the recently developed standard for LCA data reporting. This standard includes a requirement that an explicit account of the uncertainty ranges of data collected be included with data sets when they are included in databases. The standard requires that detail be retained on how the data has been collected, how it has been aggregated, whether it is accurate for a specific location or region, etc. This standard represents a significant step towards incorporating an understanding of uncertainty within LCA methodology.

Although approaches and tools for the management of uncertainty have been developed, the explicit consideration and rigorous treatment of uncertainty within LCA is not common practise. This has the potential to undermine the credibility of the assessments. It is essential that uncertainty is considered to ensure the robustness and defensibility of decisions based on LCA studies.

8 Interface with other MMSD initiatives

The MMSD project has highlighted eight challenges for the mining and minerals sector as it progresses to supporting sustainable development (Digby and Flores, 2001). These challenges relate to:

1. Structures within the industry which potentially constrain its response to changing societal, legislative and political pressures
2. The ability of the sector to support the development of national economies (with a focus on poorer economies)
3. The potential of the industry to contribute to sustained improvement in quality of life at a community level
4. The minerals sector as leaders in Environmental Management
5. Constraints on the industry as a result of limitation of access to land and methodologies for addressing this issue
6. Placing metals markets and consumption patterns within the context of sustainable development
7. Access to information for all stakeholders
8. Governance of the Industry as well as the roles and responsibilities of the industry in the context of a more sustainable future.

LCA has been highlighted by MMSD as a potential tool to be used in addressing issues relating to future markets and consumption patterns for metals (item 6 above). Discussions in this report have demonstrated that LCA can only deliver the environmental elements of this argument. In order for this initiative to be addressed fully an understanding of markets and their drivers need to be included. In addition, attention needs to be paid to where environment lies relative to other consideration in the development of Sustainability benchmarks for investment, ethical funds etc.

However, placing LCA in the context of structured decision making, and linking LCA to other assessment tools (social and economic) means that it is possible to apply LCA to the broader range of decision contexts represented by the list above. This with particular reference to the potential to explore the ability of different proposed initiatives and policies to meet their stated goals.

With respect to environmental management (item 4) there is the need to determine how Life Cycle Management could be used to inform environmental management systems – their definition, and implementation. In this context, attention should be paid to the development of the Life Cycle Management element of the UNEP/SETAC Initiative.

With respect to item 7, LCA has the potential to be used to interpret the information generated by different parties in a relatively accessible and comparable fashion. This was highlighted in Section 3.1.

In addition, there has been a call for an LCA focus within the regional research programs of MMSD – this coming from a number of the regions (Hancock, 2001; Petrie, 2001). There is value in viewing LCA as a potential tool to integrate the output of the regional assessments, and specifically the baseline assessments for the regions. Life Cycle Thinking can be used to integrate the baseline assessments be ensuring that all assessments have been conducted relative to a consistent boundary, and by placing them within the Value Chain (this with the assumption that the different baseline assessments will progress up the Value Chain to different extents).

9 Conclusions and Recommendations

This section summarised the conclusions presented at the end of each section of this report. Detailed recommendations are presented. Suggestions are made as to potential responsible parties for each recommendation.

9.1 CONCLUSIONS

Life Cycle Thinking has value in supporting decision making for sustainable development in that it ensures that the entire life cycle of a metal is considered when developing policies, plans, programs and projects to promote more sustainable practices within the industry. LCA is a useful tool to provide an assessment of environmental considerations during decision making within the industry, whether this be of a strategic or operational nature. LCA does not provide all the requisite information to support decision making for sustainability. Additional tools should be brought on board to supply techno- and socio-economic information. However, as much as LCA can inform decision making, the educational value of conducting LCAs should not be underestimated. In many cases, the process of conducting the LCA has been of as much, or more, value than the results of the assessment.

Specific conclusions drawn are listed below:

- Advantages of LCA in mining, minerals and metals are improved communication with stakeholders, and the potential to effect change to improve the environmental performance.
- Constraints on the application of LCA relate to methodological considerations, the value judgements inherent in conducting an LCA, and potential misinterpretation of LCA information by stakeholders.
- Further opportunities for LCA include the facilitation of better supply chain management, and broader based scenario development.
- LCA has been used in mining and minerals processing to effect process integration and change with lessons learnt from conducting the assessments often being more valuable than the results.
- LCA has been widely applied to the production of metals and in product improvement; this includes determining the effect that the product has on the environment throughout its material life cycle, determining where it is best to focus efforts to decrease these effects and improving communication with customers.
- The integration of LCA and MFA is seen as having potential to inform industry-wide decision making.
- Life Cycle Thinking can be used to guide development of policy to support sustainable development. However, LCA is not the only tool which should be applied in this context. Additional tools are required to ensure that techno-economic and socio-economic considerations are included
- LCA on its own may not be adequate for informing the set of environmental considerations as the indicators within LCA are damage focused and not benefits or outcomes focused.
- In developing policy for sustainable development, it is best that the indicators of performance be defined by comprehensive discussions with stakeholder groups. The quantification of these indicators can then be achieved using other assessment tools where necessary.

- Complexities in applying LCA within the metals value chain highlighted were boundary definition and selection of impact categories, allocation regimes, aggregation methodologies and impact assessment models.
- LCA methodological and information deficiencies in existing impact assessment categories and aggregation methodologies are significant.

9.2 RECOMMENDATIONS

A summary of the key recommendations of this report are presented in this section. Effort has been made to categorise these recommendations relative to a ranking of "high" (requiring immediate attention), "medium" (requiring attention in the medium term) and "low" (requiring attention in the longer term). These rankings are purely subjective. It should be recognised that all issues discussed at the workshop were considered to be of significance, for this reason none of the recommendations have been categorised as "low".

Responsibility for these recommendations is allocated to different stakeholder groups in section 9.3.

9.2.1 Education and outreach

LCA information has the potential to generate both value and goodwill for the mining, minerals and metals industry. Users of LCA information need to be educated in the interpretation of LCA information (sections 3.1.2 and 3.2.3). It is necessary to generate information sheets that explain the value and limitations of LCA information, as well as the meaning of the information and how it should be interpreted. Both an inter-metals industry association, as well as individual industry associations can be actively involved in this exercise. Reviewing the trust placed in information from different sources, NGOs also have a significant role to play in this respect. Efforts should be co-ordinated to ensure that there is no duplication of effort, and to learn from experiences in other industrial sectors. The mining and minerals industry also plays a part in this as they are one of the main points of contact with stakeholders along the material chain of metals. (HIGH/MEDIUM)

A specific focus on recyclers of metals is called for as they are a constituency which has not been included in previous data/information gathering exercises. Industry associations have a role to play here in facilitating access to recyclers, bringing them on board in the data gathering process through outreach and education, and building consensus within the group (section 5.2). (HIGH)

9.2.2 LCA Methodological Shortcomings

These are detailed explicitly in sections 6.2 and 6.3. The best approach to addressing these shortcomings would be through the Life Cycle Impact Assessment element of UNEP/SETAC Life Cycle Initiative – the main body directing LCA methodological development at present. Input is required from industry personnel and academics. Specific note should be taken of the fact that methodological issues will be discussed at the international workshop co-organised by Natural Resources Canada and ICME under the UNEP/SETAC Life Cycle Initiative in North America in spring 2002. Industry attendance at this workshop should be seen as a priority. (HIGH)

In addition, it is necessary to gain consensus from the industry on boundary definitions for industry-wide assessments (section 6.1), allocation procedures to be used (section 6.7), and approaches to aggregation over space and time (section 6.5). This should be facilitated by an industry association such as an inter-metals initiative and should have input from, among others, industry personnel, up-stream users of LCA information and academics. (HIGH)

9.2.3 LCI Information and Data Deficiencies

These deficiencies are described in section 6.6.2. The origin of the call for data on mining, minerals processing and metals is in order to support LCA studies further down the material chain. The data/information used at the moment does not necessarily give a fair and accurate reflection of the performance of the sector. The Life Cycle Inventory element of the UNEP/SETAC Life Cycle Initiative is the best platform on which to explore this task. Care should be taken to ensure that any data/information gathering exercise:

- Conforms to a consensus-based boundary definition
- Contains an indication of data quality and uncertainty
- Is transparent and does not result in a "black box" output

(HIGH)

There is also the potential to explore generic unit process modelling as a source of information (section 6.6.2). (MEDIUM)

9.2.4 LCIA Impact Categories and Information

Impact categories included in LCA need to be reviewed in that they are unable to reflect the performance of the mining, minerals and metals industry adequately (section 6.2). Additional impact categories should be investigated. These include salinity, land use and water management (section 6.4). (HIGH)

Information and data on the effects of mining and minerals processing with respect to eco-toxicity, resource depletion and other impact categories needs to be generated (section 6.6.1). The best initiative to combine this with is the Life Cycle Impact Assessment element of UNEP/SETAC Life Cycle Initiative. Input is required from academics, researchers and industry personnel. (HIGH)

9.2.5 LCA and Decision Making for Sustainable Development

Research into the use of LCA in decision making for sustainable development is ongoing. There is not clear indication of where and how this will be incorporated in the UNEP/SETAC initiative. Specific attention should be paid to the work of the Life Cycle Management element of the initiative to determine what tools external to LCA can be used to incorporate an understanding of the "social performance" of the system (section 2.2.2).

An inter-metals industry association needs to follow developments in this area and ensure that the minerals industry is using LCA to best effect. There is potential for LCA practitioners, both consultants and academics, to advise on the process. (MEDIUM)

9.2.6 LCA and Policy

LCA has been highlighted as a tool which is already being used in policy development in a number of different contexts (section 5). These policies are both industrial (sustainable use of metals, section 4.2) and governmental (sustainable products, sections 4.2, 5.1 and 5.3). With respect to industrial initiatives, these are being developed by industry organisations. There are lessons to be learnt from existing initiatives and an inter-metals industry association should facilitate discussion between the various groups to augment these efforts. (MEDIUM/HIGH)

With respect to governmental initiatives, there is a definite need for an inter-metals association to have input into developments at national government level to ensure that policies developed are adequate and fair. (MEDIUM/HIGH)

9.2.7 Propagation of Uncertainty through LCAs

Uncertainty and sensitivity analyses have been highlighted as powerful tools to facilitate a better understanding of LCA results, and to enhance the use of LCA information in decision making (section 7.2). These tools require significant further development. LCAs should include rigorous uncertainty analyses to ensure decisions based on these studies are robust and defensible. Again there is little indication of where responsibility for developing this lies within the UNEP/SETAC initiative. A combined industry association needs to track the development of this work. (MEDIUM/HIGH)

9.3 ALLOCATION OF RESPONSIBILITY FOR RECOMMENDATIONS

Potential stakeholders who can take responsibility for the recommendations included in section 9.2 are:

- MMSD – this term is used to represent both the present MMSD Project, and those organisations that will continue participatory analysis concerning mining, minerals and sustainable development after publication of the MMSD Final Report in April 2002. The continuation of the work currently undertaken by MMSD is of extreme importance
- Industry – Corporate entities whose enterprises form part of the metals value chain
- Industry Associations – Also called industry organizations, these associations could be individual metals associations, or a collaborative effort between some/all industry associations
- Academia and Research organizations – All bodies involved in research into the techno-economic, and/or environmental, and/or social performance of the industry; including researchers into decision making for sustainability, structured decision making and LCA.
- Recyclers – all entities involved in the recycling of secondary scrap
- NGOs – Non-governmental organizations, international and national
- Government – Local, regional and national governments
- Consultants – Practitioners using LCA, includes users of LCA information

Responsibility for the recommendations included in section 9.2 are allocated to these stakeholders in Table 7.

Table 7 *Allocation of Responsibility for Recommendations to Stakeholders*

Recommendations	MMSD	Industry	Industry Associations	Academia and Research Organisations	Recyclers	NGOs	Government	Consultants
Education and Outreach								
Education into the interpretation and use of LCA information	X	X	X	X		X		
Outreach to Recyclers	X		X		X			
LCA Methodological Shortcomings								
Attendance at UNEP/SETAC Life Cycle Initiative workshop on metals	X	X	X	X	X	X	X	X
UNEP/SETAC Life Cycle Initiative	X	X	X	X				X
Definition of Impact Categories		X	X	X				X
Selection of Impact Assessment Models		X	X	X				X
Boundary Definitions		X	X	X				X
Allocation Issues		X	X	X				X
Aggregation over space and time		X	X	X				X
LCI Information and Data Deficiences								
UNEP/SETAC Life Cycle Initiative LCI	X	X	X	X				X
LCI data		X	X	X	X			X
Unit Process Modelling		X	X	X				X
LCIA Impact Categories and Information								
UNEP/SETAC Life Cycle Initiative LCIA	X	X	X	X				X
Further development of Existing Impact categories		X	X	X				X
Development of new impact categories		X	X	X			X	X
Generation of better impact assessment information		X	X	X				X
LCA and Decision Making								
UNEP/SETAC Life Cycle Initiative Life Cycle Management	X	X	X	X	X	X	X	X
LCA and Policy								
Policy for Industry	X	X	X	X	X	X		X
Governmental Policy	X	X	X	X	X	X	X	X
Uncertainty in LCA								
UNEP/SETAC Life Cycle Initiative Data Quality	X	X	X	X				X

9.4 CONCLUDING STATEMENT

The MMSD workshop on LCA was successful in that it delivered a significant set of recommendations for the development and application of LCA in mining, minerals processing and metals. Life Cycle Thinking and LCA were seen as significant in assisting the mining, minerals and metals industry in their pursuit of sustainable development. The challenge remains for the industry to engage actively in the methodological development of tools such as LCA to support decision making for sustainability.

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Appendix 1 – Workshop Objectives, Programme and Attendees

Workshop Background and Objectives

One of the central challenges facing the MMSD project is to develop a robust understanding of the scale and nature of the social and environmental impacts, positive and negative, generated by current patterns of minerals production and consumption and to develop some predictive capability also to assist the move to Sustainability. Policy makers need to be able to prioritise areas for change in the chain from extraction through processing use, reuse and recycle, and disposal. Mining companies need to be able to identify the critical sustainability problems that their operations face, upstream and downstream. Society needs to be able to see how the impacts of minerals dissipation compares with other materials.

Dissipative uses of some metals (such as lead) have a direct impact on human health as well as the natural environment. Some chemical uses, especially of by-products (such as arsenic) are virtually limited to exploiting their toxic properties. Concerns related to the increasing contamination of agricultural soils with lead, cadmium and other toxic heavy metals may lead to restrictions, or even bans on certain uses. This could affect markets, and economics of mining vs. recycling. It makes sense to view the minerals mining, concentration, refining, utilisation and recycling system as an interrelated whole.

Life cycle assessment (LCA) is one tool that is being used to tackle the environmental dimensions of these problems. LCA is generally divided into four stages: first, goal and scope definition; second, making an inventory of inputs and outputs; third, assessing the impacts; and fourth, analysing options for improvement.

Life cycle inventories (LCI) have been carried out for a number of metals, and currently, there are several industry association initiatives underway to apply life cycle inventories to the metal group they represent. Many problems continue to confront the application of LCA, such as a perceived lack of accepted conventions (in spite of standardisation under ISO), and the use of inconsistent and unverified data.

This workshop is being convened to discuss the usefulness of Life Cycle Assessment as one of a suite of decision support tools used in achieving a more sustainable future and to develop recommendations for its future use, which will address some of the current methodological and information deficiencies in LCA.

The workshop plans to include the following:

- Review of the manuscript prepared by Professor Robert Ayes for the MMSD project, which is a materials flow analysis of copper, lead, zinc and associated by-product metals.
- Discussion of practical relevance of materials flow analysis and life cycle assessment for the metals and minerals industry and for policy makers in facilitating the transition toward sustainable development
- Consideration of the current state of understanding on the appropriate methodology, data requirements and interpretation of the results of these studies
- Discussion of the obstacles to progress around these issues and scoping of the array of options for progress.

Workshop Programme
Thursday August 9

8.30 Coffee and registration

9:00 Welcome, Introductions and MMSD
Luke Danielson – Project Director, MMSD

9:15 Workshop Objectives (including overall process)
Caroline Digby, Research Manager, MMSD

9:30 Overview of Copper Industry Study (½ hour)
Robert Ayres, INSEAD

10:00 Differing Perspectives on LCA and Minerals Sector (1 hour)
Chair: Luke Danielson
10 minute presentations by representatives of NGOs, government and industry to understand their point of departure in considering LCA and the minerals sector:

1. Why is LCA important?
2. How is LCA being used and how can it best be used in decision-making?
3. Key opportunities and constraints of LCA as a policy tool
4. Vision for future

Discussants
Frank Almond, WWF – (NGO perspective)
Anne Landfield, PricewaterhouseCoopers (LCA as product defence)
Christian Bauer, Aachen University of Technology – (academic perspective)
Alain Dubreuil, NRCan (LCA for public policy)

11:00 Refreshments

11:30 Differing Perspectives on LCA and Minerals Sector – Panel Discussion (45 minutes)
Panel discussion following the presentations

12:15 Overview Presentation (45 minutes)
Professor Robert Ayres, INSEAD will present the main conclusions of his manuscript

13:00 Lunch

14:00 Discussion of Ayres' Manuscript - Different Perspectives (1.5 hours)
Chair: John Tilton, Colorado School of Mines
10 minute presentations by individuals, providing different perspectives on Professor Ayres' manuscript

Discussants:
Gustavo Lagos, Catholic University, Santiago
John Young, Environmentalist
Mary Stewart, University of Sydney
Len Surges, Noranda

Mary Ann Curran, US EPA

15:30 Refreshments

16:00 Discussion continued (1 hour)

17:00 Summing-up and Organisation of Break-out Groups for Day Two

Mary Stewart, University of Sydney

19:30 Optional Dinner – Manhattan Yacht – Dinner on a Boat Trip around Manhattan Island

Friday August 10th

09:00 Learning from Existing Initiatives (2 hours)

Chair: Scott Baker, International Copper Association

10 minute presentations by representatives of different organisations to describe various initiatives relating to LCA and minerals. The aim is to provide a short description of the initiative to include:

1. Aims, objectives, activities
2. The underlying motivation and rationale
3. Actual and expected benefits and costs
4. Opportunities and constraints
5. Lessons learned
6. How to build further on opportunities and overcome challenges

Scott Baker, International Copper Association
Gregory Norris, UNEP/SETAC
Louis Wibberley, BHP Research
Eric Rodenburg, US Geological Survey
Guy Thiran, Eurometaux

11:00 Refreshments

11:30 Break out groups (1½ hours)

Discussion will focus around how, where and why to apply LCA – the complexities, strengths and deficiencies of LCA and MFA as tools. Each group will nominate a chair and a rapporteur to report identified actions back to plenary.

- What are the shortcomings in LCA with respect to its application to mining, minerals and metals?
  - Methodological
  - Information
- Is LCA a suitable tool to support Recycling initiatives within the industry?
  - Are there better tools?
  - Is information availability the limiting factor in these initiatives?
- Can LCA be used to address the "North-South divide"?
- Can LCA be used in Policy development for Sustanability?

13:00 Lunch

14:00 Breakout groups (½ hour)

14:30 Plenary feedback and discussion (1 hour)

15:30 Refreshments

16:00 What next for MMSD? Reflections on the Two Days' Discussions
Chair: John Tilton

17:30 Close

Workshop Attendees

Saleem	Ali	Brown University/Industrial Economics Inc.	2067 Massachusetts Ave, Cambridge MA 02140	USA
Frank	Almond	Sustainable Development and Planning Consultancy	6 Bowen Road, Rugby, Warwickshire CV22 5LF	UK
Patrick	Atkins	Alcoa Inc.	201 Isabella Street at the 7th St Bridge, Pittsburgh, PA 15212-5858	USA
Robert	Ayres	INSEAD	Boulevard de Constance, 77305 Fontainebleu Cedex, Paris 77305	France
Scott	Baker	International Copper Association	260 Madison Avenue, New York NY 10016-2401	USA
Christian	Bauer	Aachen University of Technology	Lochnerstrasse 4-20, 52064 Aachen	Germany
Achim	Baukloh	KM Europa MetalAG	Lostaer Strasse 29, Postfach 3320, Germany 49023, Osnabruck	Germany
Craig	Boreiko	International Lead Zinc Research Organisation/International Lead Management Centre	ILMC, Suite 100, 2525 Meridian Parkway, Durham, NC 27713	USA
Mary Ann	Curran	United States Environmental Protection Agency	EPA Office of Research & Development, Cincinnati, Ohio 45268	USA
Luke	Danielson	Mining, Minerals and Sustainable Development Project	1a Doughty St., London, WC1N 2PH	UK
Jim	Diamond	Pembina Institute for Appropriate Development	The Eco-Solutions Group, #517, 604 1st St. SW, Calgary T2P 1M7	Canada
Caroline	Digby	Mining, Minerals and Sustainable Development Project	1a Doughty St., London, WC1N 2PH	UK
Alain	Dubreuil	Natural Resources Canada	555 Booth Street, Ottawa, Ontario, K1A 0G1	Canada
Bill	Eyring	Center for Neighborhood Technology	2125 W. North Ave., Chicago, IL 60647	USA
Bruce	Howard	Mining, Minerals and Sustainable Development Project	1a Doughty St., London, WC1N 2PH	UK
Janice	Jolly	Copper Industry Analyst	13861 Triadelphia Mill Road, Dayton, MD 21036	USA
Gustavo	Lagos	Catholic University of Chile	Vicuna, Mackenna 4860, Santiago	Chile
Anne	Landfield	EcoBalance/ PricewaterhouseCoopers	500 Rock Spring Drive Suite 500, Bethesda MD 20817-1100	USA
Peter	Maciulaitis	Geologist	865 7th Street, Boulder Colorado 80302	USA

Bruce	McKean	Nickel Development Institute	214 King Street West, Suite 510, Toronto, ON M5H 3S6	Canada
Gregory	Norris	UNEP/SETAC	Sylvatica - Harvard - UNH, 147 Bauneg Hill Road, North Berwick, ME 03906	USA
Eric	Rodenburg	United States Geological Survey	12 201 Sunrise, MS-988, Valley Drive, Western Virginia 20192	USA
Martin	Ruhrberg	International Copper Study Group	Rua Almirante Barroso, 38 - 6.º, 1000 - 013 Lisboa	Portugal
Payal	Sampat	Worldwatch Institute	1776 Massachusetts Ave., N.W., Washington, D.C. 20036-1904	USA
Don	Smale	International Lead Zinc Study Group	2 King Street, London SW1Y 6QP	UK
Jan	Smolders	International Copper Association	260 Madison Avenue, New York NY 10016-2401	USA
Peter	Southern	Rio Tinto plc	1 Research Avenue, Bundoora. Melbourne 3083	Australia
Mary	Stewart	University of Sydney	Sydney, NSW 2006	Australia
Leonard	Surges	Noranda Inc.	181 Bay Street, Suite 4100, P.O. Box 755, BCE Place, Toronto, Ontario M5J 2T3	USA
Guy	Thiran	Eurometaux	Avenue de Broqueville 12, Brussels B-1150	Belgium
John	Tilton	Colorado School of Mines	Division of Economics and Business, Colorado School of Mines, 816 15th Street, Golden, Colorado 80401-1887	USA
Juan	Torres	Codelco, Chile	Huerfanos 1270 - Santiago	Chile
Dirk	Van Zyl	Mackay School of Mines	Room 301 LME/Mail Stop 173, Reno, Nevada 89557-0139	USA
Louis	Wibberley	BHP Minerals	Newcastle Laboratories, PO Box 188, Wallsend, NSW 2287	Australia
John	Young	Materials Efficiency Project	2008 Klingle Road, NW, Washington DC 20010	USA

Appendix 2 – Resource Depletion Categorisation

The information presented here is an excerpt of the work of Lindeijer *et al* (2001).

Fava et al., 1993

Essentials	Full quantification through characterisastion factor Q = 1/D with D= measure of deposits, no regionalisation, no specification of resource types
Sensitivity	High, on any use of scarce resources
Mechanism & model	Simple model based on inventory flows and amounts of deposits.
Extent of representation	Limited, because of unclear endpoint concept
Choices/assumptions	Resources of different substances are with regards to the 'scarcity aspect' exchangeable.
Consistency	Unclear which substances are included. e.g if Cu ore is treated as one type of deposit one result is obtained, if it is dealt with as two types (sulphides and oxides) the same resource flow will give a different result.
Applicability	Reasonably good

Guinée and Heijungs, 1995

Essentials	Full quantification (Q = U/D with U= yearly consumption), no regionalisation, no specification of resource types, environmentally relevant only on a short-term basis.
Sensitivity	Low, if endpoint is total abiotic resource depletion, as deposits tend to be prospected and determined in relation to yearly consumption. If endpoint is deposit depletion the sensitivity is high.
Mechanism & model	Simple model based on inventory flows and amounts of total use and deposits
Extent of representation	Limited, because of unclear endpoint concept
Choices/assumptions	Resources of different substances are with regards to the 'scarcity aspect' exchangeable. Present deposit amounts are correlated to total resource amounts
Consistency	Less sensitive to dividing resources into subgroups, than the method by Fava 1993.
Applicability	Reasonably good

Heijungs et. al, 1992 and Guinée, 1995

Essentials	Full quantification (Q = 1/D*U/D with U= yearly consumption), no regionalisation, no specification of resource types.
Sensitivity	High, on any use of scarce resources
Mechanism & model	Simple model based on inventory flows and amounts of total use and deposits
Extent of representation	Limited, because of unclear endpoint concept
Choices/assumptions	Resources of different substances are with regards to the 'scarcity aspect' exchangeable.
Consistency	Unclear which substances that are included. E.g if Cu ore is treated as one type of deposit one result is obtained, if it is dealt with as two types (sulfides and oxides) the same resource flow will give a different result.
Applicability	Reasonably good

Pedersen, 1991 and Weidema, 2000

Essentials	Resources are not an endpoint, and can be dealt with through system expansion making an inventory with scenario's on future resource extraction
Sensitivity	High, on any use of scarce resources
Mechanism & model	Include interventions from future resource extraction in the inventory
Extent of representation	Land use explains only part of the impacts on the category endpoints
Choices/assumptions	Future scenario of resource extraction is chosen
Consistency	Good
Applicability	Some scenario data are available from the author, some is lacking

Müller-Wenk, 1999

Essentials	Quantitative, characterisation factor based on increased energy demand caused to future generations, no regionalisation
Sensitivity	High, on any use of scarce resources
Mechanism & model	Model based on impacts from anticipated future resource extraction processes. Resources per se is not a safeguard subject. Low extent of empirical observations as a base.
Extent of representation	Energy explains only part of the impacts on the category endpoints
Choices/assumptions	Future scenario of resource extraction is chosen.
Consistency	Good
Applicability	Some data are available from the author, some is lacking

Finnveden & Ostlund, 1997

Essentials	Quantitative, no regionalisation, exergy by itself is of low environmental concern
Sensitivity	High for ore exery, but low for scarcity
Mechanism & model	Model based on exergy. Clear scientific concept, but with allocation choice and choice of system boundaries.
Extent of representation	If ore exergy is the endpoint, then the representation is good.
Choices/assumptions	Exergy is a good indicator of resource availability.
Consistency	Fair, but use of a lower ore grade may result in higher exergy consumption
Applicability	Some data are available from the author, some is lacking