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The Application of Two Models of Life Cycle Assessment (Lca) for Transition to the Low-Carbon Economy: a Case Study in the Aluminum Industry

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THE APPLICATION OF TWO MODELS OF LIFE CYCLE ASSESSMENT (LCA) FOR TRANSITION TO THE LOW-CARBON ECONOMY: A CASE STUDY IN THE ALUMINUM INDUSTRY

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Abstract

THE APPLICATION OF TWO MODELS OF LIFE CYCLE ASSESSMENT (LCA) FOR TRANSITION TO THE LOW-CARBON ECONOMY: A CASE STUDY IN THE ALUMINUM INDUSTRY

Master of Applied Science 2012
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This study examined two approaches that account for recycled materials in LCA studies, the recycled content (RC) approach and the end-of-life recycling (EOL) approach, which were reviewed with reference to aluminum. Interviews were conducted to obtain best practices in using these two approaches and carbon footprinting was used as an environmental performance metric. The interview results showed that across the stakeholder groups there was no unanimity or preferences regarding either approach where LCA studies involved metals/aluminum. The case study of aluminum recycling applied a custom computer model developed for a Canadian primary producer that compared the carbon emissions of producing 1 metric ton (mt) of aluminum for the two approaches. The average value of mt CO_2 eq. produced per mt aluminum was lower using the EOL approach versus the RC approach in every scenario. Percentage differences indicated substantial differences in the results when the two approaches were compared.

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1.0 Introduction

Climate change is regarded as the most prominent and challenging environmental problem, and its mitigation is a major objective in environmental management. Strategies that promote a shift to a low carbon economy have been agreed upon in an attempt to try and mitigate this global environmental problem at the most recent Conference of the Parties meeting (COP16) that took place in December, 2010 in Cancun, Mexico (United Nations Framework Convention on Climate Change, 2010). The *Cancun Agreements* included the following provisions: formalization of pledges made by 55 countries to reduce carbon emissions, financial deals for countries that opt not to deforest land, an initial $30bn of climate aid from industrialized countries to support climate projects in developing companies with an increase of up to $100bn by 2020, knowledge transfer of low carbon technologies from industrialized to developing countries, and inspections of emissions cuts made by large emitter countries (Vaughan, 2010). Compared to the discussions that occurred the previous year at COP15 in Copenhagen, Denmark, the 2010 conference results are regarded as a step in the right direction. As of this writing, COP17 is in progress in Durban, South Africa and therefore international decisions on climate policy are currently being updated.

Despite the potential progress of these agreements, there is still ambiguity as to when specific greenhouse gas (GHG) emissions policies will be implemented in North America and how the private sector should move toward reducing emissions. Fortune 500 companies expect that mandatory carbon emissions reporting will be put into effect soon (Fleet and Dhillon, 2010) and fortunately, businesses have been taking initiatives to develop their own plans to address the climate change issue. One initiative adopted by industries is life cycle assessment (LCA). LCA is a method used to express the cumulative environmental impacts derived from a product or process. LCA has the ability to provide a detailed and more comprehensive examination of the environmental impacts caused by a product, process, or service. Due to its wide applicability, it is likely that more companies will use LCA as they prepare to make the necessary changes to meet impending GHG regulations.

The overall goal of the study was to examine how LCA could help industries transition to a low-carbon economy. The narrow focus of this research aimed to examine two different approaches used to account for recycled materials in LCA studies. Specifically, the recycled content approach and the end-of-life recycling approach were reviewed with special reference to aluminum. This study employed a mixed method approach. The first phase conducted interviews to obtain thoughts on best practices of the use of these two LCA allocation approaches and the use of carbon footprinting as an environmental performance metric. The second phase involved the application of a custom computer model developed for a Canadian primary aluminum producer, which was used to compare the carbon emissions output of producing 1 metric ton (mt) of aluminum according to the two approaches of interest.

This paper provides a review of literature on LCA, carbon footprinting, and the recycling approaches used in LCA studies. Aluminum processing and the profile of the aluminum industry as it relates to LCA are outlined, followed by the goal and objectives of the proposed study. Methods of how to achieve the goal and objectives are also included.

This study offers a focus on the selection of LCA methodology as it pertains to its use in the metals/aluminum industry. This is a very narrow scope that examined the technical aspects of these two methodological approaches and did not address the broader context in which formally choosing a mandatory method would take place. It's important to mention that in the broader context, methodologies that may be chosen as most appropriate or at the highest level regarded as the best practice, are often selected for political, economic and/or social reasons. A broader examination of the policy context within which choices of LCA accounting are made, would be beneficial in revealing the external or related reasons for making those choices including corporate responsibility, marketing and political preferences.

2.0 Study Objectives

The overall purpose of this study was to determine how LCA could help industries transition to a low-carbon economy. The narrow focus of this research aimed to examine two different approaches used to account for recycled materials in LCA studies. Specifically, the recycled content approach and the end-of-life recycling approach will be reviewed with special reference to aluminum, for their effects in reducing carbon emissions. There is uncertainty in the literature whether one approach is superior to the other in regard to GHG reduction estimates. The specific objectives of the study are as follows:

a) Outline the central concepts of both the recycled content approach and the end-of-life recycling approach with respect to metals/aluminum recycling and assess the weight of evidence in support of either approach within the metals/aluminum community. This will be achieved through the completion of interviews with key stakeholders.

b) Assess the impacts these differing recycling approaches may have on a primary aluminum production company's carbon emissions reductions. This will be achieved by performing a case study on the effects that these two approaches may have on the primary aluminum producer, Rio Tinto Alcan, in the Canadian market.

3.0 Literature Review

3.1 Life Cycle Assessment

Life cycle assessment (LCA) is a management tool often used in environmental decision-making processes that aims to achieve more sustainable development. LCA is a technique that allows for the identification of inputs and outputs of a process or product in order to approximate the total inferred environment impacts. For example, *Figure 1* shows a typical life cycle for building materials such as steel or aluminum which would include an analysis of the inputs and outputs of all the life cycle stages from the resource extraction phase to the recycling/reuse/disposal phase (Athena Institute, 2010). The use of LCA is often called for during policy development in governments as well as determining alternative process options in industry operations. LCA has also been referred to as product life cycle analysis, ecobalance, cradle-to-grave analysis, and resources and environmental profile analysis (Curran, 1993). Curran (1993) cites the Society of Environmental Toxicology and Chemistry (SETAC)'s definition of LCA as "looking holistically at the environmental consequences associated with the cradle-to-grave life cycle of a process or product" (p. 432). Overall, LCA uses a systems level approach in order to gain a comprehensive view of the environmental and human health effects produced by the product or process being evaluated.

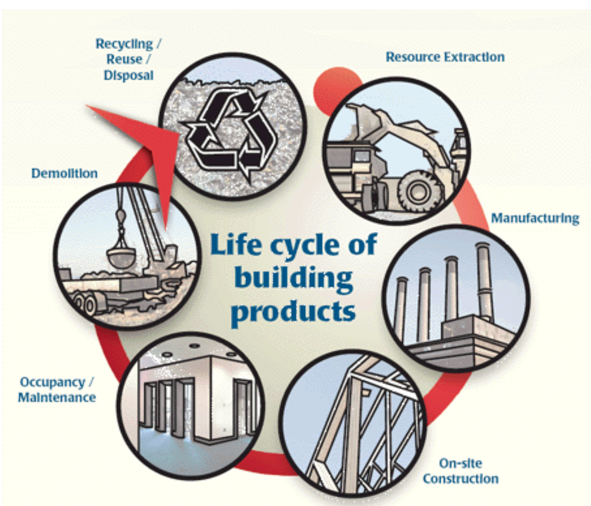

Figure 1. Typical life cycle of building materials (Athena Institute, 2010).

The fundamental assumption is that one part of a product's complete life cycle may create significantly larger impacts compared to others. To clearly understand the environmental impacts, the complete life cycle has to be known. For example, MacLean, Lave, Lankey, &

Joshi (2000) note that when comparing vehicles in terms of emissions exhaust, a hybrid electric vehicle would produce fewer emissions per kilometre than a typical gasoline-fuelled automobile. However, if a broader systems approach were undertaken to compare the two vehicles, it becomes apparent that the higher production cost and emissions for the hybrid may outweigh the minor benefits resulting from the lower driving emissions and fuel costs. The decision to choose a hybrid vehicle over a gasoline car would then depend on whether the objective is cost minimization or environmental improvement, but regardless of this, it is clear that the use of LCA allows for a more informed decision to be made. Additionally, when process changes are implemented to prevent pollution from entering one medium, it is often found that discharges to a different medium will increase. As Curran (1993) points out, scrubbers installed to limit air pollution produced by hazardous waste incinerators may result in large releases of hazardous wastewater. From these examples, it is apparent that LCA offers the ability to obtain a more holistic view of environmental impacts and assist in the identification of tradeoffs made during alterations to product and process designs.

3.2 LCA Methods

The International Organization for Standardization (ISO) (2006) has created requirements and guidelines as well as principles and a framework for LCA methods. According to the ISO (2006), a LCA is generally comprised of the following stages: goal and scope definition, inventory analysis, impact assessment, and interpretation. These stages are presented in *Figure 2* (ISO, 2006a).

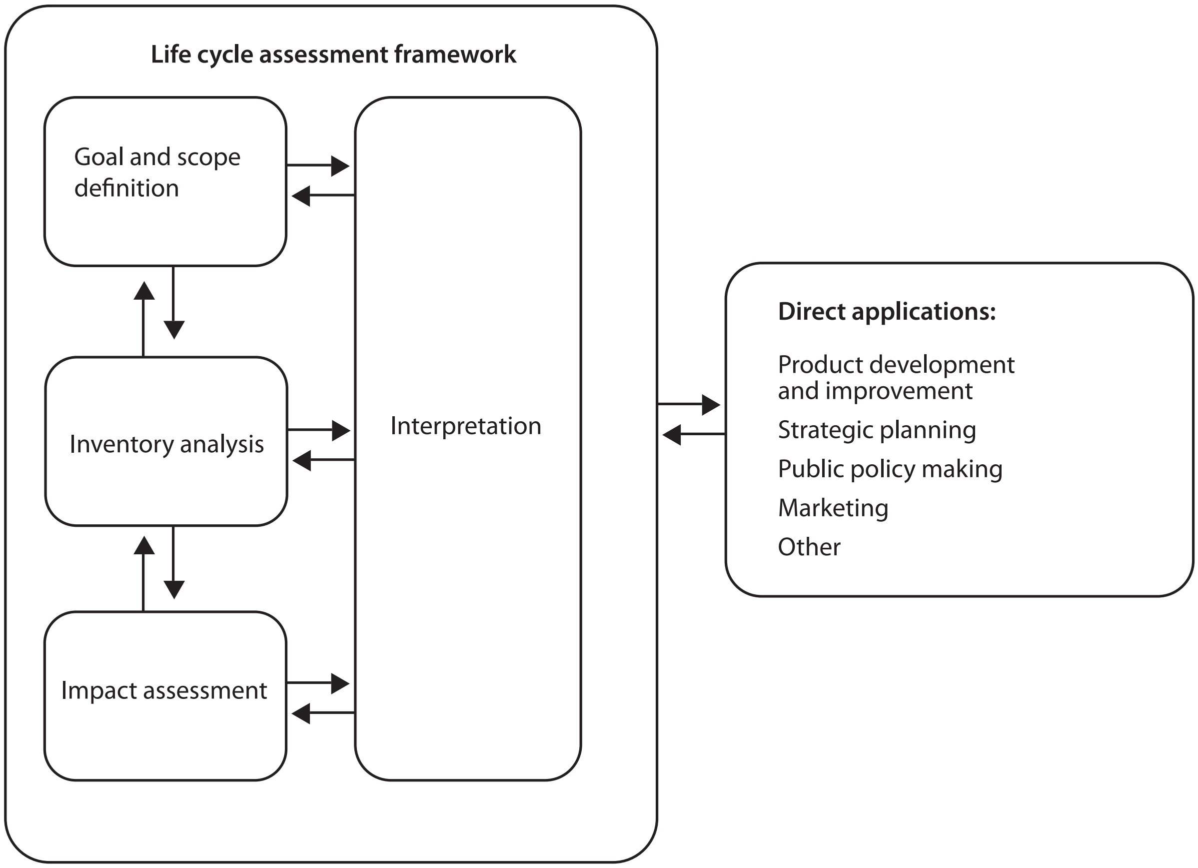

Figure 2. LCA Stages (ISO, 2006a, p.8).

3.2.1 Goal and Scope Definition.

Goal and scope definition refers to clearly establishing what the study aims to achieve and the degree of detail that is desired. The ISO (2006b) requirements and guidelines document states that the goal should include the following: "the intended application, the reasons for carrying out the study, the intended audience, and whether the results are intended to be used in comparative assertions intended to be disclosed to the public." (p. 7). In regard to the scope of the study, ISO (2006b) recommends that the following should be clearly described: the product system and its functions, the functional unit, the system boundary, allocation procedures, life cycle impact assessment method and impacts, data requirements, assumptions, and limitations. Though LCA studies are meant to be comprehensive analyses, the fact that a scope for the analysis must be set indicates that the level of comprehensiveness will depend on the desires of the LCA practitioner. The product system model should indicate the material and energy flows as inputs and output exchanges between the system and the natural environment over the entire life cycle of the product (Rebitzer et al., 2004). The functional unit is a common measure used to quantify the differences in the environmental exchanges being analysed during the LCA study (Rebitzer et al., 2004). The system boundary uses a set of criteria to indicate the cutoff points and determines which processes are included in the study and which are not (ISO, 2006a). *Figure 3* shows an example of a product system for a typical LCA (ISO, 2006a).

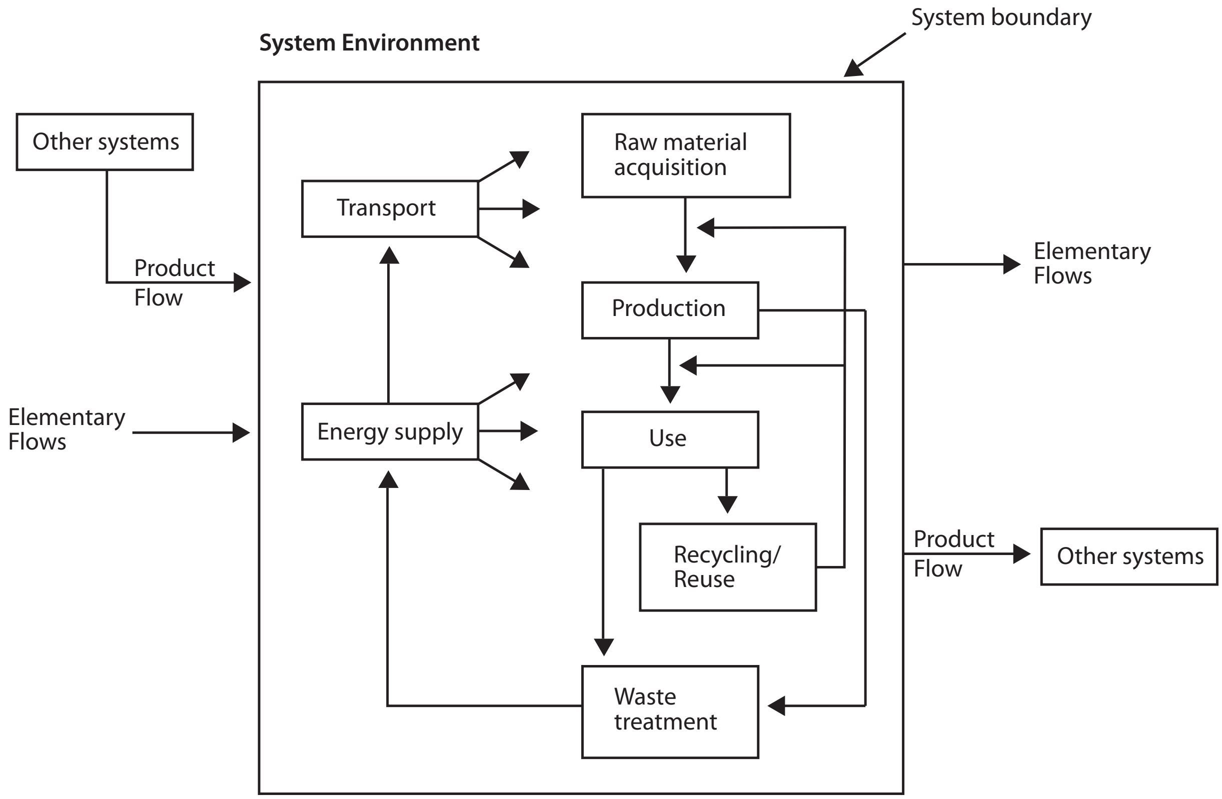

Figure 3. Example of a product system for LCA (ISO, 2006a, p.10).

The goal of the LCA, by and large, takes one of the following two forms: to simply describe the inputs and outputs of a product system or to describe how the inputs and outputs of the system will differ in response to a change imposed on the product system (Heintz & Baisneé (1992) and Weidema (1993) as cited by Rebitzer et al., 2004). The former approach is often referred to as an “attributional LCA”, while the term “consequential LCA” is used to refer to the latter approach. Depending on the goal the LCA aims to achieve, certain methodological choices become more appropriate.

3.2.2 Inventory Analysis

Inventory analysis refers to the collection of data associated with the individual inputs and outputs of the system to calculate the total of the individual unit processes (ISO, 2006a).

Studies are often completed without the impact assessment phase so that the inventory analysis is the sole focus. In these cases, the term 'life cycle inventory' (LCI) study is used.

3.2.2.1 LCA Databases and Software Tools

There are several processes that are frequently included in the various product systems investigated in LCA studies. This has led to the development of several databases intended for use by LCA practitioners that contain these commonly used data values. Several countries such as the US, Japan, Germany, Switzerland, and Sweden have made efforts to establish publicly available databases at the national level (Rebitzer et al., 2004; Curran & Notten, 2006).

In order to compile the massive amounts of data typically involved in a LCA study, several software applications have been developed. Rebitzer et al. (2004) explain that most LCA software can be categorized as generic, specialized, or tailored LCA software systems. Generic LCA software is meant for general researchers, specialized LCA software is geared towards certain types of decision-makers, such as those in the engineering and waste management sectors, while tailored LCA software packages are usually created for particular applications in specific industries (Rebitzer et al., 2004). Tailored LCA software programs are often directly linked to the company's internal data. The purpose of all LCA software is to capture the accounting of inputs, outputs, and impacts of the product's complete life cycle as in the schematic shown in *Figure 3*.

Popular LCA software programs include 'GaBi' developed in Germany and 'SimaPro' developed in the Netherlands. However, there are several more LCA software tools available on the market, in addition to the development of custom models developed by LCA consultants. Menke, Davis, & Vigon (1996) evaluated 37 LCA software tools, five of which were subjected to an in-depth analysis. The five that were selected for the in-depth review were KCL-ECO, LCAiT, PEMS, SimaPro, and TEAM and the criteria these were assessed against were as follows: computer requirements and interface; system definition; data and data management; flexibility; calculations and comparisons, and outputs and exports (Menke et al., 1996). Their results highlighted and compared unique features of each tool relevant to certain needs of the user; for example, four of the five applications support impact assessment capabilities. However, when considering the broader picture, their compilation of 37 LCA software tools indicated that there is no received model within the LCA community. Menke et al. (1996) indicated similarities between some programs; however, due to the conceptual nature of LCA models there is still considerable variation between different applications. In contrast, modeling applications that estimate soil loss erosion or Gaussian plumes allow for more accurate and highly specific results that LCA software applications generally cannot achieve; this is made possible due to the fact that these models have a narrower scope. This reality makes it all the more important to document all assumptions and data sources that are built into the software tool in any given LCA so that the reader is aware of the study's limitations.

Tailored or custom software tools can be very useful as they are specifically designed to meet a company's interests and desires. For example, the primary aluminum producer, Rio Tinto Alcan, with assistance from the Interuniversity Research Centre for the Life Cycle of Products, Processes and Services (CIRAIG), has developed a customized modeling tool that allows for the calculation of the GHG footprint for producing an aluminum ingot determined on a LCA basis. This tool allows Rio Tinto Alcan to quickly estimate its total GHG emissions in terms of carbon dioxide equivalent while making slight adjustments to their manufacturing and productions outputs.

3.2.3 Life Cycle Impact Assessment (LCIA)

The impact assessment phase of a LCA uses the results of the inventory analysis to determine the effects on environment and human health. This phase shares the same analytical difficulties as conventional environmental impact assessment (EIA). The impact assessment phase is open to broad interpretation leading to inconsistent results, as observed in the practice of EIA (João, 2002; Noble, 2004).

However, there is no streamlined approach used when performing a life cycle impact assessment (LCIA). As a result, ISO (2006a; 2006b) requires that the method used during the LCIA be clearly explained in the final LCA report. There are different approaches used during the LCIA stage, but the mandatory components are: selection of the impact categories, classification of the inventory results in the impact categories, and characterization of the category indicator results (ISO, 2006b). There are also optional elements that may be included as part of a LCIA. These are normalization, grouping and/or weighting of the category indicator results (Pennington et al., 2004). *Figure 4* displays the elements of the LCIA phase (ISO, 2006a).

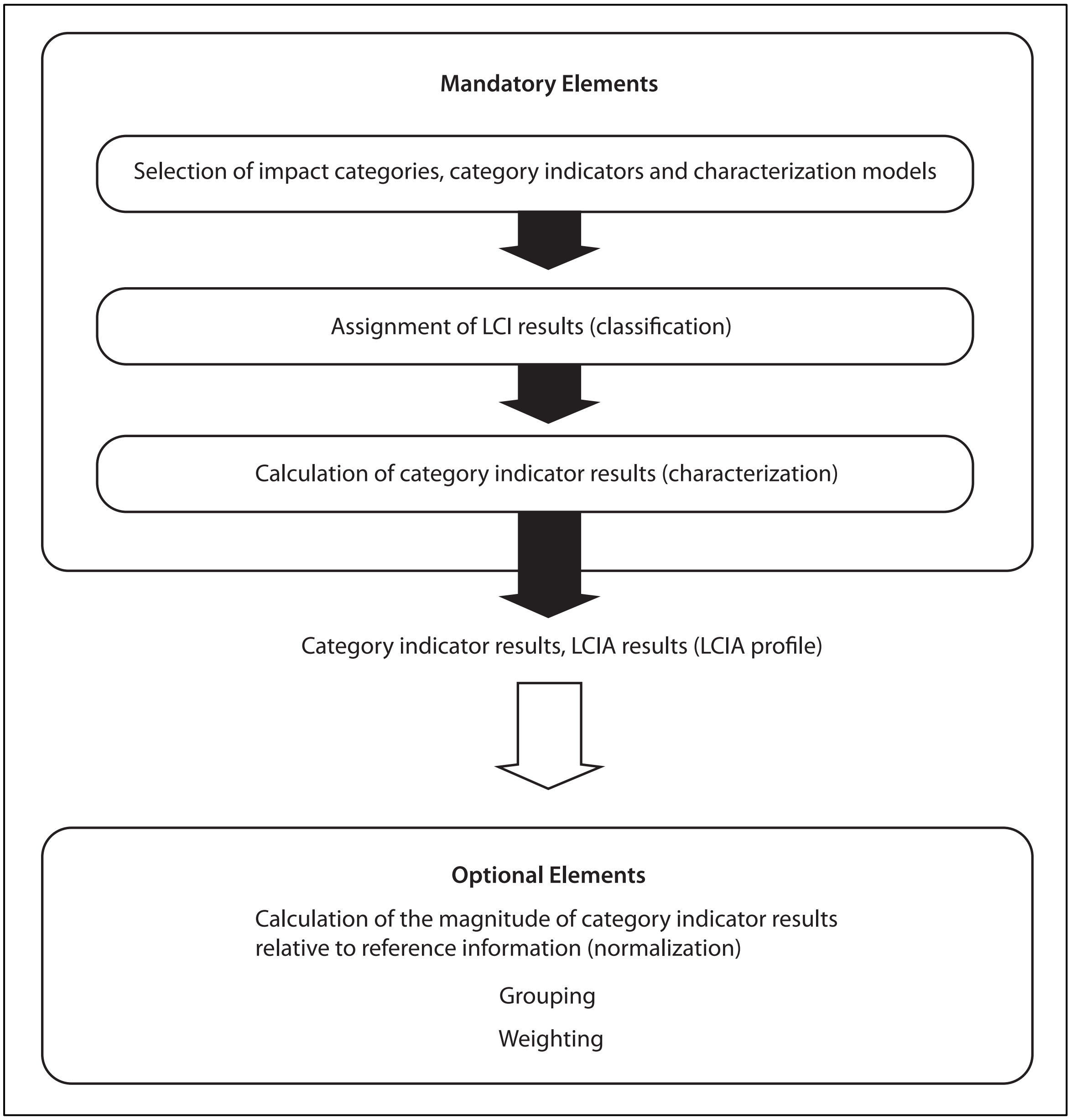

Figure 4. Elements of the LCIA phase (ISO, 2006a, p.15).

The impact categories selected often depend on the goal and scope of the LCA being performed, which is why LCIA methods varies on a case-by-case basis. There are commonly used impact categories such as climate change, stratospheric ozone depletion, photooxidant formation (smog), eutrophication, acidification, and water use, etc. (Pennington et al., 2004). However, when these frequently used categories do not fulfill the goal of the study, new ones may be defined (ISO, 2006b) or supplementary categories may be added. The classification component refers to the assignment of the LCI results to an appropriate selected impact category (ISO, 2006b; Pennington et al., 2004). Following this, impact characterization factors derived from models are used to evaulate the category indicators, which are measures that may reveal the environmental relevance of the results and/or the effect on category endpoints (ISO, 2006b; Pennington et al., 2004). In order to clarify the terms used in this section, an example that uses climate change as the impact category is presented in *Table 1* (ISO, 2006b).

Table 1. LCIA terminology using climate change as an example (ISO, 2006b, p.18).

Term	**Example**
Impact category	Climate change
LCI results	Amount of a greenhouse gas per functional unit
Characterization model	Baseline model of 100 years of the intergovernmental Panel on Climate Change
Category indicator	Infrared radiative forcing (W/m^2)
Characterization factor	Global warming potential (GWP_{100}) for each greenhouse gas (kg CO_2-equivalents per functional unit)
Category indicator result	Kilograms of CO_2-equivalents per functional unit
Category endpoints	Coral reefs, forests, crops
Environmental relevance	Infrared radiative forcing is a proxy for potential effects on the climate, depending on the integrated atmospheric heat adsorption caused by emissions and the distribution over time of the heat absorption

Often, impact assessment methods are built into the above-mentioned software packages. For example, the program SimaPro includes more recent and previous versions of the following impact assessment methods: Building for Environmental and Economic Sustainability (BEES), CML, Cumulative Energy Demand, Ecoindicator, Ecological Footprint, Ecopoints, Ecological Scarcity, Ecosystem Damage Potential, Environmental Design of Industrial Products (EDIP), Environmental Product Declarations (EPD), and Impact 2002+ (PRé Consultants, 2008). These impact assessment methods differ in terms of the impact categories selected, the characterization models used to calculate indicator results, as well as the normalization of reference values and weighting methods. The goal and scope of the LCA study determines which impact assessment method is most appropriate to be used. The weakness is that without a secured method, analysts can use methods that are favourable to specific products and/or projects.

3.2.4 Interpretation

Interpretation occurs at each of the previous stages of the LCA. If two products are being compared based on their resource consumption alone, interpretation of just the LCI results might be able to determine the better alternative (Rebitzer et al., 2004). However, this may not be sufficient in all cases depending on data availability for the two products. Comparison across different impact categories may also be of interest to estimate the different trade-off effects that may occur between the different products or alternative processes (Rebitzer et al., 2004). Overall, following interpretation of the inventory and impact assessment results, direct applications can be made to aid with product development and improvement, public policy, and marketing initiatives (ISO, 2006a).

3.3 Origins of LCA

The ISO standards for LCA were first published in 1997 and the most recent revised version was published in 2006. Prior to the inclusion of LCA in the ISO's Environmental Management series of standards, development of process-based LCA methodology as it is known today was being pursued by other organizations. In the early 1990s, SETAC was one of the pioneers that started to develop the process analysis methodology that preceded the ISO versions (Curran, 1993). Around the same time, the United States Environmental Protection Agency (USEPA) also started development of LCA to determine the "environmental releases and impacts of a specific product from raw material, through its production, and to eventual disposal" (Curran, 1993, p. 432). The USEPA definition of the system boundaries of a LCA is expressed in *Figure 5*.

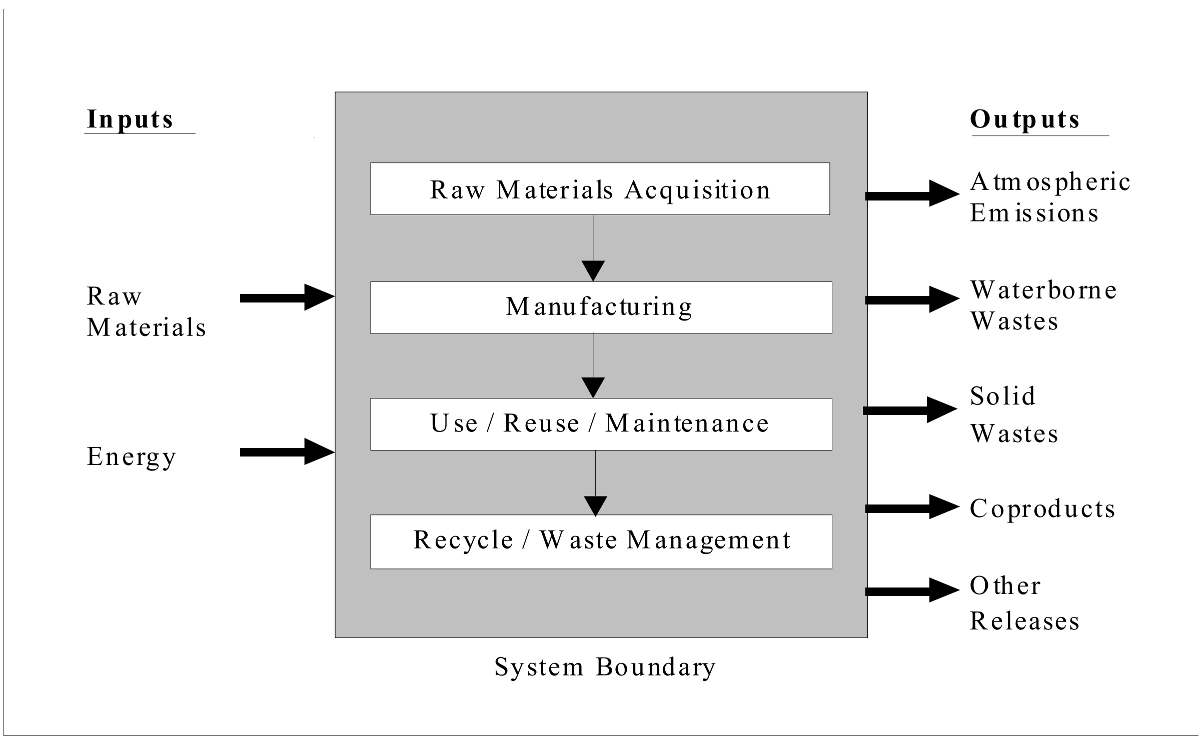

Figure 5. USEPA system boundary for a typical LCA (USEPA, 2006).

Although formalization of life cycle methodology began in the early 1990s, studies involving life cycle inventories and systems level input-output analysis were being performed much earlier. In 1969, the Midwest Research Institute in Kansas City performed one of the first LCI studies for the Coca Cola Company (Curran, 1993). This study was referred to as a Resource and Environmental Profile Analysis (REPA) and aimed to quantify the amounts of resources used and emissions released to the environment (Curran, 1993). Around the time this study was completed, concerns over the depletion of resources were high due to the oil shortages of the 1970s and the environmental effects caused by products had became more salient (Curran, 1993). As a result, 15 REPAs were completed in the US during the period between 1970 and 1975 (Curran, 1993). Following this period, only one or two life cycle inventory analyses were completed per year (and were mainly specific to energy analysis) as the public's environmental interest moved more towards hazardous waste issues instead of resource depletion (Curran, 1993). Though LCI analyses showed a decline, interest in these studies resurged in 1988 when municipal solid waste became a prominent environmental problem and from 1988 to 1991, it was estimated that over 100 LCI analyses were performed in the US (Curran, 1993).

As mentioned above, energy impacts are often the primary goal and scope of LCI studies. The term 'energy analysis' first came into use in the 1970s and refers to an evaluation tool that is used to compare policy alternatives in terms of their energy requirements (McAllister, 1980). McAllister (1980), viewed energy analysis as a valid technique for evaluating the energy impacts of a policy or action. However, he pointed out that comparing several forms of energy using a generalized index may not result in an accurate interpretation. McAllister (1980) suggested that the conversion of different energy forms to a common unit should not necessarily be considered equal since "conversion factors are based on a general theoretical concept of work, not on a specific type of work" (p. 181). Therefore, it is suggested that the impacts derived from different forms of energy should be reviewed individually rather than normalized on the same scale (McAllister, 1980).

3.4 Authorities on LCA

There is some degree of consensus that the ISO is the primary authority providing the basic guidelines and framework for conducting LCA studies. The ISO has also published two additional documents related to LCA: ISO 14047:2003 which provides examples of LCA applications and ISO 14048:2002 that explains the standard format to be used when documenting data sources used in LCA studies (ISO, 2010).

As previously mentioned, SETAC and the USEPA have also played a large role in the development of LCA methods, especially in North America. These bodies have continued their commitment to use and develop the LCA technique.

SETAC and SETAC Europe have a LCA Advisory Group Steering Committee that organizes LCA conferences such as the Annual Meetings in North America and Europe as well as the LCA Case Studies Symposium (SETAC, n.d.). Furthermore, SETAC has partnered with the United Nations Environment Programme (UNEP) to form the Life Cycle Initiative, an endeavor with the goal of promoting life cycle practice at the international level while facilitating the development and improvement of LCA in general (Life Cycle Initiative, n.d.).

The USEPA has also continued its support for LCA by promoting its use as an environmental management tool. Moreover, in conjunction with the SETAC/UNEP Life Cycle Initiative, USEPA researchers, Curran & Notten (2006) have compiled a summary of the life cycle inventory data resources available worldwide. The USEPA has also pursued research into LCA simplification techniques such as applying different cut-offs to the system boundary to see how the results would be affected (Rebitzer et al., 2004).

There is also the Society for the Promotion of Life Cycle Assessment Development (SPOLD). This organization has been dedicated to increasing data documentation within the LCA field. Meta-information about LCI data such as geographical, temporal, or technical aspects are often not included as part of the final reports (Rebitzer et al., 2004). The importance of data documentation was communicated to LCA-software developers and this resulted in commonly used databases, such as SPINE and ecoinvent, to share the same data format for their meta-information (Rebitzer et al., 2004).

3.5 LCA and Carbon Footprinting

Referring to the principles of natural capital and carrying capacity, Rees (1992) was the first to introduce the concept of calculating an "ecological footprint" to describe the environmental needs of a given area. Using data describing resource use levels of industrial cities, Rees (1992) developed an average per capita index and discussed how to estimate the area required to support the associated population, referred to as the "ecological footprint". Essentially, the "ecological footprint" describes the geographical area required to meet the resource demands of a community inhabiting a given area. The idea of the carbon footprint is a variation of the "ecological footprint", but instead of determining the production of carbon that exceeds the carbon sink capacity,the carbon footprint (CFP) generally refers to the calculation of the *total* GHG emissions, expressed in carbon, derived from a product, process, or activity. There is no universally accepted definition for CFP; however, Weidmann & Minx (2008) offer the following definition "The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life" (p. 6). The term GHG footprint is often used interchangeably with carbon footprint.

Despite the lag amongst governments to implement specific GHG reduction policies, there has been progress towards the development of streamlined processes for carbon footprinting methods that are based on LCA principles. In 2001, the United Kingdom (UK) government formed a Carbon Trust, an independent non-profit organization with the goal of aiding in the transition to a low carbon economy through low carbon technology research initiatives and incentive programs and guidelines for businesses (Carbon Trust, 2010). The Carbon Trust (2008) prepared a technical paper outlining CFP guidelines to be applied to any product or service entitled "Product carbon footprinting: the new business opportunity". This technical paper was largely based on the "Publicly Available Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" (PAS2050) put forth by the UK's Business Standards Institute (BSI) in the same year (BSI, 2008). The PAS2050 document offers instructions for business-to-business ("cradle-to-gate") and business-to-consumer ("cradle-to-grave") approaches to assessing GHG emissions. The document included detailed descriptions of how to tackle certain method issues that are often ambiguous in general LCA practice such as setting criteria for global warming potential data, how to set system boundaries, and how to treat emissions from land use changes as well as biogenic and fossil carbon sources. Similarly, in the US, the company Scientific Certifications Systems has developed the Life-Cycle Stressor Effects Assessment (LCSEA) GHG Accounting Framework and a draft version based on this method is currently under review by the American National Standards Institute (ANSI) to be accepted as the national standard (Scientific Certification Systems, 2010). As recognition of the importance of estimating the environmental effects of products and processes over their entire life cycle has increased, it is no surprise that LCA principles are being adopted as part of these methods.

A barrier to carbon footprinting is that a standard method is not well developed. Though some methods including the PAS2050 and LCSEA have been suggested as possible options, there are complications associated with choosing one of these as a standard. There has actually been some backlash in the LCA community due to the ANSI's decision to consider LCSEA as the basis for the national GHG accounting standard. In a recent letter to the ANSI, the American Center for Life Cycle Assessment, a non-profit organization, stated "we are further concerned that its starting point, Life Cycle Stressor-Effects Assessment (LCSEA) is a proprietary methodology that does not represent LCA practice in the U.S. or elsewhere in the world" (Stein, 2010, para. 3). Currently, the ISO is in the process of developing a carbon footprinting standard namely, ISO14067, a Carbon footprint of products, which is anticipated to be completed in 2012. There are several issues that the working group is dealing with: scope of emissions, life cycle stages to be included, system boundary definitions, offsetting, data sources, allocation, end-of-life scenarios, carbon storage, and capital goods. Ultimately, more case studies and research into carbon footprinting methods should be pursued before establishing any kind of standard.

3.6 LCA Limitations and Challenges

LCA certainly has advantages in the field of environmental management. However, it is not a perfect tool and there are several limitations and challenges associated with its use.

General issues include difficulties associated with defining functional units, setting of system boundaries, and selection of impact categories since LCAs are very case-specific in nature. A lack of appropriate resources is also a key reason why LCA has not achieved mainstream usage. LCA software programs are generally very expensive and the complexity associated with methodology choices frequently ends up with experts from the LCA community being the only ones able to obtain meaningful results. Simplified approaches to LCA have been suggested to make the technique more accessible to a broader user base (Rebitzer et al., 2004).

There are also issues associated with the data collection portion of a LCA since it is often regarded as the most laborious and time-consuming phase of the entire process (Curran, 1993; Rebitzer, et al., 2004). Though there has been a push for the improvement of public databases, a lack of data accessibility often results in significant labour hours required to collect and verify it (Curran, 1993). Therefore, studies such as this one, where the researcher employs data generated directly from a company is a valuable endeavor as it bypasses the typically arduous data collection phase. Additionally, data documentation is an area of LCA that requires improvement. Due to data being collected from several sources and their origins not generally being well documented, Curran (1993) stresses "it is impossible to determine whether the uncertainty of the data significantly affects the final result" (p.434). The lack of proper data documentation also presents the problem of not being able to accurately describe the quality of data used. Even though the inclusion of comments on data quality are recommended in the ISO guidelines for LCA, Pennington et al. (2004) state that the data quality analysis stage is "receiving little attention in current practice" (p. 722).

There are also methodology issues related to how LCAs are performed. A common dilemma that LCA practitioners have is how to go about calculating processes that result in multiple products. ISO (2006b) states that allocation should be avoided if possible. Where it cannot be avoided, the document states "inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them" (p. 14). The document goes further to say that economic valuation methods may be used if no physical relationships can be established.

This problem of how to allocate impacts where multiple products are produced is similar to issues that arise when determining how to allocate impacts associated with recycling processes included in the life cycle. This methodology problem will be a primary focus of this study. This topic is discussed in more detail in the following section.

3.7 Recycling Approaches in LCA Studies

There are several proposed methods to account for recycled material used in LCA studies. In particular, there are several approaches that have been developed to address allocating impacts when open-loop recycling systems are under examination (Nicholson, Olivetti, Gregory, Field, & Kirchain, 2009; Tillman & Baumann, 2004). ISO (2006b) describes open-loop recycling systems as "product systems where the material is recycled into other product systems" (p. 15). Despite the various approaches that have been presented, there are two different approaches that have particular prominence in the metals industry. These two different approaches are the recycled content (RC) approach and the end-of-life recycling (EOL) approach which are considered applicable to both closed-loop and open-loop recycling systems.

Figure 6 shows an example of a closed-loop recycling system for a generic aluminum product. The RC approach (also known as the cut-off approach) credits the recycling inputs involved in the manufacture of a product at the start-of-life; "the environmental impacts of extraction, beneficiation and refining of primary metal are attributed to the first use of that metal product. The second use of the metal bears the environmental impacts of collection, beneficiation and refining of scrap" (Frischknecht, 2010, p. 667). The EOL approach (also known as the avoided burden approach, the substitution method, or the closed loop system expansion method) credits the post-consumer material inputs recovered at the end of life of a product minus any environmental impacts associated with the recycling processes; "the share of the metal recycled after the use phase of a product determines the amount of primary metal that is not required to be replaced by primary metal feedstock" (Frischknecht, 2010, p. 667). The timelines of the two approaches are shown graphically in *Figure 7* and *Figure 8*. Though in this study these approaches are presented as distinct, it should be noted that others suggest that they can be combined and used as a 50/50 approach (Nicholson et al., 2009; Jones, 2009). This study is interested in exploring this distinction and its application to specifically aluminum.

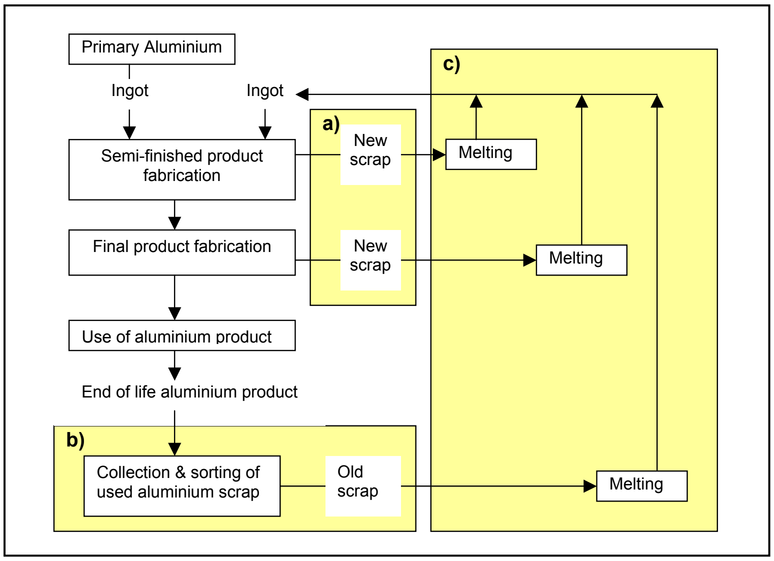

Figure 6. Closed-loop Recycling Diagram for Aluminum Product (European Aluminum Association, 2007, p. 3)

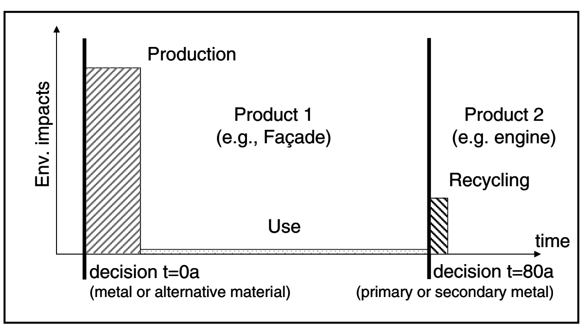

Figure 7. Recycled content approach (Frischknecht, 2010, p. 667).

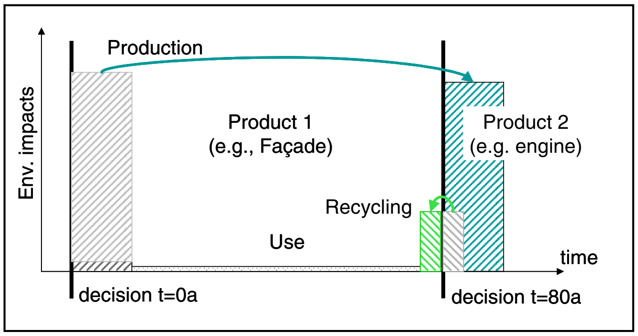

Figure 8. End-of-life recycling approach (Frischknecht, 2010, p. 667).

Recently, Frischknecht (2010) reviewed these two approaches in regard to their sustainability, risk-perception, and eco-efficiency. In the context of this study, risk perception refers to the general mindset or attitude of the decision maker with respect to the use of metal resources over time. This study found that the RC approach supports a strong sustainability concept, a risk-averse attitude, and that recycling aluminum had a higher eco-efficiency than producing primary aluminum (Frischknecht, 2010). Conversely, this study found that the EOL method supported a weak sustainability concept, a risk-tolerant attitude, and primary aluminum production had a higher eco-efficiency compared to recycled aluminum (Frischknecht, 2010). From Frischknecht (2010), the RC approach has environmentally positive attributes associated with it, while the EOL approach was found to have negative attributes associated with it. Additionally, since the RC approach is a variation of the cut-off approach, it is characterized as being relatively easy to apply, as it requires less data, allowing for time and cost savings during the LCA process (Ekvall and Tillman, 1997). The lengthy process and high costs associated with LCAs are often seen as barriers to completing studies, therefore the RC approach may offer a feasible methodology option for certain practitioners.

There are also criticisms of the RC approach. Since the RC approach assigns all of the recycling credits to the start-of-life or input side of the life cycle inventory, any benefits arising from the end-of-life recyclability of that material are not accounted for (Hammond & Jones, 2010). This may present a problem particularly for materials that are experiencing an increase in demand (Frees, 2008). Using aluminum as an example, Frees (2008) noted that even if all of the aluminum produced globally were recycled, it would not be enough to meet the increasing demand for the material. This view is also supported by Betram, Martchek, & Rombach (2009) in their paper that describes material flow analysis in the Aluminum industry. Furthermore, Frees (2008) recommended that in consequential LCA studies, the EOL approach should be favoured because due to the “inelastic price elasticity of aluminium scrap, it is [the] production of primary aluminum which is avoided by recycling.” Promoting a higher recycled content of aluminum in products is not achievable due to the lack of available scrap aluminum that is unable to meet the total demand (Betram et al., 2009). Rombach (2010) furthers the claim that recycled content of products remains low due to the fact that there is an increasing demand for long-life applications, citing the statistics from the European building sector, where old scrap only meets 23% of metal demand even though the recycling rate is greater than 95%. Despite these concerns, it should be noted that the lower level of aluminum scrap availability is only problematic if the objective is to keep increases in demand for the aluminum constant. However, Rombach (2010) notes the following scenarios for changes in aluminum demand and the effect this would have on recycled content: if the growth rate of demand stays at the current average of 4%, recycled content will be less than or equal to 25%; if the growth rate decreases to 0% until 2050, the recycled content will be less than or equal to 40%; and increasing collection by 10% until 2050 only adds 5% to recycled content. These modeling scenarios suggest that even if demand decreased and efforts to increase collection were implemented, the recycled content could still only rise to approximately 45%. Rombach (2010) provides another criticism of the RC approach in regard to the Eurometaux definition of recycled content that includes some amount of fabricator scrap; he notes that “trying to increase the recycled content by fabricator scrap would base a credit for recycling on a process-caused inefficiency” (p. 281). Another criticism of the RC approach is that it requires that the fractional inputs of primary and recycled metals to be known, which is often very difficult to determine (Gesamtverband der Aluminiumindustrie, 2006). This point indicates that accuracy may be limited when using this approach.

Although the EOL approach also has advantages and disadvantages, it essentially reveals how recycling materials may offset primary production. Providing credits for avoiding primary production can encourage reuse or recycling principles in the design of products (Frees, 2008). This approach also suggests that higher product recovery be incorporated in the design of products (Atherton, 2007). Furthermore, Ekvall and Tillman (1997) consider this approach to be the “most adequate and relevant” method to account for materials where open-loop recycling systems are concerned (pg. 160). There are also limitations in the EOL approach. Hammond & Jones (2010) point out that putting emphasis on the future savings that result from recycling may under-account for the present impacts when product lifetimes are longer (Hammond & Jones, 2010). The end of life recycling benefits are very apparent when products have a short life such as a metal food can, but this method may not provide an accurate picture of impacts when product lifetimes are longer, as is the case with building and construction projects (Hammond & Jones, 2010). Another disadvantage of the EOL approach is that expanding the system boundaries to include the recycling systems can make the LCA more time consuming and complex (Ekvall and Tillman, 1997).

It is apparent from the literature that each approach has positive and negative attributes associated with it. However, it is not clear whether either approach provides a superior carbon footprint reduction. There is a need for more clarity regarding the suitability of each method in terms of LCA studies that involve recycled metals.

3.8 Aluminum

3.8.1 Aluminum Life Cycle

Aluminium is one of the most important commodities of our modern society as it is a critical component in a wide range of primary industries that include construction, transportation (aerospace and automotive), healthcare and food packaging (Altenpohl, 1998). Moreover, with the shift to a low carbon economy, the structural strength and lightweight features of aluminum have a major impact on energy savings and reduction in GHG emissions through their role as structural composites in the automotive and aerospace industries.

Primary aluminum is derived from the mineral ore bauxite that is mined from deposits located mainly in Africa, West Indies, South America, and Australia (International Aluminum Institute (IAI), 2010a). *Figure 9* provides an overview of the aluminum life cycle. Through chemical steps known as the Bayer Process, the bauxite ore is refined to extract pure alumina (aluminum oxide trihydrate) that is contained in the ore (IAI, 2010b). Alumina is a precursor to metallic aluminum and approximately two tonnes of alumina are required to produce 1 tonne of aluminum (IAI, 2010b). First, the bauxite is crushed and mixed with caustic soda (sodium hydroxide) and high temperature and pressure is applied which results in sodium aluminate and bauxite residues such as iron, silicon, and titanium (IAI, 2010b). The bauxite residues settle out of the process cycle, while the clear sodium aluminate is transferred to a precipitator chamber where alumina hydrate is added to initiate the precipitation of pure alumina (IAI, 2010b). Following this, calcination occurs with the application of high heat to remove water and form alumina (IAI, 2010b). Alumina is then sent to the smelters to be converted to aluminum through electrolysis, which is known as the Hall-Heroult process.

The Hall-Heroult process involves the production of molten cryolite (sodium aluminum fluoride mineral) that is used to dissolve alumina and the resulting chemical/electrochemical reactions enable the production of metallic aluminum (Grjotheim & Kvande, 1993). The cryolite, which is the electrolyte, is contained in large carbon-lined pots and is subject to electrolysis using a carbon anode and cathode (IAI, 2010c). Although the DC voltage is low, the current is very high (at least 100,000 to 150,000 amps) and the electrolytic process produces metallic aluminum and carbon dioxide (IAI, 2010c). The molten aluminum settles to the bottom of the pot where it is periodically siphoned off into crucibles while the gaseous carbon dioxide escapes (IAI, 2010c). For this reason the industry is not only a major consumer of electric power but is generally also a significant contributor to GHG emissions.

3.8.2 Secondary Aluminum and Alloys

Secondary aluminum is aluminum that is created from scrap aluminum by recycling processes. Scrap metal can be classified as new scrap (aluminum left over from manufacturing processes) or old scrap (aluminum left over following consumer use) (IAI, 2010e). Since a certain quality level is required in order to recycle aluminum, the scrap metal must be sorted based on its aluminum purity (IAI, 2010e). The scrap metal is then melted down in a high heat furnace so it can be processed into other products (IAI, 2010e). Due to the ease of this process, it is often observed that the production of a recycled aluminum ingot only requires 5% of the fuel that a primary aluminum ingot requires (IAI, 2011b). However, though these energy savings are quite the feat, secondary aluminum processes still produce pollution. There are air emissions of HCl/Cl_2 and particulates, as well as solid waste slag produced during smelting that may contain magnesium and chlorides (Wang, Shammas, & Hung, 2009). Both primary and secondary aluminum are processed in similar ways to create aluminum products. Common processing methods include casting using molds, rolling into sheets and plates, and extrusions to create shapes and sections (IAI, 2010f).

Aluminum alloys are generally designated as either wrought or casting alloys depending on the type and amount of alloy content in the secondary material. Typically wrought alloys are characterized as having a low percentage of alloying elements while casting alloys have a higher percentage (Ramachandra Rao, 2006). For example, wrought alloys usually have restrictions on the amount of silicon (Si) they may contain, usually less than 1% Si is allowed, while casting alloys allow for a higher Si content in the range of 1 to 12% (Ramachandra Rao, 2006). Such restrictions on the amounts of allowable alloying elements can pose issues during secondary aluminum production processes. During scrap processing, it is common for Si and iron (Fe) impurities to build up (Das, 2010). The amounts of these elements are generally difficult to control in recycled metal processing and they tend to slightly increase each time the metal is recycled (Das, 2006). Furthermore, though Si and Fe are the most common impurities, other elements such as magnesium, nickel, and vanadium may accumulate over time as well (Das, 2006).

The issue of impurities building up during scrap processing makes it easier to create casting alloys over wrought alloys. Therefore, cast scrap is regularly used to create new cast products (Das, 2010; Ramachandra Rao, 2006). So while producing recycled cast products is not an issue, producing secondary wrought products is not as simple. The separation of wrought and cast particles is required if increased recycled metal content is desired in secondary wrought alloys, since the cast scrap contaminates the wrought scrap (Ramachandra Rao, 2006). This separation can be difficult during the shredding and sorting of scrap stages meaning a more arduous effort is required to produce secondary non-castings such as sheets, plates, and extrusions.

In regard to identifying aluminum alloys, there are designation systems used to classify aluminum alloys. For wrought alloys, the International Alloy Designation System (IADS) developed in the 1970s, assigns a 4-digit number to each alloy (Granta Design Limited, 2010). The first number indicates the principle alloying element; for aluminum the first digit is represented by "1" and appears as a "1xxx" series. The second digit indicates a close relationship between alloys, while the third and fourth digit merely act as a serial number for different alloys (Granta Design Limited, 2010). However, the third and fourth digits serve a more significant purpose when describing the 1xxx series, as they describe the minimum purity (i.e. 1145 has a minimum purity of 99.45%) (Granta Design Limited, 2010). There is also a suffix that may be added to indicate the hardness or heat treatment and the basic designations are: F means 'as fabricated', O means 'annealed wrought products', H means 'cold worked', and T means 'heat treated' (Granta Design Limited, 2010). These suffixes may be subdivided further, but this information is beyond the scope of this study.

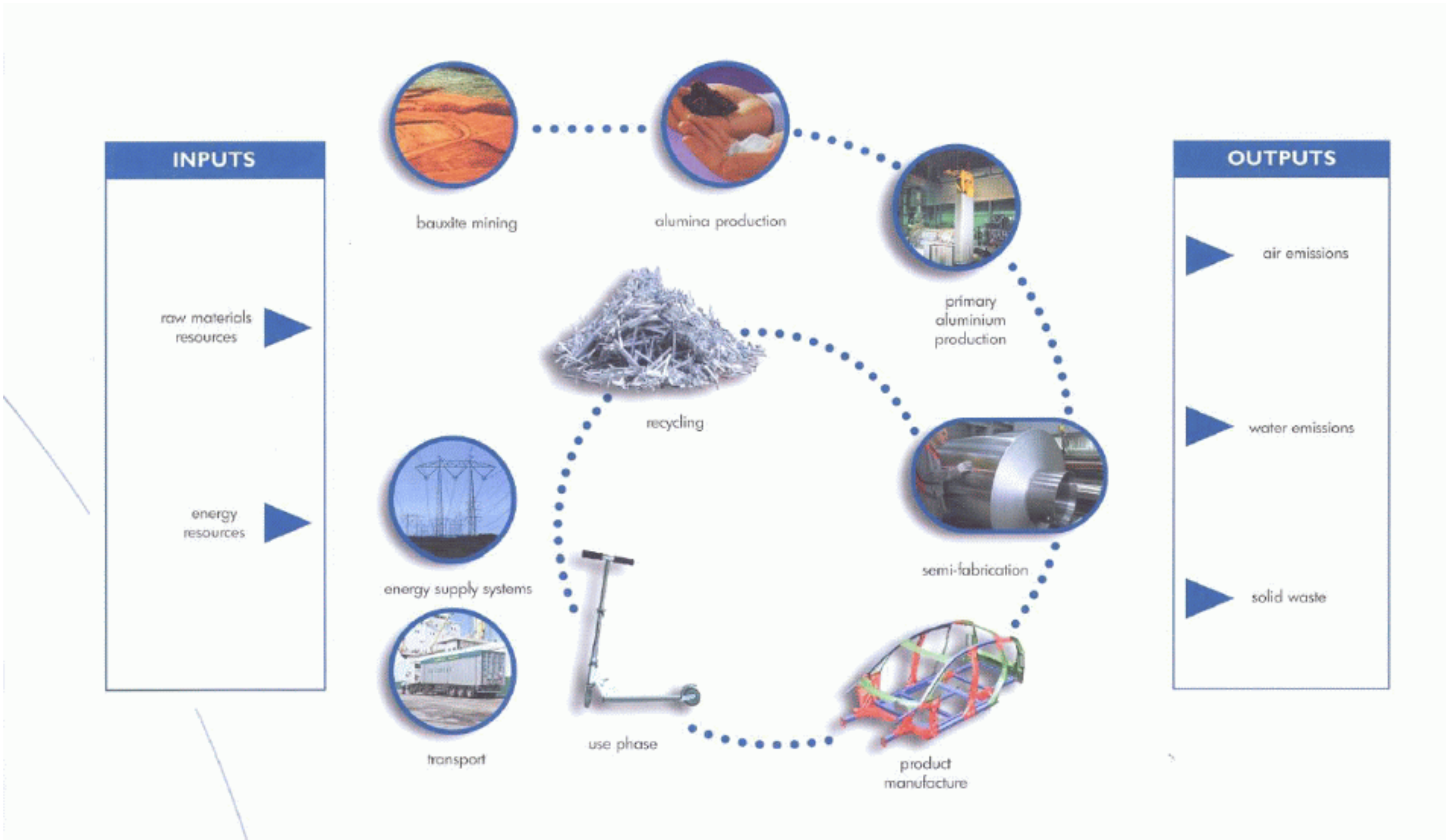

Figure 9. Aluminum Life Cycle (International Aluminum Institute, 2011a, p.1)

For casting alloys, there is no international designation system, but the Aluminum Association of the United States (AAUS) published a system that is most commonly used (Granta Design Limited, 2010). The first digit describes the main alloying element. Aluminum alloys, the first digit is a 1 and is represented with 1xx.x series. Similar to the IADS for wrought alloys, the second and third digits indicate the minimum percentage of aluminum (Granta Design Limited, 2010). The digit following the decimal point describes the final shape of the product with 0 meaning 'casting' and 1 or 2 meaning 'ingot' (Granta Design Limited, 2010). There can also be a capital letter prefix that means a modification has been made to the original alloy (ESAB Welding and Cutting, 2011). *Figure 10* provides an example of a casting alloy using the AAUS system.

Alloy - A356.0
The capital A (Axxx.x) indicates a modification of alloy 356.0. The number 3 (A3xx.x) indicates that it is of the silicon plus copper and/or magnesium series. The 56 (Ax56.0) identifies the alloy within the 3xx.x series, and the .0 (Axxx.0) indicates that it is a final shape casting and not an ingot.

Figure 10. Example of an Aluminum Cast Alloy using the AAUS system (ESAB Welding and Cutting, 2011, p.1)

3.8.3 Aluminum Industry in Canada

Aluminum is an important commodity produced in Canada. In 2007, Canada was the third largest primary producer of aluminum in the world after China and Russia (Aluminum Association of Canada (AAC), 2009a). There are three major aluminum companies that have operations in Canada: Rio Tinto Alcan, Aluminere Allouette, and Alcoa (ACC, 2009b). In Quebec, aluminum production has great economic importance; The aluminum industry is the third largest exporter in the province with shipments worth $8.5 billion, creates over 8,000 direct jobs in the region, and smelters pay approximately $50 million/year in municipal taxes (AAC, 2009c). In general, primary aluminum production is often regarded as a dirty industry because the smelting process requires high amounts of electricity. For example, the aluminum industry generates approximately 1% of the human-induced global GHG emissions (IAI, 2010d). However, in Canada the scenario is quite different; the environmental impacts of primary aluminum are considerably lower as hydropower is the main source of electricity used (AAC, 2009d).

Rio Tinto Alcan is the top aluminum producer in Canada producing 46% of all of the primary aluminum made in Canada with 7 smelters across the country (6 in Quebec, 1 in British Columbia) (AAC, 2009b). Its head office is located in Montreal, Quebec and it is a global supplier of bauxite, alumina, and primary aluminum with operations located in North America, South America, Europe, Asia, Africa, and Australia (Rio Tinto, 2010a). It is very committed to LCA thinking and GHG improvements and has been audited quite extensively internally and externally in terms of the GHG emissions (personal communication, October 26, 2010). Furthermore, in 2007 it achieved the maximum score on the Carbon Disclosure Leadership Index, an indicator meant to highlight companies that have displayed professional approaches to climate change disclosure practices (Rio Tinto, 2010b).

3.9 Gaps and Limitations regarding LCA and the Aluminum Industry

The use of LCA is prominent in the minerals and metals industries due to the environmental impacts associated with mining and processing activities. These industries are committed to the use of LCA in order to present the most sustainable perception of their products. In LCA studies, assigning credits using the RC approach versus the EOL recycling approach may offer significantly different results. The following issues represent gaps and limitations that are present in the metals and aluminum production industries.

Metals are often recycled continuously as they undergo little to no change in their inherent properties. Aluminum in particular can be recycled very easily and there are significant energy and environmental savings associated with producing aluminum from scrap; for example, to form recycled aluminum only requires 5% of the energy necessary to form primary aluminum and this process generates only 5% of the GHG emissions (IAI, 2010g). With such large differences between recycled and primary aluminum impacts, it is apparent that the computation of the life cycle inventory results would vary to a large degree depending on whether the RC or EOL method was chosen. This also raises an interesting issue when considering aluminum production in Canada; since impacts from energy usage are lower due to the use of hydropower, there is even more uncertainty surrounding the impacts of incorporating recycling on a LCA basis.

Another main issue that is often discussed in the literature is the case of metals involved in open-loop recycling systems. These types of systems present a problem of how to allocate the environmental impacts resulting from the inputs and outputs of other product life cycles. The ISO (2006b) provides the following guidelines to address this issue: 1) allocation should be avoided, by dividing into sub-processes or through system expansion 2) when allocation cannot be avoided in this manner, "allocation should reflect the physical relationships between environmental burdens and functions" and 3) "when physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them" (p.14). However, the ISO standard advises this same ranking order regardless of the type of LCA study. Ekvall and Tillman (1997) criticized this streamlined approach and noted that these guidelines do not consider the suitability of the allocation method chosen in relation to the goal of the study. Boustead (2001) points out that LCAs can demonstrate whether the introduction of an open-loop recycling system adds some kind of environmental benefit, but there is no objective scientific method available to allocate the impacts between product flows. Ultimately, arbitrary factors have to be chosen usually based on the interests of the practitioner and goal of the study (Boustead, 2001; Jones, 2009). With respect to the RC and EOL recycling approaches, the differences these may have on the results of the LCA studies' containing open-loop recycling systems have not been estimated.

There is also the limitation that LCAs generally do not take into account the economics of the product being investigated. There is controversy related to the outcome of promoting either the RC approach or the EOL recycling approach when considering market influences. Atherton (2007) claims that promoting the RC approach "may stimulate the market to direct recycled feedstock towards designated products and away from production where recycling is most economical" (p.60). Furthering this claim, others suggest that since there isn't enough scrap available to meet the increasing demand for aluminum, directing scrap flows to certain products to increase their recycled content ultimately means that other aluminum products elsewhere will have a decreased recycled content; this results in no true environmental benefit when considering the global aluminum market as a whole (EAA, 2007; Hammond & Jones, 2010). Additionally, Weidema & Norris (2002) point out that since aluminum scrap is an expanding market, all the scrap that is collected will be used, resulting in some amount of virgin aluminum production being displaced by secondary production. This suggests that the EOL is appropriate for materials such as aluminum. On the other hand, Frischknecht (2010) points out that the EOL method relies heavily on the future benefits of the product and these benefits are only validated under the risky assumption that a commodity such as aluminum will continue to stay in high demand.

Finally, there is generally a lack of real LCA studies that compare the RC and the EOL recycling approaches. One study by PE Americas (2010) compared the two approaches using the case of the aluminum beverage can. Using a functional unit of 1000 cans, it showed that the amount of raw material extraction and processing contributing to total primary energy demand was 67% for the EOL approach and 62% for the RC approach (PE Americas, 2010). This study shows that the choice between methods can affect the final results. This study has attempted to establish that difference in the context of energy usage to indicate the relative differences between the two methods.

4.0 Methods

4.1 Literature on Interviews

4.1.1 Qualitative Research Methods

Qualitative research is "interested in the perspective of participants in everyday practices and everyday knowledge referring to the issue under study" (Flick, 2007, pg. 2). This type of research is well established and is often utilized in the social sciences as well as areas such as education, psychology and the health sciences (Flick, 2007; Kvale, 2007).

There are several methods that are used to conduct qualitative research. Some examples of methods include observation, analysis of written text and documents, interviews, and audio/video recordings (Silverman, 2000). The use of focus groups and approaches to analyzing visual data are also popular methods (Flick, 2007). When planning how to perform qualitative research, Flick (2007) notes the importance of taking a research perspective. Common research perspectives include the following: a) grounded theory research – developing theory and explanations from data regarding everyday practices b) social representation theory – identifying everyday practices while using theories and models as a starting point and c) Biographical Research – based on personal experiences and events of the participants involved (Flick, 2007). In order to clearly define the research question of a study, clarification of the research interest and perspective are necessary (Flick, 2007).

4.1.2 Qualitative Research Interview

The qualitative research interview is a prominent tool used in this study that aims to describe and understand the experiences of the subjects of interest (Kvale, 2007). It is also often stated that deeper insights may be obtained through the use of qualitative methods such as interviewing instead of using methods that are more quantitative in nature (Silverman, 2000). Kvale (2007, pg. 35-36) explains that the interview inquiry generally consists of the following seven phases: 1) thematizing 2) designing 3) interviewing 4) transcribing 5) analyzing 6) verifying and 7) reporting. Qualitative interviews are often used in market research, feminist research and psychoanalysis (Kvale, 1996). Furthermore, interviews are commonly used to derive information from stakeholders in authoritative circles such as elite experts in specific subject areas (Kvale, 2007).

There are several different types of interviews that are appropriate for various areas of research. Factual interviews aim to gather accurate information from interviewees and are common in the fields of forensics and witness psychology (Kvale, 2007). There are also conceptual interviews that try to clarify the meaning of a term as it exists within a group of subjects, for example clarifying linguistic terms for different relatives as they exist in foreign cultures (Kvale, 2007). Other approaches include focus group interviews that generally bring a group of approximately six to ten interviewees together to provide varying perspectives on an issue and narrative interviews, which explore the stories and personal accounts of the subjects (Kvale, 2007). Regardless of the form of the interview, Kvale (2007) summarizes that qualitative interviews are generally semi-structured in nature, meaning they are designed to include a combination of a series of themes to be discussed as well as actual prepared questions.

An interview guide or script is often a component created prior to the interviewing stage of the process. Kvale (2007) mentions how it is useful to use two lists while developing the interview script; one that contains the main research questions to be answered and one that contains questions to be asked in the interview in order to obtain adequate responses to the research questions. Flick (2007) also states that performing interviews over telephone or via the internet has become quite common in order to interview subjects located around the world and that often interviews are recorded so they may be transcribed during subsequent analysis of the responses.

When trying to determine who may be suitable interviewee candidates, the process is generally not random. Silverman (2000) and Flick (2007) both describe how purposive sampling is the most frequented approach taken when performing interviews. Purposive sampling refers to searching out subjects that may have familiarity with the topic at hand or have some qualification or feature related to the focus of the study (Flick, 2007; Silverman, 2000). Additionally, this may lead to the construction of groups that places individual subjects into categories of interest – common examples in social science studies include attributes such as gender, age or profession (Flick, 2007).

4.1.3 Qualitative Data Analysis

Coding and categorizing are common approaches that are generally applied to analyze qualitative data. Kvale (2007) states that "coding involves attaching one or more keywords to a test segment in order to permit later identification of a statement, whereas categorization entails a more systematic conceptualization of a statement, opening for quantification (pg. 105)" but notes further that the terms coding and categorization are "often used interchangeably (pg. 105)." Coding or categorization is the most popular method when data is collected as interviews, focus groups or observations and the analysis process is usually comparative in its design (Flick, 2007). Computer software tools may be used during the data analysis process and this is particularly effective when the user is already familiar with the software and/or datasets are large (Flick, 2007). Regardless of whether a computer program is utilized, the overall goal of the coding and categorization method is to compare and classify the data of interest.

In addition to coding, Kvale (2007) references the methods of condensation and interpretation as modes of analysis that focus on finding meaning in interviews. Condensation refers to the process where central themes are extracted from long interview statements and then are summarized into shorter, more concise statements (Kvale, 2007). Interpretation of the meaning of interview texts generally has the opposite result, where longer statements are often lengthened as the researcher aims to provide a deeper critical understanding of the data (Kvale, 2007).

There are common approaches used to identify differences and similarities in the data during the categorization phase. Flick (2007) notes that comparisons are generally made on the following three levels: 1) within a category 2) within a case and 3) between cases. The results of the aforementioned comparisons will offer some organizational structuring of the data that may be shown as a hierarchy or in the form of tables (Flick, 2007). Tables and figures may be generated and include "+" and "-" to show occurrence or non-occurrence of certain events (Kvale, 2007). The comparisons displayed in these types of formats allow for generalized statements to be drawn from the data. To assure that generalizations are not exaggerated claims, Flick (2007) cautions that researchers should be aware of the limitations of their dataset and the sample that their research is founded on. Ultimately a clear definition of the categories and how they relate to the conclusions made are necessary in order to produce accurate and reliable results.

4.1.4 Stakeholders and Interviews

The use of stakeholders in participatory research is common in the areas of corporate business management, tourism, health policy, and natural resources management. Grimble & Wellard (1997) assert that stakeholder analysis is a tool particularly useful for developing an adequate response plan to situations that involve several players with differing objectives and perspectives. The literature contains a plethora of definitions for the term "stakeholder". Examples of these definitions include "affected parties whose interests are at stake because of a proposed action" (Finsterbusch 1980, as cited in Babiuch & Farhar, 1994, pg. A-1) and "groups who are immediately affected by a project or policy, as well as groups who will be impacted in the future" (Francis 1975, as cited in Babiuch & Farhar, 1994, pg. A-1). Depending on the nature of the research program, identifying key stakeholders may be helpful during the sampling stage of the process. The purposive sampling process is comparable to identifying stakeholders likely affected by a certain issue. Furthermore, determining stakeholder groups is essentially the same as dividing interview subjects with similar features into groups.

There are various instances where interviews with stakeholders have been used to obtain information in the area of environmental management. For example, Eberling & Yasué (2008) held semi-structured interviews with stakeholders in Ecuador and Bolivia to determine factors that entice companies to pursue certified forestry operations. Additionally, Helland, Kastenholz, Thidell, Arnfalk, & Deppert (2006) collected information from expert stakeholders via phone interviews to gauge perceptions of environmental and health impacts of nanoparticulate materials and the policy and regulations associated with the industry. Furthermore, in an attempt to identify potential management strategies that may be employed to reduce the environmental effects of human pharmaceuticals, Doerr-MacEwen & Haight (2006) interviewed leading scientists, researchers and policymakers from areas of government, academia, and the pharmaceutical industry. Overall, the use of stakeholder interviews appears to be a valid approach to effectively obtain opinions and critical information from experts in policy and management fields.

4.2 Interview Methods

To determine the weight of evidence in support of either of the RC or EOL methods that account for recycled material in LCA studies, as it pertains to the aluminum industry, interviews with key stakeholders were completed. Key stakeholders were identified as environmental and/or LCA experts from the following groups: industry associations related to aluminum, standards organizations related to LCA, aluminum producers, companies which are significant users of aluminum, members of government, as well as LCA researchers and consultants. The breadth of the stakeholder groups was to limit industry bias where possible. The interview subjects were recruited from the various companies and organizations via networking and cold contacting. The selected interview participants were either practitioners of LCA or individuals holding senior environmental positions at their respective companies and/or organizations. Several respondents were leading experts on LCA studies involving metals/aluminum and some were involved with the development of formal LCA standards. Furthermore, though several respondents were situated in Canada, many were also based internationally. **Appendix A** contains the letter of introduction that was used to contact the potential interview candidates. In total, 13 interviews were completed and the number of interviewees in each stakeholder group is summarized in *Table 2*. The narrow scope of the topic of interest lends itself to a smaller sample size and the selected respondents represent the highest level of opinion on the issue of recycling allocation approaches in LCA studies involving metals/aluminum. The interviews were semi-structured and consisted of open-ended questions. The interview guide containing interview questions is presented in **Appendix B**. Interviews were carried out via telephone and responses were recorded using audiotapes and supplemented with written notes. Following the interviews, the audio tape recordings were transcribed and combined with the written notes. The transcripts were coded based on thematic responses to the interview questions and grouped by stakeholder group.

Table 2. Stakeholder Groups and Number of Interviews.

Stakeholder Group	Number of Interviews
Industry associations related to aluminum	4
Standards organizations related to LCA	2
Primary aluminum producers	1
Industry sectors using aluminum	3
Government	1
LCA researchers and consultants	2

4.3 Case Study Methods

For the case study, Rio Tinto Alcan provided data and their modeling tool to assess the impacts that these two LCA allocation procedures may have on their business operations. Rio Tinto Alcan received assistance from the Interuniversity Research Centre for the Life Cycle of Products, Processes and Services (CIRAIG) and Quantis Canada, to develop their modeling tool. The principal researcher used this model and updated it to determine the impacts the end-of-life recycling approach and the recycled content approach may have on the company's GHG footprint.

4.3.1 Background Information on Case Study Model

The interactive modeling tool developed for RTA calculates the environmental footprint of aluminum on a life cycle basis from the stage of bauxite mining to the production of hot liquid aluminum. Specifically, it calculates environmental impacts associated with the production of metric ton (mt) output of aluminum taking into consideration the impacts of the 3 major phases of aluminum production: bauxite mining, alumina production (refinery), and smelting. The tool provides results based on 4 different impact categories as follows: climate change, human health, ecosystem quality, and non-renewable resource depletion. Since this study is primarily focused on shifts in carbon emissions, only the impact category of climate change will be discussed in detail. For that impact category, final LCA results are presented in metric tons of carbon dioxide equivalent (mt CO_2 eq.).

The modeling tool is based in Microsoft Excel. The core version of the tool consists of 9 worksheets (*Table 3*).

Table 3. Worksheets contained in custom modeling tool developed for RTA.

No.	Name	Description of Worksheet Function
1	Title	Contains name of the calculator, name of company that developed the tool, and for whom the calculator was made.
2	Introduction	Contains general information on how the tool works and functions including basic instructions for the user.
3	Hypothesis	Contains assumptions that the tool makes and databases it references.
4	Bauxite	Where the user may enter data associated with the bauxite phase of aluminum production.
5	Refinery	Where the user may enter data associated with the alumina refinery phase of aluminum production.
6	Smelter	Where the user may enter data associated with the smelter phase of aluminum production.
7	Electricity Mix	Where the user may input different electricity mixes that add up to 100%. This worksheet is referenced by the 3 phases of aluminum production in worksheets 4, 5, and 6.
8	Comparison	Where the user may build scenarios choosing the desired combination of mine, refinery, and smelter that they wish to evaluate. This worksheet is linked to worksheets 4, 5, 6, and, 7 and sources data for the scenario as selected by the user. This worksheet also contains the number value result for each phase of a scenario based on 1 mt of aluminum production for each of the impact categories.
9	Results	Offers graphical representation of the values summarized in Worksheet 8
16	Report	Summary report of mt CO_2 eq. produced at a particular smelter based on 1 mt of aluminum production for a scenario designed by the user

Worksheets 1, 2, and 3 are informational in nature and are not directly linked to the results produced by the model. Worksheets 4, 5, and 6 are the worksheets where the user may enter data associated with these phases of aluminum production. The user is able to input site-specific data for each phase, but in instances where there may be gaps or uncertainties in datasets, the tool also provides the option to choose generic data from established organizations. The calculator tool has the option to pull data from the International Aluminum Institute (IAI), the European Aluminum Association (EAA), and/or the Ecoinvent database for each phase of aluminum production. In addition to being the sheet where the bauxite, refinery, and smelter data is formed into a scenario, Worksheet 8 also contains other input options that the user may indicate including travelling distance between sites (i.e. transport 1 - from mine to refinery and transport 2 - from refinery to smelter), proportion of recycled content, and the proportion of different alloys included in the mix. *Figure 11* shows the general process flow that the model follows indicating user inputs and *Figure 12* displays the general process flow when a recycled content value is included. As noted in *Table 3*, Worksheet 8 also contains the number value result for each phase of a scenario based on 1 kg of aluminum production for each of the impact categories. For example, based on an entered scenario, for the climate change impact category, this worksheet reveals a value of mt CO_2 eq. for each phase (bauxite, transport 1, refinery, transport 2, smelter, and alloy) as a well as a total value that encompasses all phases. Assumptions associated with data input and impact calculations entered into the modeling tool are noted in **Appendix C**.

As noted in the previous section and *Table 3*, there are 9 worksheets that comprise the basic version of the modeling tool. As further interests of Rio Tinto Alcan were identified, additional worksheets were created to address their needs. Some worksheets are not relevant to this study and will not be discussed. However, Worksheet 16, the report worksheet is very relevant to this study. Worksheet 16 provides a summary report of mt CO_2 eq. produced at a particular smelter based on 1 mt of aluminum production for a scenario designed by the user. This worksheet will be discussed further as it is used in this study.

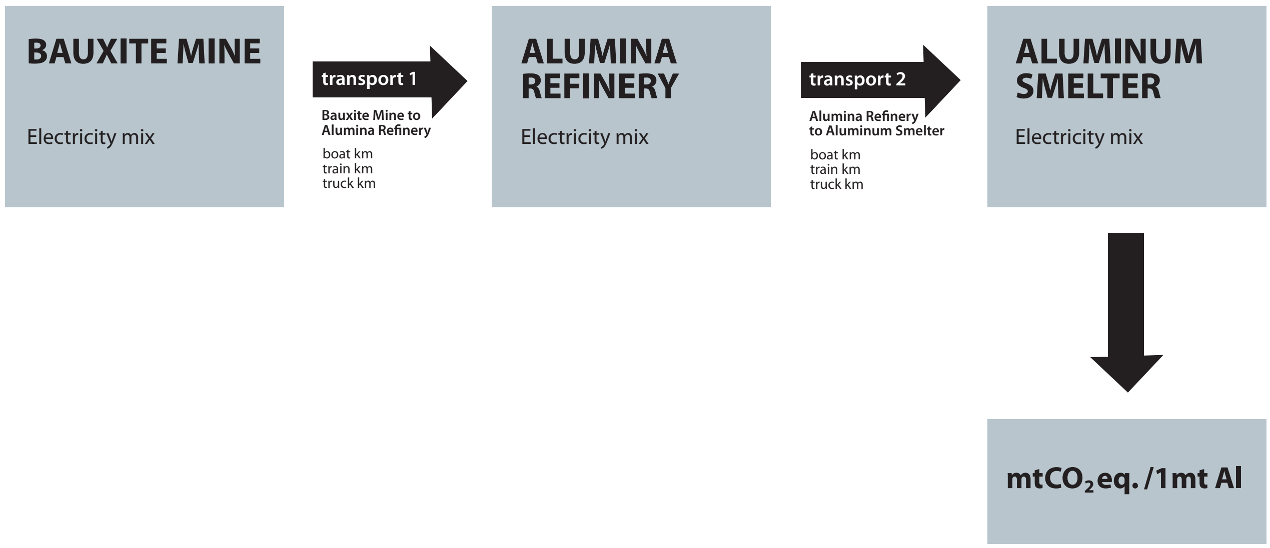

Figure 11. General process flow of the model.

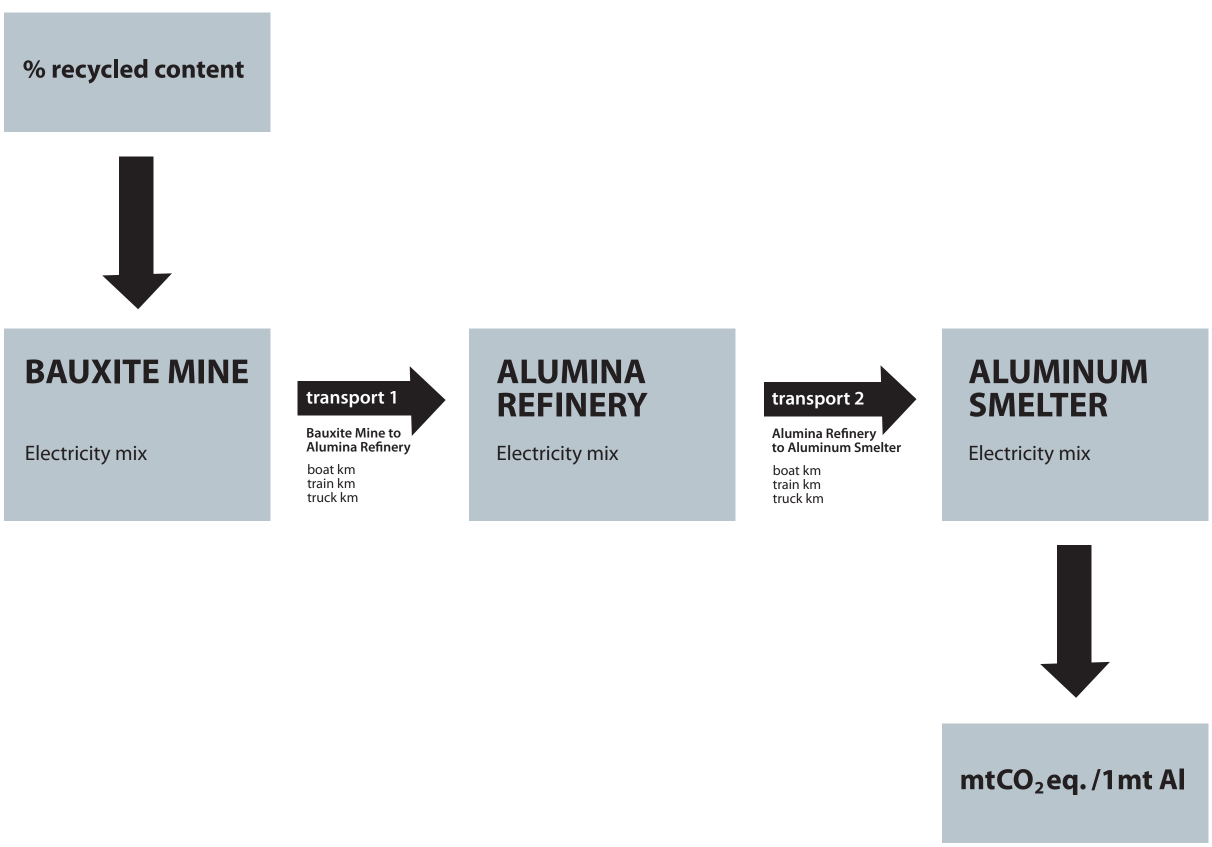

Figure 12. Process flow of the model including recycled content.

4.3.2 Model Scenario Methods

The purpose of this case study portion is to determine the impacts the end-of-life recycling approach and the recycled content approach may have on the company's GHG footprint. As detailed in the previous section, the original version of the modeling tool contained an option to input a percentage value of recycled content included in the production mix. The modeling tool did not include an option for an end-of-life recycling rate to account for the end-of-life recycling approach. The model was updated to have the option to input a recycling rate. Worksheet 17 was added as the end-of-life recycling rate worksheet. This worksheet takes the total mt CO_2 eq. produced at a particular smelter produced in Worksheet 16, the report worksheet, and multiplies this value by (1- % recycling rate). This addition allows for scenario results that compare the input of recycled content or the consideration of recycling at a specified rate at the end of life. *Figure 13* shows the process flow of the model when considering the EOL approach.

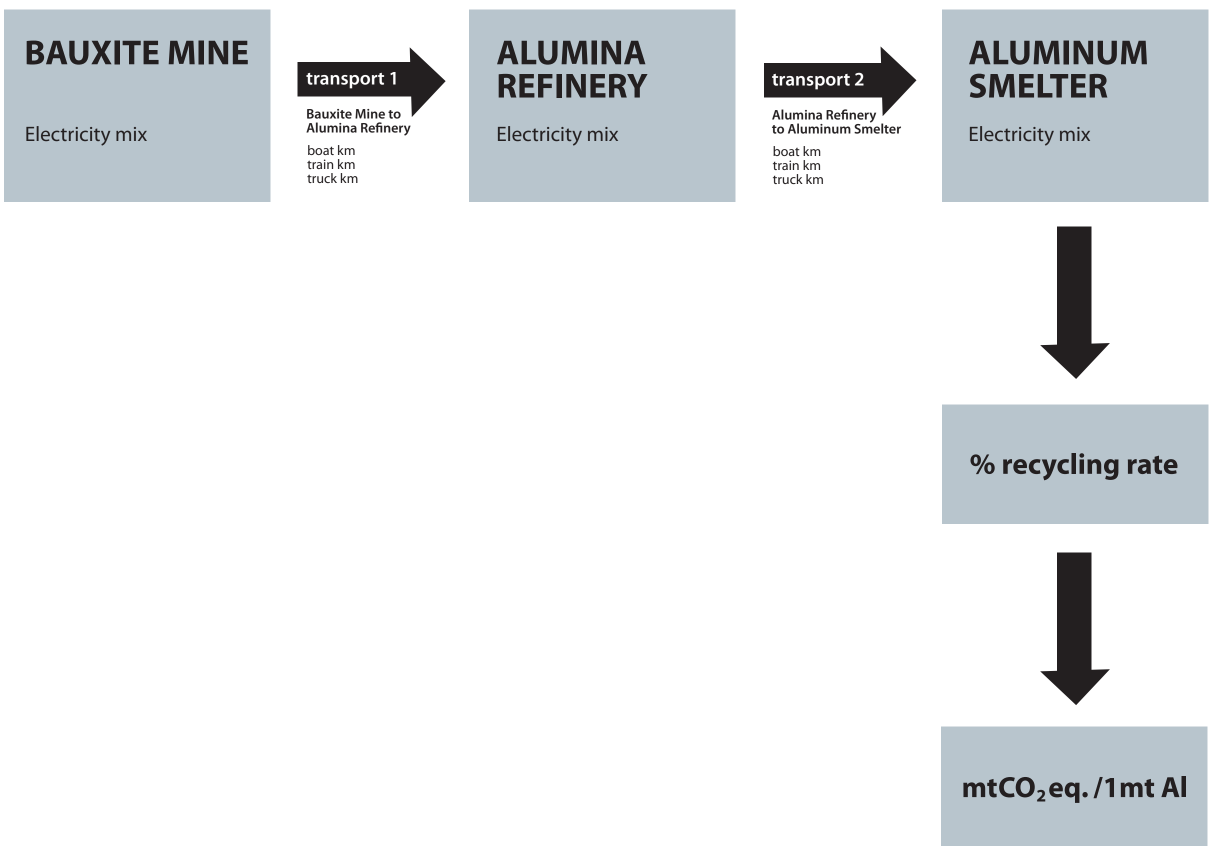

Figure 13. Process flow of the model including end of life recycling rate.

The EOL approach is typically used when considering the life cycle of a single product instead of the production manufacturing material such as aluminum. However, in order to use this custom modeling tool to assess this company's internal production data in terms of the two approaches, it was assumed that this aluminum will be used to manufacture products in different markets.

4.3.2.1 Rio Tinto Alcan Site-Specific Data

The modeling tool contains data for specific Rio Tinto Alcan (RTA) sites at each of the 3 phases of aluminum production. The version of the modeling tool provided to the principal researcher contained RTA site-specific data for two bauxite mines, four alumina refineries, and 16 smelters.

4.3.2.2 Case Study – Canadian Smelters

The focus of the study has been narrowed to address how these two LCA approaches may affect the Canadian portion of RTA's business operations. Therefore, the scenario was designed to accommodate the 6 Canadian RTA smelters included in the modeling tool. *Table 4* summarizes the Canadian smelters and their locations. It should be noted that RTA has 7 smelters located in Canada, but only data for 6 of these smelters were contained in the model.

Table 4. RTA Canadian smelters included in the modeling tool.

Saguenay-Lac-Saint-Jean, Quebec (Alma)
Saguenay-Lac-Saint-Jean, Quebec (Arvida)
Saguenay-Lac-Saint-Jean, Quebec (Grande-Baie)
Saguenay-Lac-Saint-Jean, Quebec (Laterriere)
Shawinigan, Quebec
Kitimat, British Columbia

For each smelter, the most realistic process flow was determined and data were selected accordingly. *Table 5* provides a summary of the process flow data selections. A more detailed description of these data selection choices can be found in subsequent sections.

The main industries that use aluminum are transportation, building and construction, and packaging. A product from each of these markets was chosen and percentage RC values and percentage EOL recycling rates for these products in North American markets were obtained. The products selected for each market were auto aluminum (transportation), rolled aluminum (buildings and construction), and the aluminum can (packaging).

Table 5. Summary of data selected for each smelter scenario.

Smelter	Electricity Mix - Smelter	Bauxite Mine	Electricity Mix - Mine	Transport 1	Alumina Refinery	Electricity mix - Refinery	Transport 2
Alma	100% hydroelectricity	IAI	Ghana 68% hydro 32% thermal	50% x (km from Ghana to Canada) plus 25% x (km from Brazil to Canada) plus 25% x (km from Jamaica to Canada) = 8088 boat km	Vaudreil	100% hydroelectricity	Km from Vaudreil to Alma = 520 km truck
Arvida	100% hydroelectricity	IAI	Ghana 68% hydro 32% thermal	8088 km boat	IAI	IAI	506 km truck
Shawinigan	100% hydroelectricity	IAI	Ghana 68% hydro 32% thermal	8088 km boat	IAI	IAI	196 km truck
Grande-Baie	100% hydroelectricity	IAI	Ghana 68% hydro 32% thermal	8088 km boat	IAI	IAI	513 km truck
Laterriere	100% hydroelectricity	IAI	Ghana 68% hydro 32% thermal	8088 km boat	IAI	IAI	490 km truck
Kitimat	100% hydroelectricity	IAI	Ghana 68% hydro 32% thermal	8088 km boat	IAI	IAI	4912 km train

Table 6 summarizes these percentages and their sources. It should be noted that North American values were used because specific Canadian values could not be obtained. Furthermore, these percentages generally came from aluminum industry sources. Aluminum organizations have a high level of authority in regard to statistics associated with their industry and it is reasonable to assume that these percentages are the best and most accurate information available. However, there is always the possibility of bias when an industry produces statistics on their own processes. If there were any bias in these percentage values, it would be that they might be inflated.

Table 6. % RC values and % EOL recycling rates for major products in relevant sectors that use aluminum

Auto Aluminum (Transportation)	% RC	57%*
	% EOL recycling rate	90%*
Rolled Aluminum (Building and Construction)	% RC	85%*
	% EOL recycling rate	95%**
Aluminum Beverage Can (Packaging)	% RC	68%*
	% EOL recycling rate	58%*

* (The Aluminum Association, n.d.)
** (Das & Yin, 2007)

The purpose of the case study was to compare the RC and EOL approaches and how they influence total mt CO_2 eq. produced. Each smelter scenario was run nine times as follows:

1) baseline scenario (% RC or % EOL recycling rate not entered)
2) % RC transportation
3) % EOL recycling rate transportation
4) % RC buildings and construction
5) % EOL recycling rate buildings and construction
6) % RC packaging
7) % EOL recycling rate packaging
8) 50% RC
9) 50% EOL recycling rate

For the results, all mt CO eq. totals were averaged for RTA's Canadian smelters in order to protect sensitive proprietary information.

4.3.2.3 Data – Bauxite Mines

The modeling tool includes data for two RTA bauxite mines, but these mines are not the source of bauxite for the Canadian smelters (D. LeClerc, personal communication, October 20, 2011). Instead, bauxite is shipped from off-shore mines of which approximately 50% is derived from Africa, 25% from Brazil, and 25% from Jamaica. Due to this, generic data for a bauxite mine were selected for each smelter scenario. IAI (2005) data were used instead of EAA or ecoinvent data because they were deemed the most current and accurate of the generic data contained in the model (D. LeClerc, personal communication, October 20, 2011). For the electricity mix used at the bauxite mine, a more realistic electricity mix was selected instead of relying on a generic mix. Since approximately 50% of the bauxite ore fed into Canadian smelters is shipped from Africa, the electricity mix for an African country was thought to be more realistic. Though D. LeClerc gave no specific source African country, Ghana was selected because it is a country known to have bauxite mining operations in Africa (Conceptualee Inc., 2009-2011). Ghana's electricity mix is as follows: 68% hydroelectricity and 32% thermal energy (Energy Enterprise Learning Platform, 2006).

4.3.2.4 Data – Transport 1

For each smelter scenario, it was assumed that bauxite ore was shipped from Ghana, Brazil, and Jamaica to Canada. Distances from each country to Canada were calculated using the distance calculator at http://www.mapcrow.info/. The approximate proportion of bauxite ore being shipped from each country was multiplied by these distances and subsequently added to obtain the value of 8088 km. This distance was assumed to be boat travel and inputted as such.

4.3.2.5 Data – Alumina Refineries

The modeling tool contains four RTA alumina refineries. Of these refineries, only one is part of the process flow for any of the Canadian smelters. The RTA alumina refinery located in Saguenay-Lac-Saint-Jean, Quebec (Vaudreuil) feeds into the smelter located in Saguenay-Lac-Saint-Jean, Quebec (Alma). Site-specific alumina refinery data for Vaudreuil were used for the Alma smelter scenario. The electricity mix for the Vaudreuil refinery is 100% hydroelectricity. For the remaining five smelter scenarios, generic alumina refinery data from IAI (2005) were selected. To correspond with these generic alumina refinies, generic electricity mix as defined by IAI (2005) was selected.

4.3.2.6 Data – Transport 2

For the Alma smelter scenario, the distance from Vaudreuil to Alma was determined to be 520 km using Google Maps (2011). This distance was inputted as km travelled by truck. For the remaining five smelters, the alumina refinery was unknown. Since this study has a Canadian focus, the location for the Vaudreuil refinery was used to determine the Transport 2 value for these five smelters. The distance from Vaudreuil to each smelter was determined using Google Maps (2011) and are listed in *Table 5*. For the smelters located in Quebec, these distances were inputted as travelled by truck. For the smelter in British Columbia, the distance was inputted as travelled by train.

4.3.2.7 Data – Smelters

The site-specific RTA data were selected for each of the six Canadian smelters. The electricity mix for all of the smelters is 100% hydroelectricity.

5.0 Results

5.1 Synopsis of Interview Responses

The interview transcripts from each stakeholder group were reviewed for common thematic responses to questions in the interview guide. These questions aimed to determine the weight of evidence in support for either the end-of-life recycling approach or the recycled content approach amongst relevant expert individuals related to the aluminum industry. Additionally, the interviews also tried to gather opinions on the use of carbon footprinting or single indicator approaches to assessing environmental impacts instead of the use of a broader set of environmental indicators.

The responses in relation to the topic 1, end-of-life recycling approach versus the recycled content approach, were first reviewed within each stakeholder group. Following this, comparisons across stakeholder groups were completed. The responses associated with topic 2, carbon footprinting versus broader set of environmental indicators, were only reviewed across all stakeholder groups, as there was a greater level of consensus amongst all participants.

Industry Associations Related to Aluminum

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach

In this stakeholder group, four individuals affiliated with industry associations related to aluminum were interviewed. Amongst the four respondents, there was a very strong consensus regarding the use of the two allocation approaches. Overall, they held the opinion that the use of the end-of-life recycling approach in LCA studies was preferred when metals/aluminum are involved. Respondents 1 to 3 preferred the end-of-life recycling approach for LCA studies when metals/aluminum were involved. Respondent 4 gave the opinion that both methods were valid from a LCA methodology standpoint, but that there is some reasoning to suggest that the end-of-life recycling approach is more appropriate for metals such as aluminum.

The common themes gathered from all 4 respondents are as follows:

1) Metals such as aluminum are elemental in nature and maintain their value during the recycling process.

Respondent 1: "Aluminum is a very valuable material and you're doing something good for the environment if you recycle the material."

Respondent 2: "Recycling metals does not affect the properties by melting."

Respondent 3: "(refers to aluminum as) a material, which doesn't lose its properties in the recycling process, or its value in the recycling process."

Respondent 4: "If it's properly recycled there's no difference for you to use primary material or secondary material, they are the same. But for other materials there is a problem, for example, plastic; when you recycle [plastic] the property of the material has been changed."

2) The end-of-life recycling approach is more appropriate as it encourages metals to actually be recycled.

Respondent 1: "The value of end-of-life recycling vs. recycled content must be higher."… "The intention must be to get as much aluminum as possible back into the recycling system. This may be done based on recycling rates."…"[The] end-of-life recycling approach gives the incentive of accounting for end of life recycling rates [and] end of life recycling. That's one thing, incentive on collecting and recycling aluminum [is] given by the end-of-life [approach]."

Respondent 2: "The end-of-life approach more accurately expresses the recyclability of the product."

Respondent 3: "It's for the end-of-life approach. The reasons for that are that, there's a number of reasons, but really we see that as the primary environmental indicator."… "Really the positive environmental impact comes at the end of life and trying to maximize recovery."

Respondent 4: "The EOL approach will make more sense for metals to be fully recycled. So, if you see that you have a higher recycling rate [or a higher] end of life recycling rate, you'll have a better footprint. If you have a worse recycling rate, you'll have a worse footprint and this will encourage the industry and also the society to make the best effort to recycle as much [of the material] as possible (the material) back into our lives."

Additionally, the following common theme was gathered from 3 out of 4 respondents:

1) The recycled content approach diverts aluminum scrap to certain applications. However, since there is limited aluminum scrap available, the result is that there is no overall environmental benefit to the aluminum market as a whole.

   Respondent 1: "The other thing is, if you put the recycled content approach into perspective, in theory [it] would have the probability to produce one product with a very high recycled metal content, but this would lead to other products with a lower recycled metal content and currently there is not enough scrap available." …"Scrap is not growing on trees --- it must be collected and available."

   Respondent 2: "The recycled content approach will create distortions in the market as it will direct scrap towards specific products/applications. This is inefficient when considering the aluminum industry globally. The recycled content approach may make certain products appear greener but the actual environmental impacts of the global aluminum industry have not improved."

   Respondent 3: "Increasing recycled content for a material which doesn't lose its properties in the recycling process or its value in the recycling process, and in a growing market, increasing recycled content doesn't improve environmental outcomes. It just has the potential to shift material around the world, which doesn't necessarily have a positive environmental outcome."

Finally, this section outlines additional themes that were brought up by individual respondents in this stakeholder group:

1) The definition of recycled content is not standardized and in some cases may be a misleading environmental measure, particularly if manufacturing scrap is included in the calculation. In general, there is uncertainty associated with how recycled content is calculated and this makes its use questionable.

   Respondent 1: "More production scrap means less efficient process... "Therefore it's a measure of inefficiency. With your definition of recycled metal content you would benefit from a less efficient process, as your recycled metal content would grow. It would get higher and higher."… "And this is already an indication that the recycled metal content approach is more or less a doubtful approach in general."

2) The time scale of products makes a difference in regard to how appropriate each method is to a study. The recycled content approach may be more appropriate for products with short life spans.

Respondent 3: "All of these things have to do with time, is my personal view, as far as I see it. When you have material going into a building let's say that doesn't come out of that building for 50 years, the aluminum is doing good work, it's doing what it's meant to do. It's operating in the use phase or light-weighting a vehicle for 20 plus years. So you're not going to see that material until the end of its life, but it's still doing positive in the use phase. For short term, packaging and so on, recycled content, in a closed loop may be a good indicator. But things with longer lifetimes, we need to take that into account."

Standards Organizations related to LCA

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach

In this stakeholder group, two individuals with backgrounds in developing and enforcing standards related to LCA were interviewed. The two respondents were in strong agreement regarding the use of the two allocation approaches. Overall, they had the opinion that neither method is preferred for LCA studies where metals/aluminum are involved. The common theme gathered from both respondents was that the methods and assumptions used in a LCA study should coincide with the purpose of the study. The following quotes embody the unanimity of their opinion on the matter:

Respondent 1: "What's the purpose [of the study]? Is it a consequential study? Is it an attributional study? Is it a public policy study? Is it an internal business decision? There are 100 different ways to use that information in a study"…"The method that you choose has to fit the purpose of the study."

Respondent 2: "It depends on what you will go through and what particular [parameters you set] (you have to set your own parameters and decide how you're going to go). But if you put your assumptions in a specific way, then you have to follow through with that. So, I wouldn't really say that this [approach] is preferable to the other one. It depends on your assumptions and where you want to go."

Primary Aluminum Producers

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach

In this stakeholder group, one individual with a background in producing aluminum was interviewed. Overall, the respondent had the opinion that the use of the end-of-life recycling approach in LCA studies was preferred when metals/aluminum are involved. The common themes gathered from this individual were as follows:

1) Metals such as aluminum are elemental in nature and maintain their value during the recycling process.

   Respondent 1: "Aluminum, copper, many kinds of materials, to a lesser extent steel, these materials have good intrinsic value. So there is already quite a good efficient value chain for recycling because of the intrinsic value. Comparable materials like plastic or paper do not have the same intrinsic value."

2) The end-of-life recycling approach encourages metals to actually be recycled and offers a better representation of impacts in the long term.

   Respondent 1: "The end-of-life approach is much more efficient in terms of the environment and making sure that what can be recycled is actually recycled." … "The end-of-life recycling approach [offers a] better picture of the long term"

3) The recycled content approach does not accurately reflect the environmental value of a metal/aluminum product.

   Respondent 1: "The other one [the recycled content approach] is a measure [of] what is the recycled content of the product will be…it doesn't really take the environmental value behind it."

4) The recycled content approach diverts aluminum scrap to certain applications. However, since there is limited aluminum scrap available, the result is that there is no overall environmental benefit to the aluminum market as a whole.

Respondent 1: "You may not find the scrap available because (it's) [the market is] already efficient and already all [of] the metal that can be recycled is (already) recycled. By measuring recycled content it might get some dynamics that may actually not be environmentally friendly, because [it] may divert recycled content for specific applications away from the original pool of the recycled content pool which isn't really more efficient."

Industry sectors using aluminum

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach

In this stakeholder group, three individuals were interviewed who are familiar with the following markets that use aluminum: transportation, packaging, and building/construction. There was one individual interviewed for each market. All three of the respondents in this group were not as familiar with the definitions of the two approaches relative to respondents in other groups. However, the respondents did have ample understanding of LCA and sustainability concepts and were thus regarded as suitable interview candidates. The respondents were able to offer the opinions of the two allocation approaches after receiving an explanation of their definitions.

Overall, the respondent from the transportation sector held the opinion that both the end-of-life recycling approach and the recycled content approach were appropriate for LCA studies where metals/aluminum are involved, the respondent from the packaging sector did not have a preference for either approach, while the respondent from the building/construction sector slightly preferred the recycled content approach. In addition, there are themes that appeared in their individual responses. The respondent from the transportation sector referred to how incorporating recycling initiatives, be it recycled content or recycling at the end of life, may make a difference in a materials' ranking with respect to its environmental impacts. The respondent representing the packaging sector referred to how metals such as aluminum are elemental in nature and maintain their value during the recycling process. The respondent representing the building/construction sector referred to how the recycled content approach may be more appropriate to projects with longer lifetimes. Finally, the respondents from both the packaging and the building/construction sectors mentioned that the ease in which they are able to communicate the environmental benefit of either approach to their customers would play a role in which approach would be more suitable for LCA studies within their sectors. These respondents particularly highlighted that there may be a public relation or marketing benefit to using the RC approach. They stated that there could be a high recycled content in a building or packaging material and this is a relatively simple concept for customers to comprehend versus recycling rates associated with the EOL approach.

The following quotes exemplify the opinions of the respondents from each market relevant to aluminum:

Respondent 1 (transportation): “[Regarding the two approaches] Both of them are important. We are on the look out for ways in which the percentage of recycled content in our product can be increased and we are also cognizant of using materials that are amenable to post-consumer recycling. Whether or not the recycling is directly back into our products or some other uses.”… “Moreover, consideration of recycled content and the ability of reusing post-consumer material, recycling changes the ranking of those materials in terms of their environmental impacts.”… “For aluminum, one way or another, if it appears in our product, and therefore appears in our post-consumer recycling streams—that aluminum is going to be used.”

Respondent 2 (packaging): “I would say, there is no preference and the reason (is all) [has to do with] how (will) you [will] explain and justify the environmental benefit.”… “For me as a consumer packaged goods company, I want a benefit [and it’s valuable] if I can communicate this benefit. So let’s take recycled content. The more (my packages have) recycled content [in my packages], the more I can eventually communicate as (this is) an advantage.”… “So there is the notion of competitive advantage and what is the incentive.”…“I would say both approaches are interesting and in theory they should not be opposite, they should work together. Personally, I would say the recycled content [approach] is also something that people are familiar with, it’s a notion that people (kind of) accept. While, [considering if] this is recyclable or if it will it be used again—it’s harder to explain. I think from a marketing or a messaging standpoint, recycled content is easier to explain.”

Respondent 3 (building/construction): “I would prefer to look at the initial state [or recycled content approach]”… “For a builder, there’s a benefit to include recycled content for their customers as a marketing strategy. To have 30% aluminum in their siding of their window—it’s easier to control that or know what that it is. Whereas what happens at the end of life, we don’t really know. If I were to build a condo today, [and considering when the end of its life will happen—it is difficult to determine] how long might that be.”… “Aluminum is (something,) [a material where] recycling is not bad, it doesn’t lose its properties. You can actually measure [the amount of recycled content in a product].”… “The only benefit at end of life, (maybe) [if] it’s an older city and they’re demolishing (a lot of) [several] old buildings and then putting up new buildings. [Then you could more easily determine] What (did) you (do) [did] with that aluminum and then you build something in its place.”

Government

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach

In this stakeholder group, one individual working in policy research related to metals/ aluminum was interviewed. Overall, the respondent had the opinion that the use of the end-of-life recycling approach in LCA studies was preferred when metals/aluminum are involved. The common themes gathered from this individual were as follows:

1) The definition of recycled content is not standardized and in some cases may be a misleading environmental measure, particularly if manufacturing scrap is included in the calculation. In general, there is uncertainty associated with how recycled content is calculated and this makes its use questionable.

   Respondent 1: "(regarding the definition of the recycled content approach) Sometimes even people from the industry are saying that they have their recycled content [and] they count the manufacturing scrap in it. If you are counting that recycling loop as the recycled content, really you are just giving (to) yourself credit on something that you are not efficient in your manufacturing process"… "I think there's a lot of uncertainty in that system if we are using recycled content."

2) The end-of-life recycling approach encourages disposed items to actually be recycled.
   Respondent 1: "With the EOL approach you really have to think about the fate of material at the end. If you can help the recycling at the end, you will get the credit for the old system."

3) When using the recycled content approach it can be difficult to differentiate between the sources of the secondary scrap. This is misleading if manufacturing scrap is included
   Respondent 1: "With the recycled content approach, you are saying ok, I will just look at materials, source materials, that are coming from secondary sources and even if you don't know if it is coming from prompt scrap or (is it) [if it is] coming from end of life scrap."

4) The recycled content approach gives no credit for recycling at the end of life of a product, so there is no incentive for the producer to recycle.
   Respondent 1: "You are promoting, (making some kind of) [to] help(ing) the environment by using scrap material and it will be burden free; and so you won't care about the end of life of your

product and you won't get any credit for that. It will be somebody else to try and get the credit for that, but not you."

LCA Researchers and Consultants

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach

In this stakeholder group, two individuals performing LCAs in a research/consulting setting were interviewed. Overall, the two respondents were not in agreement. Respondent 1 held the opinion that neither method is preferred for LCA studies where metals/aluminum are involved and felt that that the methods and assumptions used in a LCA study should depend on the context of the study. To contrast, Respondent 2 had the opinion that the use of the end-of-life recycling approach in LCA studies was preferred when metals/aluminum are involved. However, Respondent 2 did note that the recycled content approach was still a relevant metric able to show impacts of the production phase of a product.

The two respondents had additional points of interest to add to the discussion on the two allocation approaches. Respondent 1 mentioned that there are several other allocation options that they use when performing LCAs involving metals/aluminum and pointed out that data availability would play a role in which allocation method was chosen. However, Respondent 1 did note that in a consequential LCA study involving metals/aluminum, the end-of-life recycling approach might have some relevance. Respondent 2 also pointed out that for products with short lifetimes, for example the aluminum beverage can, the end-of-life recycling rate may be almost equal to the recycled content value.

The following quotes exhibit these individuals' perspectives:

Respondent 1:

"The choice of the allocation methodology used for recycling is highly context specific. The only possibility that would justify system expansion is when the scope of the study is to identify the environmental impact of a change, where this change increases the recycling availability of aluminum. The change would increase the recycled aluminum, which could potentially reduce the production of virgin aluminum. Generally, for metals, we would use a cut-off approach or a variation of it, depending on available data."

Respondent 2:

" I consider End-of-Life recycling rates as the most appropriate environmental indicators for LCA studies and in general as [an] indicator highlighting the better performance of products and applications based on aluminum solutions. Nevertheless the recycled content is a valid environmental attribute, i.e. an indicator that provides partial and/or indirect information with respect to the environmental performance of a product in the production phase of a product".

Topic 1: End-of-Life Recycling Approach vs. Recycled Content Approach — Comparisons Across Stakeholder Groups

Across the six stakeholder groups, amongst the 13 respondents, there was not unanimity or a general consensus regarding using either approach where LCA studies involved metals/aluminum. In summary, 6 respondents preferred the end-of-life recycling approach, 1 respondent preferred the recycled content approach, and 5 respondents did not prefer either approach. *Table 7* provides an outline of the overall opinions for each of the respondents in the study.

Table 7. Topic 1: Summary of Overall Opinion from Each Respondent

Stakeholder Group	**Respondents**	**EOL approach is preferred**	**RC approach is preferred**	**Neither approach is preferred**
Industry associations related to aluminum	Respondent 1	X		
	Respondent 2	X		
	Respondent 3	X		
	Respondent 4	X		
Standards organizations related to LCA	Respondent 1			X
	Respondent 2			X
Primary aluminum producers	Respondent 1	X		
Industry sectors using aluminum	Respondent 1			X
	Respondent 2			X
	Respondent 3		X	
Government	Respondent 1	X		
LCA researchers and consultants	Respondent 1			X

Although there was no general consensus across stakeholder groups, there was a common view in the aluminum industry. The metals industry publicly promotes the use of the end-of-life recycling approach over the recycled content approach. Therefore, it is not surprising that aluminum associations and primary producers would support the end-of-life recycling approach. It is interesting that the government representative also supports this allocation approach. Furthermore, the responses from these groups indicated that a more accurate or complete LCA was achieved when the EOL approach was exercised.

The majority of the remaining respondents did not hold a preference for either approach. Given the complexity associated with most LCA studies, it is reasonable to come to the conclusion that the choice of allocation method would depend on details specific to individual LCAs. The end-of-life recycling approach and the recycled content approach have been presented as mutually exclusive approaches and sometimes as the only allocation options; however, this is false as the approaches may be used in conjunction and there are a myriad of other allocation methods that may be applied to LCA studies that involve metals/aluminum.

It is interesting that only 1 respondent preferred the recycled content approach. This does not seem like an outlier. Given the small sample size of the study, it is reasonable that only 1 respondent would support this approach. Also, since this view hails from the building/construction perspective, there is some agreement with the literature. Recall, that Hammond & Jones (2010) noted that end of life recycling benefits may not provide an accurate picture of impacts when product lifetimes are longer.

Topic 2: Carbon Footprinting vs. Broader Set of Environmental Indicators — Comparison Across Stakeholder Groups

Across the six stakeholder groups, amongst the 12 respondents, there was a very strong consensus regarding the use of environmental indicators. Overall, they held the opinion that the use of a broader set of environmental indicators was preferred instead of a single indicator, such as carbon footprinting. Some respondents alluded to the fact that single indicators require a value judgment in order to focus on a specific environmental impact. This response is somewhat expected since the majority of the respondents were LCA experts and practitioners who would most often be reviewing impacts at a fairly comprehensive level. This view goes beyond the focus of this study, which aimed to look specifically at carbon emissions of a primary aluminum production company. Despite this, some respondents made specific comments about carbon footprinting; they referred to it as an important and valuable indicator, especially if carbon dioxide emissions are of particular concern for the product or process in question, but that users and audiences should be made aware of its limitations. This brings some relevance and support to the focus of this study since aluminum processes require high electricity inputs and carbon emissions are definitely a major pollutant of concern. The subsequent quotations comprise a sample of the responses that best represent the overall perspective of the participants:

Respondent 1 (Industry Associations related to aluminum): "You need a broader picture. In (that) case[s], [where] you reduce carbon dioxide emissions, but you increase other emissions (like) relevant for the summer smog or acidification, then you cannot claim that you have done something good for the environment. So, I'm against single indicator approaches. An important indicator is climate change of course, but it's not the only indicator and if you are talking based on carbon dioxide, you're talking (over) [about] climate change and not (over) [about] the environment [as a whole]."

Respondent 1 (Standards organizations related to LCA): "Clearly, carbon, or more accurately, global warming potential is a limited indicator and we just have to know that it is a limited indicator."

Respondent 2 (Standards organizations related to LCA): "I would really go to a broader one, but some people just focus on one element, which is the most, if you will, the most destructive for the environment, or in their opinion the most destructive for the environment. But in my opinion, I would really go on a broader elements rather than one indicator."

Respondent 1 (Primary aluminum producers): "[At our company], we are measuring our environmental performance with many criteria such as emissions and other impacts on the environment. Carbon, water use, energy consumption, there are many (many things), indicators [that we use]."

Respondent 1 (Industry sectors using aluminum): "There's a whole bunch of them, because there are many different aspects of them. Among them are various kinds of emissions from our product and from our manufacturing facilities. There are also issues about where, how some materials are produced, water usage, worker issues, [and] we are concerned with conflict materials. It runs a gamut, to pick out any one metric and say that's the one; it's tough."

Respondent 3 (Industry sectors using aluminum): "It has to be broad, because you could lower your greenhouse gases but pollute a lot of water. That's why you have to look at water and air."

Respondent 1 (Government): "You need several indicators. Each time that you are try(ing) to have a focus on (the) [a] single indicator, (like) a single number, you are making some kind of, in the ISO language, it is not based on science. So, you are making some value judgement."

Respondent 1 (LCA researchers and consultants): "[When] we go and evaluate and measure sustainability, (and) we always go broader than carbon dioxide. We use life cycle impact methodology 2002+. There are 4 indicators: human health, ecosystem quality, climate change, and non-renewable resource use."

The following provides additional themes that were identified within the responses, supported by quotations from the respondents:

1) Ideally, additional indicators associated with economic, social, technology, and functionality aspects of products and processes could be reported to try and improve upon sustainability/environmental performance.

   Respondent 1 (Industry associations related to aluminum): "Sustainability (really) also needs indicators in other areas – economic and social aspects. I will even go further and suggest indicators on technological issues and functionality. If the product is not able to fulfill its functionality anymore, it may not be used anymore."… "maybe no further improvement [is] possible otherwise you would lose functionality."

   Respondent 3 (Industry associations related to aluminum): "For instance, if you're building, if have a building, you may do an LCA on a particular product, it wouldn't be on the material, it would be on the product itself, which could be a window frame. But the performance of that building against environmental, social, and economic performance is much more than just your LCA. So, you would need to look of course at the life cycle impacts of the window in terms of greenhouse gases, acidification and so on so forth. But you also need a building that works. One that does its job, that protects people, [and] that allows people to do what they would do inside a building. So, there are value judgments in there as well and LCA is only one part of that and carbon footprinting is only one part of that as well."

2) Since carbon emission calculations are simpler relative to water or air, carbon footprinting is valuable because its use is helping to more accurately describe environmental impacts of products and processes.

Respondent 1 (Standards organizations related to LCA):"I think what will happen though is, through the use of carbon footprinting, people will start to realize that there are other benefits and disadvantages that are not captured around water or other air criteria, land use, and things like that. It helps put information on the table, which will need to be more contextually understood"… "[In regards to LCA] The fundamental issues of data availability and data appropriateness, and boundaries and allocation including recycling and then data quality and data quality representation—None of these have been dealt with very well. And none of them can be done well for carbon and carbon is probably the simplest of those indicators"…"But by going through the exercise and going through the analysis and seeing these systems is tremendously valuable."

3) LCA is complex and regardless of whether a single indicator or broad set of indicators is used, a knowledgeable person is required in order to have meaningful results.

Respondent 3 (Industry sectors using aluminum): "The person doing the LCA has to be knowledgeable. LCA software is good, but you need someone who knows how to use it."

5.2 Results of Case Study

The total mt CO_2 eq. produced from each smelter scenario was averaged for each of the nine different RC and EOL scenarios completed. The averages are presented in *Table 8*. Percent differences between RC and EOL scenarios are presented in *Table 9*.

Table 8. Averages of mt CO_2 eq. produced for nine different RC and EOL scenarios

Scenario	**Average of total mt CO_2 eq. produced**
baseline scenario (% RC or % EOL recycling rate not entered)	6.17
% RC transportation	3.44
% EOL recycling rate transportation	0.62
% RC buildings and construction	2.10
% EOL recycling rate buildings and construction	0.31
% RC packaging	2.91
% EOL recycling rate packaging	2.59
50% RC	3.77
50% EOL recycling rate	3.09

Table 9. Percent differences between RC and EOL scenarios.

Market	% RC and % EOL recycling rates	Average $mtCO_2$ eq./ mt Al produced	Percentage Difference
Auto Aluminum (Transportation)	57% RC	3.44	139%
	90% EOL recycling rate	0.62	
Rolled Aluminum (Building and Construction)	85% RC	2.10	149%
	95% EOL recycling rate	0.31	
Aluminum Beverage Can (Packaging)	68% RC	2.91	12%
	58% EOL recycling rate	2.59	
General 50/50	50% RC	3.77	20%
	50% EOL recycling rate	3.09	

The average value of mt CO_2 eq. produced per mt aluminum produced for the EOL approach was lower than the average value of mt CO_2 eq. produced per mt aluminum produced for the RC approach in every scenario completed. This trend was consistent across all products in industries that are significant users of aluminum. This result contradicts the earlier study completed by PE Americas (2010) where total energy usage was found to be higher when the EOL approach was applied versus the RC approach.

The percentage differences presented in *Table 9* indicate that there are substantial differences in the results when the RC and EOL approaches are compared. When reviewing the general comparison of 50% RC versus 50% EOL recycling rate, there is a 20% difference, a considerable difference. Percentage differences are even greater for the results for the transportation and buildings and construction industries, which both are >100% difference.

6.0 Discussion and Conclusions

The purpose of this study was to examine the recycled content (RC) and the end-of-life recycling (EOL) approaches as they are used in life cycle assessment (LCA) studies involving aluminum. The results of the case study showed that the average value of mt CO_2 eq. produced per mt aluminum produced for the EOL approach was lower than the average value of mt CO_2 eq. produced per mt aluminum produced for the RC approach in each scenario completed. This trend was consistent across all products in industries that are significant users of aluminum and therefore the results of this study suggest that there are benefits to using the EOL approach over the RC approach when considering CO_2 output on a life cycle basis. This coincides with a trend found in the results of the interview portion of the study. The interviews showed that there was a common view on the two approaches as all respondents in the aluminum industry supported the EOL approach over the RC approach. These results imply that there may be an advantage to aluminum industry associations and aluminum producers from a marketing perspective as they communicate their carbon footprint values to internal and external audiences.

Though the advantage to industry can be speculated from the results from both phases of the study, the case study results do not necessarily provide an indication of which approach is more accurate at calculating environmental impacts such as the carbon footprint. This topic of accuracy remains unclear from the case study results, but respondents from the aluminum industry during the interview portion did advocate that the EOL approach was more appropriate and accurate for LCA studies where metals are involved.

It should also be noted that the results from the case study are controversial and do not agree with the PE Americas (2010) study which found that the RC approach showed a lower total energy usage, while the EOL approach showed a higher total energy usage when considering the life cycle of the aluminum beverage can. The substantial difference in method in the PE Americas (2010) study was its focus on a single post-consumer product rather than an industry LCA approach. Without careful and thorough comparison of the difference in assumptions made and method used between this study and the PE Americas study, it is difficult to pinpoint why the results conflict. This difference in result may partially be due to the fact that the PE Americas (2010) study compared the two approaches while considering the life cycle of a single product. The custom model used in the case study of this research expresses only the production side of aluminum, but was used under the assumption that this aluminum was going be used to manufacture products in different markets. If this model was expanded to incorporate the consumption side of products the results could possibly be different. This may be an area for further research.

7.0 Significance

The incorporation of LCA thinking into business management practices is part of a rapidly evolving trend in the private sector. Fortune 500 companies and other major corporations desire to address the issue of carbon emissions before stricter regulations are set in place. From the actions of policymakers and governments, it is almost certain the trend towards lower carbon emissions will become mandatory. The use of LCA principles seems to be the most effective strategy for the long-term reduction of GHG emissions.

While it is expected that the present study will have broad industry relevance, it is hoped that it may assist Rio Tinto Alcan improve on their existing LCA practices and make more informed decisions to advance their overall environmental performance. Providing a methodology, approach, and template for comparing the accounting methods for recycled materials will be extremely valuable as such a system specifically tailored to the needs of the metals industry is not presently available. Ultimately, there is not enough information currently available on effective strategies that will allow primary metal producers to meet the impending stricter carbon targets and this study will be a useful addition to the body of research in this area.

8.0 Opportunities for Future Research

The focus of this study was for RTA's smelters in the Canadian market. A characteristic that is particularly unique of Canadian smelters is that they are all operated using 100% hydroelectricity. The modeling tool developed for RTA includes site-specific data for RTA bauxite mines, alumina refineries, and smelters located globally. For comparison purposes, it may be of interest to perform additional scenarios for other regions that may have differing electricity mixes for their smelters. For example, Australian and NZ smelters could serve as an interesting comparison because some of these smelters do not operate on 100% hydroelectricity and instead operate on a mixture of non-renewable and renewable energy sources.

Appendices

Appendix A: Letter of Introduction

To Whom It May Concern:

My name is Elizabeth Trenton and I am a Masters student in the Environmental Applied Science and Management at Ryerson University and my supervisor is Dr. Bernard Fleet.

I am currently researching how to account for recycled material when performing life cycle assessment studies with specific interest in the following two approaches: the recycled content matter approach and the end-of-life recycling approach. I am trying to identify any policy trends that may be present with regards to this topic. I hope that you may be willing to answer some questions about this subject by participating in a short telephone interview with myself and my supervisor.

Please let me know if you are available to participate in this study. If you know someone in your office that is better-suited to complete the interview, please email me at etrenton@ryerson.ca or alternately call me at 647-218-5499. Thank you very much for your consideration and I look forward to hearing from you at your earliest convenience.

Sincerely,

Elizabeth Trenton
B.Sc. (Env.), University of Guelph
M.A.Sc. Candidate, Environmental Applied Science and Management, Ryerson University

Appendix B: Interview Guide

We are researching how recycled material may be accounted for in LCA studies. Specifically, we are interested in gathering more information about the end of life recycling approach and recycled content approach.

First, I will provide a definition for each of the two approaches, as I understand them:

The end-of-life recycling approach credits post-consumer material inputs recovered at the end of life of a product.

The recycled content approach credits recycling inputs from any source (internal or external).

Do you agree with this definition? If not, let's clarify the definition.

Does your company or organization have a preference to either the end of life recycling approach or the recycled content approach?

If there is a preference, what are you reasons for favoring this approach?

How do you prefer to measure sustainability/environmental performance of your organization or company? (i.e. CO_2 or broader set of environmental indicators)

Can you describe to what extent your organization/company uses LCA?

Appendix C: Case Study – Assumptions of the Modeling Tool

Bauxite

Main inputs for bauxite are energy related: fuel and electricity (see below for exact process). Other processes included by default come from the Bauxite, at mine/GLO process: inputs from nature, blasting, mine structure and recultivation. Process also includes particulate emission.

Refinery

Main inputs for the refinery are energy related: fuel and electricity (see below for exact process). Other processes included by default come from the Aluminium hydroxide, at plant/RER (water use, emissions to water and plant building). Other inputs are

- Lime modeled with Quicklime, milled, loose, at plant/CH
- Caustic soda modeled with Sodium hydroxide, 50% in H2O, production mix, at plant/RER
- Redmud disposal modeled with Disposal, redmud from bauxite digestion, 0% water, to residual material landfill/CH

Smelter

Main inputs for the smelter are energy related: fuel and electricity (see below for exact process). Other processes included by default come from the **Aluminium, primary, liquid, at plant/RER** (plant building and waste). Other inputs are

- Aluminium fluoride modeled **Aluminium fluoride, at plant/RER**
- Cathode modeled with **Cathode, aluminium electrolysis/RER**
- Anode modeled with **Anode, aluminium electrolysis/RER**

Electricity and fuel

Electricity and fuel are often the major contributors to the life cycle impact of aluminium production. If data of the user is not in the appropriate format, the following table may be of used.

FUEL combustion

Coal was modeled with **Hard coal, burned in industrial furnace 1-10MW/RER**
Fuel oil was modeled with **Light fuel oil, burned in industrial furnace 1MW, non-modulating/CH**
Natural gas was modeled with **Natural gas, burned in industrial furnace >100kW/RER**
Coke was modeled with **Hard coal coke, burned in stove 5-15kW/RER**
Diesel was modeled with **Diesel, burned in building machine/GLO**
Fuel (vehicule fleet) was modeled with **Transport, van <3.5t/RER (**2.08 tkm for 1 liter of fuel)

Impact 2002+

Climate Change is represented based on the International Panel on Climate Change's 100-year weightings of the global warming potential of various substances (IPCC, 2007). Substances known to contribute to global warming are weighted based on an identified global warming potential expressed in grams of CO2 equivalents. Because the uptake and emission of CO2 from biological sources can often lead to misinterpretations of results, it is not unusual to omit this biogenic CO2 from consideration when evaluating global warming potentials.

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