AthenaInstitute

A Cradle-to-Gate Life Cycle Analysis of Curtainwall Framing Materials:

Fiberglass-Reinforced Plastic and Aluminum Mullions

Prepared for:

GlasCurtain Consortium

by:

Athena Sustainable Materials Institute

June 26, 2009

Table of Contents

1.0 Introduction

The GlasCurtain Consortium commissioned the Athena Institute to perform an environmental life cycle assessment (LCA) of a prototypical fiberglass reinforced pultrusion (FRP) curtainwall framing system and contrast its performance with that of conventional aluminum curtainwall framing.

Life cycle assessment (LCA) is a systematic approach to quantifying the environmental impacts associated with a product throughout its entire life – from initial extraction of the raw materials through manufacturing, use, and eventual disposal or recycling. A key component within the process of LCA is the life cycle inventory (LCI). An LCI tracks all the mass and energy flows from the environment as well as the emissions to air, water and solids back to the environment. Depending on the goal and scope of the study, these LCI data may be collected first-hand from manufacturing processes (primary data), or they may be based on information drawn from existing LCI databases (secondary data). Primary data is typically collected from manufacturing facilities using questionnaires, and then is modeled using an LCA software package which links primary process data and secondary background processes (e.g., electricity generation and delivery) to generate a complete life cycle inventory. With the inventory complete, the next step in the LCA process is to prepare a life cycle impact assessment (LCIA) of the modeled product system(s) to determine the environmental burden of the various input and output flows throughout the product life cycle using or across a set of impact indicators (e.g., climate change, acidification, etc).

2.0 Scope of Study

The scope of this project was streamlined to exclude processes that the two curtainwall framing product systems have in common (finishing, installation, maintenance) in order to focus the study on the differences between the two curtain wall framing materials. The following unit processes were included within the cradle-to-gate system boundaries for the two products.

1) *Upstream-manufacturing*: includes resource extraction, commodity input manufacturing, and transportation to the mullion manufacturing facility; and
2) *Primary mullion manufacturing*: includes energy and resource use, emissions to air, water and land during the fiberglass pultrusion/aluminum extrusion processes.

The life cycle assessment assumed a similar service life for both mullion materials and excluded the end-of-life effects as both products are relatively inert and do not require specific handling. However, aluminum is a readily recycled material and its recyclability has been incorporated in this study by considering the recycled content of the commodity aluminum ingot used in building products. Essentially, post-consumer aluminum is recycled back into a wide array of new products, offsetting virgin material use, via the use of secondary (recycled) aluminum in the manufacturing process.

The functional unit analyzed for the study is the production of "one lineal meter" of mullion from the cradle (earth)-to-gate (finished mullion at the manufacturing plant gate).

3.0 Life Cycle Inventory

The following figures define the product systems and boundaries for each curtainwall material alternative considered in the study.

Figure 1: Aluminum mullion production system

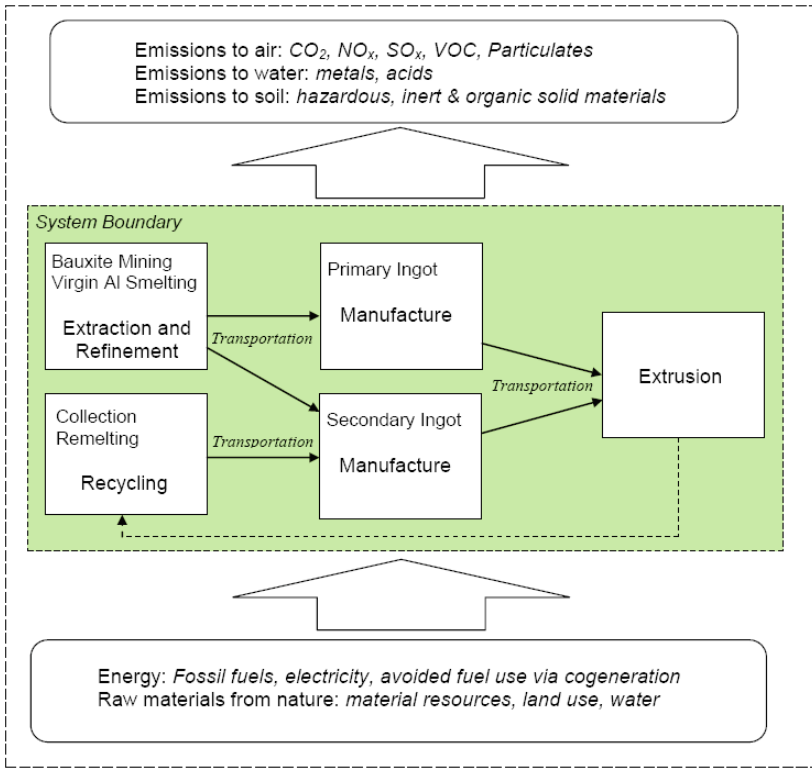
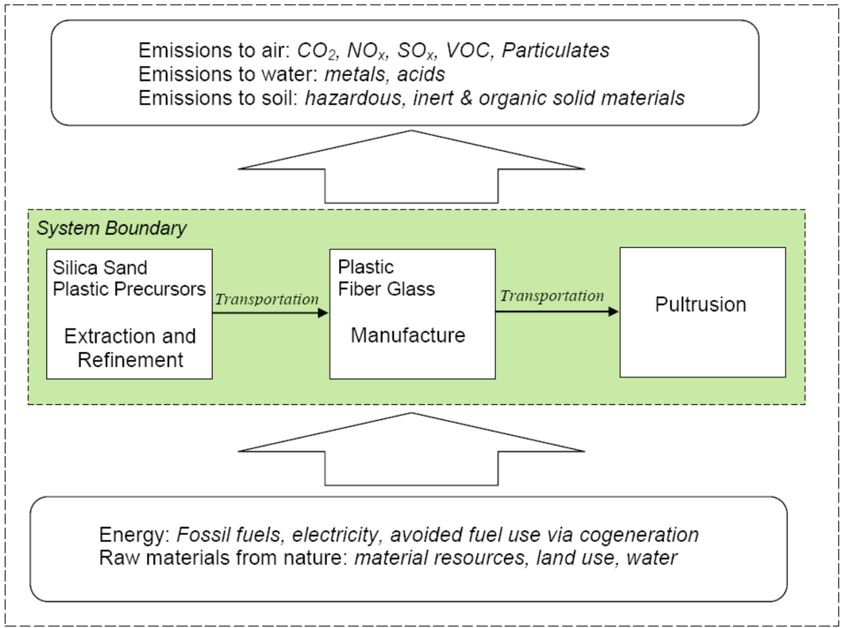


Figure 2: Fiberglass mullion production system



3.1 Manufacturing Process

The life cycle inventories were completed as a combination of primary and secondary data. Bills of materials for each curtainwall alternative were first obtained through contacts with two manufacturers (Omniglass[1] and Ferguson Glass[2]). The information they provided included the amount of material present in a lineal meter of each product on a functionally equivalent basis.

- Aluminum mullion: 2.5" x 4" section with 0.095" thick walls
- Fiberglass mullion: 2.5" x 6" section with .200" thick walls

The constituent materials that are used as inputs to manufacturing the profiles were also provided. Table 1 shows the component bill of materials for each curtainwall mullion alternative.

[1] As per Matthew de Witt, Omniglass
[2] As per Frank Babienko and Charles Kan, Ferguson Glass

Table 1: Material Inputs kg per lineal meter of mullion

	MATERIAL INPUT	AMOUNT (kg)
Fiberglass Material Inputs	Glass Fiber	2.95
	Polyethylene Resin	1.24
	Calcium Carbonate	0.41
	Polyvinyl Acetate Resin	0.28
Aluminum Material Inputs	Primary Ingot	2.04
	Secondary Ingot	0.72
	Secondary Ingot – Virgin content portion	*0.36*
	Secondary Ingot – Recycled content portion	*0.36*

To model the manufacturing process, Omniglass provided primary data for the fiberglass pultrusion process while secondary LCI data was adapted for the aluminum extrusion process. Table 2 shows the provided energy consumed during the FG pultrusion and aluminum extrusion processes.

Table 2: Manufacturing Energy inputs per lineal meter of mullion

	ENERGY SOURCE	CONSUMPTION
Fiberglass Pultrusion	Electricity (Pultrusion motor)	0.25 kWh
	Electricity (Die Heater)	0.22 kWh
Aluminum Extrusion	Electricity	5.55 kWh
	Natural Gas	0.66 m^3

3.2 Treatment of Recycling in Aluminum LCI

Aluminum is manufactured from both virgin resources (primary ingot) and recycled aluminum (secondary ingot), which may incorporate a combination of both industrial process and post-consumer aluminum scrap. The average recycled content of the product at manufacture was determined to be 17%[3] and the formula for the aluminum product mix LCI is:

[3] In 2003, 27.4 million tons of virgin aluminum were used to manufacture 33.1 million tons of products, with recycled aluminum scrap accounting for the balance (5.7 Mtons or 17.2%)-Martchek, 2006. These values were similar to the recycled content quoted by Ferguson Glass' suppliers.

$0.83\ V_{LCI} + 0.17\ R_{LCI}$

where:
V_{LCI} = LCI of cradle to commodity for virgin material (primary ingot)
R_{LCI} = LCI of aluminum scrap recycling process to produce a 100% secondary ingot

3.3 Resource Transportation to Manufacturer

Statistical average data were used to compute the transportation load of delivering the materials from the commodity manufacturer to the curtainwall frame producer. Table 3 shows the distances assumed for each of the material inputs and their total transportation loads, which are the product of the materials mass and distance, expressed on a tonne-kilometers (tkm) basis[4]. All materials are assumed to be delivered using diesel-fueled combination trucks. Transportation prior to commodity manufacturing (extraction and refinement) was included within the background secondary LCI process data.

Table 3: Transportation Data – distances and loads per lineal meter of product

	MATERIAL INPUT	DISTANCE (km)	LOAD (t-km)
Fiberglass Material Inputs	Glass Fiber[2]	716	2.11
	Polyethylene Resin[2]	372	0.46
	Calcium Carbonate[1]	107	0.04
	Polyvinyl Acetate Resin[2]	376	0.11
Aluminum Material Inputs	Primary Ingot[2]	405	0.81
	Secondary Ingot[2]	405	0.30

Sources:
1: StatCan 2000: Trucking in Canada – Catalog #053-222
2: StatCan 2003: Trucking in Canada – Catalog #353-222

3.4 Resource Extraction and Commodity Manufacturing LCI Data Sources

Several secondary data sources were used to model the production of upstream materials prior to their delivery to the frame manufacturers. These data sources either directly reflect North American practice or were modified to do so.

[4] A ton kilometer (t-km) is a unit of measure that defines transportation work as a product of the mass of the object (tons) and the distance it is hauled (kilometers).

- **USLCI.** This database is the preeminent source of life cycle inventory data currently available in North America. The USLCI database contains energy production and delivery models for thermal fuels, electricity generation, and transportation equipment. USLCI data is of recent vintage (within the last five years) and is publicly and freely available from www.nrel.gov/lci. USLCI data were used to model all energy inputs, transportation effects, aluminum profile extrusion, and were merged with European data to make these data more representative.

- **Ecoinvent.** This database contains 3,500 processes that are based on European practice and have undergone peer review. Ecoinvent data were used to model the fiberglass manufacturing process with USLCI data substituted for the energy inputs to reflect North American fuel use and conditions. (http://www.ecoinvent.ch/)

- **International Aluminum Institute.** In 2007, the International Aluminum Institute published an update of their life cycle inventory data for primary aluminum based on the 2005 production year. These data include process inputs and emissions for bauxite mining, anode and alumina manufacture, as well as smelting and ingot casting. USLCI energy data were modeled as inputs to these processes. (http://www.world-aluminium.org/)

- **European Aluminum Association.** The European Aluminum Association provided LCI data for the recycling (gathering, sorting, and bailing) as well as secondary ingot melting processes. (http://www.eaa.net/)

All manufacturing flows and upstream material and energy carriers were modeled in SimaPro v7.18 – an internationally recognized LCA software tool. The SimaPro software is capable of modeling a complete product LCI (inclusive of upstream processes) and contains various life cycle impact assessment methodologies for generating impact indicator results.

4.0 Life Cycle Impact Assessment

4.1 Methodology

The unit process LCI results for the two curtainwall mullion systems were then classified and characterized into four impact assessment indicators using the US Environmental Protection Agency (EPA)'s TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) impact assessment methodologies and factors. The life cycle impact assessment (LCIA) methodology also reports cumulative energy demand, which breaks the consumed energy for a product system into fossil and renewable sources and thereby can indicate the degree to which a product system may be depleting non-renewable fossil fuels.

Characterization results are typically compiled using a reference emission flow and multipliers or factors to equate the effect on an equivalent basis to that of the reference emission flow – e.g., all greenhouse gases are reported on a mass basis using carbon dioxide as the equivalence (eq) greenhouse gas reference flow to arrive at an overall global warming potential effect. The four selected environmental impact assessment indicators and the cumulative energy demand measure are described below.

- **Global Warming Potential (kg CO_2 eq).** The Intergovernmental Panel on Climate Change (IPCC) has made significant strides towards a uniformly accepted categorization of the greenhouse forcing potential of global warming agents. The 2007 version of their factors were incorporated in this impact assessment.

- **Acidification Potential (H+ moles eq.).** Acidification affects fresh water and forest ecosystems and causes human health effects when high concentrations of sulphur dioxide are attained. Acid rain generally causes increases in the alkalinity of soils and freshwater lakes that is measured in terms of the hydrogen ions that are produced as a result of different acid emissions as described in TRACI characterization factors.

- **Smog Potential (kg NO_x eq.).** Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog. The TRACI characterization of smog precursors is based on their intensities relative to nitrogen oxides, the most prevalent smog sources.

- **Eutrophication Potential (kg N eq.).** Eutrophication is the effect of over-fertilization of soil and water ecosystems caused by atmospheric emissions. Algae blooms that result in foul odors and eventual depletion of fish are symptoms of eutrophication. The TRACI characterization of eutrophication agents is based on their equivalence to nitrogen.

- **Cumulative Energy Demand (MJ).** Energy accounting is generally conducted to determine the total demand of a system on renewable and non-renewable sources. This convention is maintained here with totals given for each.

5.0 Results

Table 1 indicates that the fiberglass mullion is about 40% more resource intensive than its more conventional aluminum counterpart. However, the process of extruding aluminum is considerably more energy intensive than the fiberglass pultrusion process. Given the higher mass of the fiberglass mullion it is not surprising that it requires more than twice the transportation of raw resources as that of the conventional aluminum mullion. The complete cradle-to-gate LCIA results for one meter of aluminum and fiberglass curtainwall mullion are shown in Table 4 and Table 5, respectively.

For the aluminum profile (Table 4), roughly 75% of the energy use in the life cycle is used to manufacture aluminum ingot from virgin resources. The extrusion process is the next most burdensome process – higher than recycled aluminum production. Resource transportation is found to be a minor contributor to the overall profile. The results in the other impact categories correlate closely with the energy use as most are the direct result of fossil fuel combustion and related emissions.

For the fiberglass mullion profile, glass fiber production contributes 50% of the energy and is the most significant contributor to the other impacts (see Table 5). Greater than 70% of greenhouse gases are emitted in the glass fiber manufacture with process emissions (limestone oxidation) causing the increased significance in this category. High density polyetylene (HDPE) production is the next most significant contributor to the overall fiberglass mullion environmental profile. The fiberglass pultrusion process itself ranks as a minor contributor to the overall environmental profile for the fiberglass mullion.

Table 4: LCIA Results for 1 meter of aluminum curtainwall mullion profile

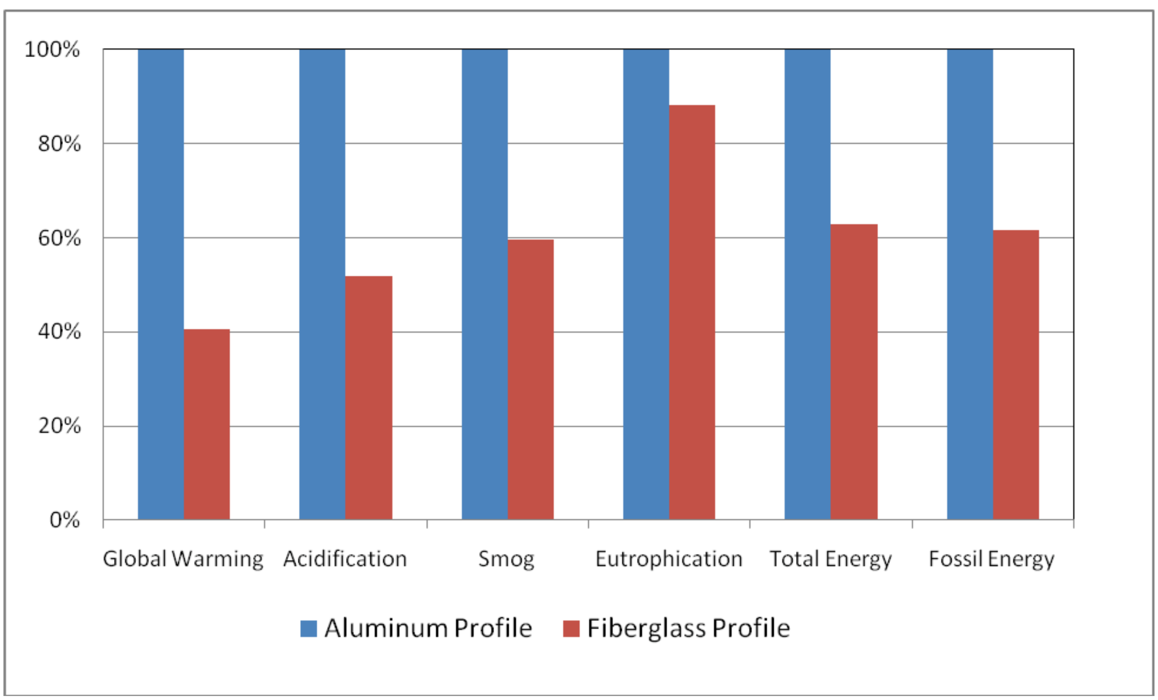
Impact Category	Unit	Total Profile per Meter	Virgin Aluminum Embodied	Recycled Aluminum Embodied	Delivery of Inputs	Extrusion
Global Warming	kg CO2 eq	30.05	23.76	0.28	0.10	5.91
Acidification	H+ moles eq	14.53	11.82	0.03	0.03	2.64
Smog	kg NOx eq	8.06E-02	6.23E-02	3.30E-04	7.10E-04	1.72E-02
Eutrophication	kg N eq	3.49E-03	2.82E-03	1.66E-05	3.27E-05	6.25E-04
Total Energy	MJ eq	442.46	334.77	4.23	1.42	102.05
Non renewable, fossil	MJ eq	421.87	328.24	3.70	1.40	88.53
Non-renewable, nuclear	MJ eq	20.49	6.50	0.46	0.01	13.52
Total Renewable	MJ eq	0.10	0.03	0.07	0.00	0.00

Table 5: LCIA Results for 1 meter of fiberglass curtainwall mullion profile

Impact Category	Unit	Total Profile per Meter	Glass Fiber Embodied	HDPE Resin Embodied	Other inputs Embodied	Delivery of Inputs	Pultrusion
Global Warming	kg CO2 eq	12.16	8.60	1.62	0.34	1.24	0.36
Acidification	H+ moles eq	7.55	4.61	1.95	0.41	0.41	0.16
Smog	kg NOx eq	4.79E-02	3.31E-02	4.01E-03	9.58E-04	8.54E-03	1.29E-03
Eutrophication	kg N eq	3.08E-03	2.28E-03	2.94E-04	6.84E-05	3.94E-04	4.30E-05
Total Energy	MJ eq	278.10	138.51	95.37	20.99	17.03	6.20
Non renewable, fossil	MJ eq	260.42	123.48	94.25	20.72	16.89	5.08
Non-renewable, nuclear	MJ eq	17.00	14.34	1.12	0.27	0.14	1.12
Total Renewable	MJ eq	0.68	0.68	0.00	0.00	0.00	0.00

The LCIA results of the two cradle-to-gate systems were then compared and the results are shown in Figure 3. As each impact indicator uses different units, showing all results on one graph required setting the aluminum mullion results to one and then normalizing the fiberglass mullion results as a percentage of the aluminum total.

Figure 3: Comparison graph of aluminum and fiberglass profile



The results indicate a strong preference for the fiberglass mullion profile. Across each indicator measure the fiberglass mullion profile demonstrates a lower cradle-to-gate environmental impact. Depending on the impact indicator of interest, the fiberglass mullion results are between 40% to 90% of the aluminum mullion environmental burden results.

6.0 References

Martchek, 2006. Modelling More Sustainable Aluminium, *Int. J. LCA*, **11**(1) www.alcoa.com/global/en/about_alcoa/sustainability/pdfs/KMartchek_IJLCA_7772.pdf

StatCan 2000. Statistics Canada, Trucking in Canada, Catalog # 053-222, Ottawa, Ontario, Canada. Retrieved on June 20, 2009 from http://www.statcan.gc.ca/pub/53-222-x/53-222-x2000000-eng.pdf

StatCan 2003. Statistics Canada, Trucking in Canada, Catalog # 353-222, Ottawa, Ontario, Canada. Retrieved on June 20, 2009 from http://www.statcan.gc.ca/pub/53-222-x/53-222-x2003000-eng.pdf

Jane C. Bare, Gregory A. Norris, David W. Pennington, and Thomas McKone, 2003. TRACI-The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, Journal of Industrial Ecology, Volume 6, Number 3–4, 2003. Updated in 2007 via personal correspondence with Jane Bare.