Research & Development Summary

Value to Wood

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Life Cycle Analysis of Windows for North American Residential Market

Assessing the environmental impacts of products and processes has become progressively more important in recent years due to the increased environmental awareness of the general public, industries and governments. Many industries have attempted to minimize the environmental impacts of their activities by providing "green" products and using "green" processes. In particular, the building sector has been recognized as a significant resource consumer and waste generator in North America. Buildings in Canada consume one-third of our energy and 50% of the extracted natural resources while generating 25% of our landfill waste and 35% of our greenhouse gases[i].

Windows are important elements of a building and account for 10 to 25% of a building's exposed surface[ii]. They perform multiple functions in a building envelope, acting as an interface to transmit light, circulate air, and provide outdoor views. While windows are available in different designs and sizes, their main components include the frame, sash and insulated glazed unit. Window frames can be made from wood, PVC, aluminum, fibreglass, and wood composites, or a combination of these materials. Windows have a fairly long lifetime, and may account for up to 25% of the heat lost in a residential building[iii]. As windows are significant components in the design of a building, this study focused on evaluating the environmental impacts of different window types.

The assessment of environmental effects of a product should be done using a holistic method that considers the entire life cycle of the product. Life cycle assessment (LCA) is a quantitative technique for evaluating the resource use and associated environmental impacts of a product from "cradle to grave". It considers all stages of a product from resource extraction and commodity manufacturing, through to secondary manufacturing, use, maintenance and end of life. *Figure 1* shows the life cycle of a window and its related product system.

As there were no published LCAs on fibreglass windows or any windows specifically designed and manufactured for the North American residential market, this research evaluated and compared the environmental impacts of windows made from aluminum clad wood, PVC and fibreglass for the North

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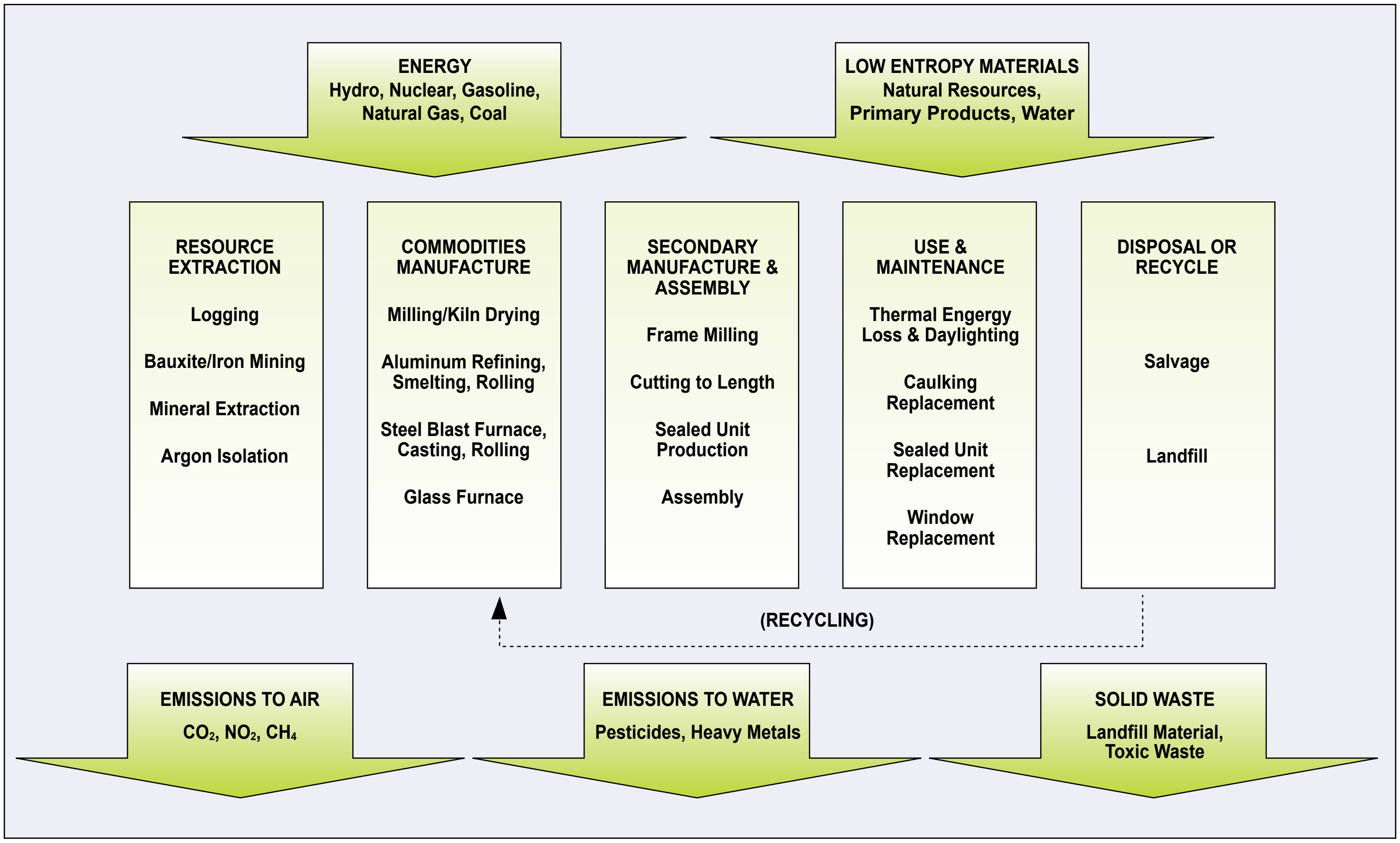

Figure 1: Life Cycle of a window.

American residential market using LCA. To do so, inventory data on manufacturing of these windows were gathered from three window producers in Canada, while available datasets were adapted for other life stages to complete the life cycle inventory.

As the function of a window is reliant on its installation in a complete structure, its service over the life cycle of the building was used to determine the impacts. The functional unit was defined as 75 years of service provided by a commonly sized and outfitted window, described as follows:

- Size: 600 mm x 1200 mm
- Style: Casement
- Glazing: Double glazed sealed unit with Low-emissivity glass
- Frame Profile: Standard frame profile for North American market
- Operability:
- Length of Service: 75 years
- Maintenance: Sealed Unit Replacements and Recaulking

The LCA study included all life stages from raw material extraction and commodity manufacturing to product manufacturing, installation, maintenance and disposal at the end of life.

Results

Table 1 depicts nine different impact categories, and the amount which each window contributes to that impact over its life cycle, from resource extraction to manufacturing through to end of life. The categories are as follows:

- **Greenhouse gases**: gases (such as carbon dioxide, methane, water vapour, nitrous oxide, ozone and halocarbons), which trap heat from the sun. Measured in kilograms of carbon dioxide.
- **Ozone layer depletion**: free radical catalysts (including nitric oxide, hydroxyl, atomic chlorine, and atomic bromine), which can negatively affect the ozone layer which protects the earth from ultraviolet light. Measured in grams of trichlorofluoromethane.
- **Acidification**: substances such as sulphur dioxide and nitrogen oxides, produced by burning fossil fuels, which lead to acid deposition (acid rain).
- **Eutrophication**: an increase in an ecosystem's chemical nutrients by compounds containing nitrogen or phosphorus, which may lead to excessive plant growth and decay, reductions in oxygen, and severe reductions in water quality and fish and animal populations. Measured in grams of phosphate.

- **Heavy metals**: metals with relatively high atomic weights, (such as lead, mercury, chromium and cadmium), which may be toxic in low concentrations. Two non -metals, arsenic and selenium, are also referred to as heavy metals.
- **Carcinogens**: substances or radiation directly implicated in the promotion of cancer. Measured in grams of benzo(a)pyrene.
- **Winter smog**: Smog particles are generally produced by products of incomplete combustion (such as vehicular and industrial emissions), which react with sunlight in the atmosphere to form secondary pollutants. Measured in kg of suspended particulate matter.
- **Summer smog**: formed when heat from the sun causes ozone to build up in the troposphere, by combining nitrogen oxides and volatile organic compounds. Measured in grams of ethylene.
- **Energy resources**: energy consumed, measured in gigajoules of lower heating value.
- **Solid waste**: materials incinerated or disposed in landfills.

Analyzing the impact results of different life stages of a window revealed that more than one-third of greenhouse gases produced by each window is related to energy use during the manufacturing stage.

IMPACT CATEGORY	UNIT	ALUMINUM CLAD WOOD WINDOW	PVC WINDOW	FIBREGLASS WINDOW
Greenhouse gases	kg CO_2	498	529	411
Ozone layer	g CFC_{11}	0.046	0.031	0.036
Acidification	kg SO_2	4.03	4.88	4.03
Eutrophication	g PO_4	428	551	433
Heavy metals	g Pb	42.1	75.6	51.1
Carcinogens	g B(a)P	0.004	0.004	0.005
Winter smog	kg SPM	2.98	3.65	3.1
Summer smog	g C_2H_4	267	322	523
Energy resources	GJ LHV	7.00	8.92	7.12
Solid waste	kg	91.8	98.4	47.8

Table1: Cradle to Grave Impacts for Clad Wood, PVC, and Fibreglass Windows.

The impact results indicate that no single window is superior in all categories. The aluminum clad wood window has the least life cycle impact compared to other windows based on acidification, eutrophication, heavy metals, winter smog, summer smog and energy resources categories. The fibreglass window has an advantage over other windows in terms of greenhouse gas effects, acidification and solid waste, while the PVC window is superior only based on ozone layer depletion.

Different sensitivity analyses were done to find out how the impact results would change with a change in cladding material, service life and energy allocation during manufacturing.

Application of Results

Based on the results, no single window is superior in all impact categories. The analysis showed that more than one-third of greenhouse gas generated during the life cycle of each window is related to the energy use during the manufacturing stage. Therefore, window producers should find ways to reduce their energy consumption. As a major portion of the energy is used for heating by these companies, improving the energy efficiency of their buildings is an important issue.

According to the sensitivity analysis results, the service life of a window is an important parameter in the life cycle model and affects the impact results. Thus, it is crucial to design and produce durable windows that require less maintenance and fewer replacements. This would consequently reduce the environmental impacts of windows.

The use of recycled materials in the production of windows reduces wastes. Our analysis showed that using recycled aluminum for cladding the wood widow reduces the greenhouse gases, acidification, eutrophication, winter smog and energy resource impacts significantly. Utilizing PVC or fibreglass cladding for the wood window diminished the life cycle impacts considerably. The PVC window was significantly affected by the more frequent replacement schedule that was assumed. The PVC window also caused greater emissions of heavy metals than the other two windows – directly caused by the PVC material processes. The heavy metals are caused by lead and mercury that are emitted during the PVC manufacturing process.

The fibreglass window was the least energy intensive option over the entire life cycle. This is due to the low embodied energy of a fibreglass window, and its durability that necessitates less frequent replacement than PVC. The fibreglass window also caused the least solid waste over the life cycle, however it generated significantly greater summer smog than the other windows. This is caused by the use of polystyrene during the pultrusion process.

It should be mentioned that the findings of this study are based on the data and assumptions used in the life cycle model. The uncertainty was addressed by performing different sensitivity

analyses. This study only considered the manufacturing process at three facilities that have different production process. The study could be improved by conducting an industry wide survey to use industry averages for material and energy flows in the manufacturing stage of the life cycle model.

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