A Life Cycle Assessment Approach in Examining Composite Raw Materials, Steel and Aluminum Materials Used in the Manufacturing of Structural Components

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Executive Summary

Strongwell is a privately owned company that manufactures a wide variety of pultruded parts in the composites market. This life cycle analysis report is Strongwell's first effort in developing a "green" message for their pultruded, composite products. Strongwell's competitors that make parts from steel, aluminum, and/or wood have been active in promoting the "Green" attributes of their products.

The goal of this project was to perform a cradle to gate (up to part manufacturing) analysis of pultruded product components versus competitors like product parts using life cycle assessment tools in order to quantify the "green" or life cycle attributes of the different raw materials.
Product component types analyzed were; grating, handrail, channel and floor plating.

The major focus for the results is on the embodied energy for the major raw materials considered in the study.

The final analysis shows that components made from composite-glass type materials have a major advantage over aluminum materials that contain no recycle component. As the recycle component for aluminum is increased, the advantage gap narrows significantly as the recycle content approaches 100%. A full cradle to grave life cycle assessment would have to be performed to determine the final comparative impact assessment.

The analysis indicated that the impact assessment burden between composite-glass and steel when used as raw materials has a narrow gap. The composite-glass advantage is due to the component weight of the products with the functional unit. The database used for the analysis did not contain data for steel with recycle content. Logic would dictate that if the steel with recycle is used, the life cycle assessment for raw material embodied energy could favor the steel component. As in the case of using aluminum, a full cradle to grave life cycle assessment would be beneficial to determine the overall impact assessment of the product.

The analysis for composite-glass versus wood indicates that wood has a clear advantage for the embodied energy of the raw materials. As in the case of the other raw materials examined, a full cradle to grave life cycle assessment would need to be performed to determine a final comparative impact assessment.

Introduction

General Project Introduction:

Strongwell is a privately owned company that manufactures a wide variety of pultruded parts in the composites market. Strongwell's competitors that make parts from steel, aluminum, and/or wood have been active in promoting the "Green" attributes of their products and Strongwell decided they needed to develop a "Green" message for their pultruded profiles.

The goal of this project was to perform a cradle to gate (up to part manufacturing) analysis of pultruded product components versus like product parts, which can be made from steel, aluminum and/or wood, using life cycle assessment tools in order to quantify the "green" or life cycle attributes of the different raw materials.

Goal

The goal of this project was to perform a cradle to gate (up to part manufacturing) analysis of pultruded product components versus competitors like product parts using life cycle assessment tools in order to quantify the "green" or life cycle attributes of the different raw materials.
Product component types analyzed were; grating, handrail, channel and floor plating.

Intended Uses

The results from this study will be used by the management of Strongwell in developing their products' "green" marketing message.

General LCA Use Limitations

LCA should not be considered the only source of environmental information relating to environmental performance of a product or process. Risk assessment and other tools or types of studies/assessments should also be taken into account when making decisions on or changes to a product or process.

Another limitation to LCA is the varying quality of data used. Because it is not feasible to collect facility-specific, or primary, data for each and every one of the many processes and materials in an LCA, it is normal and necessary to use publicly available or secondary, data for some processes. Secondary data may not always be available to exactly represent the temporal, geographical, and technological profile of the supply chain for specific systems being studied, resulting in some factor of error (usually unquantifiable given the hundreds of processes linked together in a life cycle system). Limitations specific to this study are addressed in the appropriate sections of this report.

Scope and Product Part Definitions

Summary of the Project Scope

The project scope consisted of performing a cradle to gate (up to manufacture of parts) analysis of the major raw materials used by Strongwell pultrusion process versus the major raw materials of steel, aluminum and wood as used by non-composite manufacturers. This study included the mining and manufacturing of the raw materials and the transportation of these materials to the manufacturer. Strongwell's management provided information on their five components and the appropriate competitor's products, which was used in the analysis. The analysis was performed by using the Pre`SimaPro-7 Life Cycle Assessment software.

Raw Material Definitions and Definition of Parts

Strongwell manufactures a wide variety of composite pultruded parts and products for the commercial market. The main raw material ingredients of a pultruded part consist of composite glass and a polyester resin. The ratio of glass to resin is varied among the different products in order to provide the required product performance characteristics.
Non-composite competitors make these parts from steel, aluminum and/or wood. For two of the part comparisons, the study examines aluminum supply that was virgin, containing 50% recycle and containing 80% recycle.

The following designs are compared in this study:

Grating

- DURATEK® FRP Grating consists of 61% glass and 39% resin/additives. Weight is 3.0 Lbs/ft2
- Steel Grating 1-1/2" X 3/16" bar. Weight is 10.94 Lbs/ft2
- Aluminum Grating 1-1/2" x 3/16" bar. Weight is 3.90 Lb/ft2

Functional Unit used for study was 100 square foot of grating.

Handrail

- SAFRAIL™ FRP Handrail consists of 55% glass and 45% resin/additives. Weight is 3.0 Lb/ft
- Steel Handrail – weight is 10.2 Lb/ft
- Aluminum Handrail – weight is 3.6 Lb/ft

Functional Unit used for study was 100 linear feet of handrail.

Channel

- EXTREN® 525 Channel consists of 55% glass and 45% resin/additives. Weight is 5.5 Lbs/ft
- Steel Channel – weight is 15.3 Lbs/ft

Functional Unit used in study was 100 linear feet of channel

Channel & Tubing

- EXTREN® Channel in 3 sizes, composition is 55% glass and 45% resin/additives. Channel sizes are;
  - 3-1/2" x 1-1/2" x 3/16" with a product weight of 0.9 Lbs/ft.
  - 5-1/2" x 1-1/2" x 3/16" with a product weight of 1.29 Lb/ft.
  - Square tube of 3-1/2" X 3-1/2' X 1/4"' with a product weight of 2.57 Lbs/ft.

- Wood Products are;
  - 2" x 4" pine at 1.47 Lb/ft.
  - 2" x 6" pine at 2.2 Lb/ft.
  - 4" X 4" Pine at 2.57 Lbs/ft

Functional Unit used in study was 100 linear feet.

Floor Plate

- EXTREN ® SAFPLATE ® consists of 55% glass and 45% resin/additives. Weight is 2.34 Lbs/ft2
- Steel Plate 1/4" thick. Weight is 11.26 Lbs/ft2
- Aluminum Plate 1/4" thick. Weight is 3.7 Lbs/ft2

Functional Unit used in study was 100 square feet of floor plate.

Material Description Basis

- Composite Glass: Advantex Glass manufactured by Owens Corning. Supplying facility used is the Amarillo, Texas Plant. Data on glass is from the 2007 Owens Corning Global Footprint LCA.
- Polyester Resin: Based on information as provided by Strongwell, the resin used consisted of unsaturated polyester resin and styrene, with a filler consisting of antimony, decabromodiphenyl oxide fire retardant, and clay, and miscellaneous additives of a titanium dioxide, pigments and release agents.
- A517I Steel from SimaPro LCA database: World average data, delivery in Rotterdam. For detailed information about the alloy elements see the specific records. These steel grades have very low carbon concentration (<< 0.1%). They are characterized by their properties and not by the composition. The structure of the steel is optimized for deep drawability. These materials are always supplied in sheet form. Weld ability is not an issue.
- Aluminum, 3 grades, 0% recycle, 50% recycle and 80% recycle. Data for these materials was from the SimaPro database.

1. Production of aluminium ingots from 50% virgin aluminium and 50% scrap by re-melting and casting of plain scrap from production waste (extrusion discards, sheet edge trim, turnings and millings) or plain post consumer scraps. Data derived from EAA (1993). Data for virgin aluminium are based on 40% production in Canada and 60% production in Western Europe and are representative for Switzerland.
2. Production of aluminium ingots from 75% virgin aluminium and 25% scrap by re-melting and casting of plain scrap from production waste (extrusion discards, sheet edge trim, turnings and millings) or plain post consumer scraps. Data derived from EAA (1993). Data for virgin aluminium are based on 40% production in Canada and 60% production in Western Europe and are representative for Switzerland.

3. Aluminum with 0% recycle: LCA for production of primary aluminium in Europe, transport included. Average data.

- Wood Products: Cradle-to-mill gate to produce 1000 board-feet of kiln-dried lumber. 1 bd-foot = 1.94 lbs.

This study did not include any materials or other products required in the assembly of the end use product. E.g. no welding or other assembly impacts such as fittings or additional hardware were considered in the study.

System Boundaries

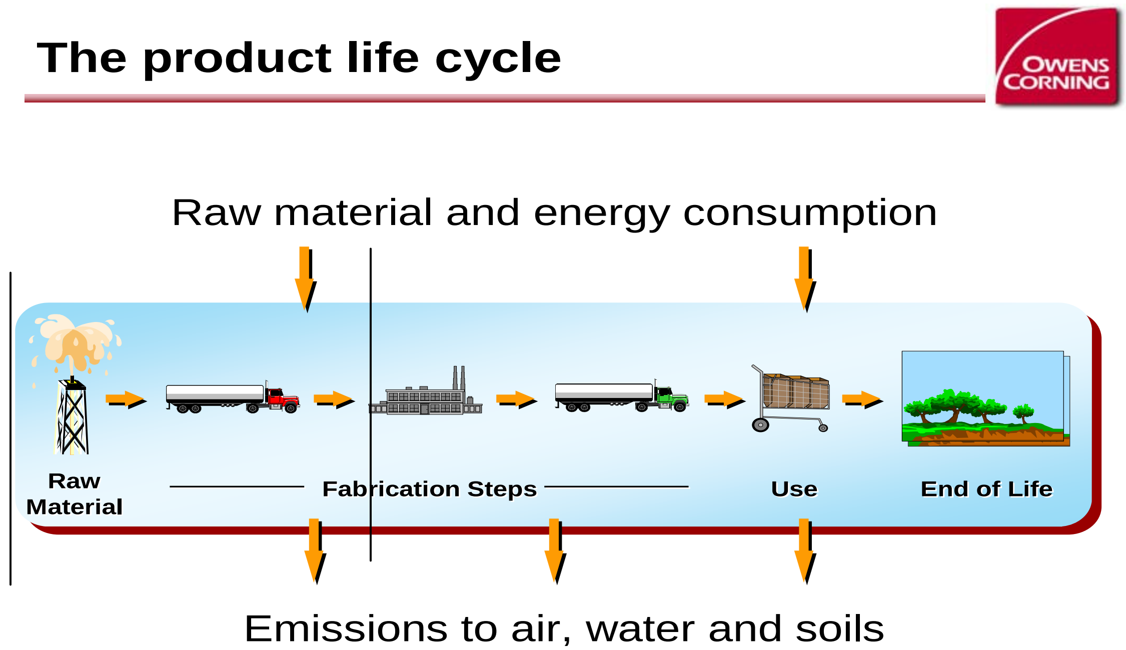

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Figure 1: General Life Cycle

Composite Materials

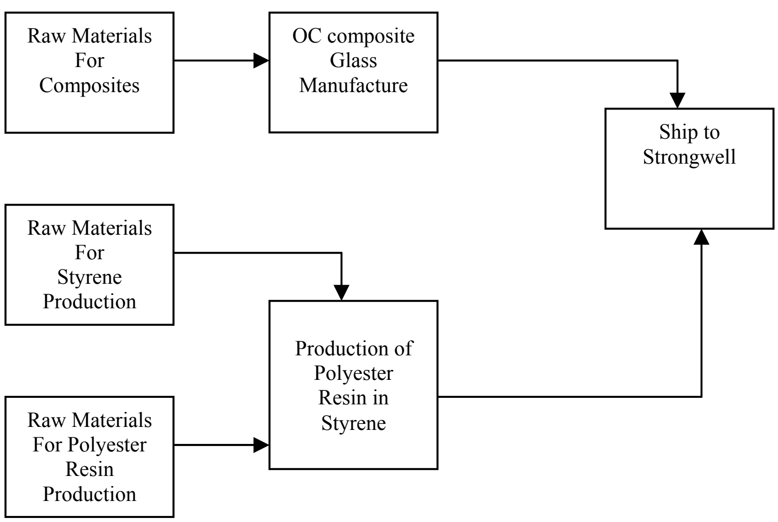

Figure 2: Block Flow Boundary for Major Raw Material Constituents of Composite.

Sheet Steel Materials

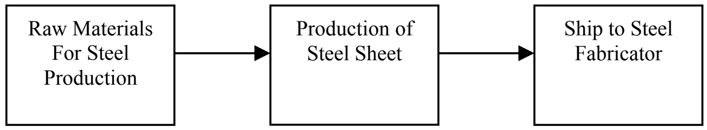

Figure 3: Block Flow Boundary for Steel Raw Materials and Sheet Steel Production

Aluminum Ingot Materials

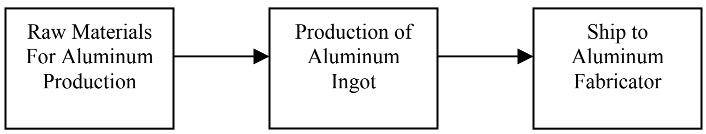

Figure 4: Block Flow Boundary for Aluminum Raw materials and Ingot Production

Pine Wood Materials

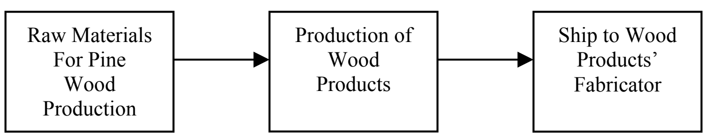

Figure 5: Block flow Boundary for Wood Product's Production

Methodology and Modeling Tools Used

Methodology

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental impacts of a product through its life cycle from extraction of raw materials through end-of-life product disposal, in accordance with the stated goal and scope. The International Organization of Standardization (ISO) developed a set of guidelines for conducting LCA. The four main parts of an LCA according to the ISO 14040 series of guidelines include:

1. **Goal and Scope definition:** specifying the reason for conducting the study, intended use of study results, intended audience, system boundaries, data requirements, and study limitations.
2. **Life Cycle Inventory (LCI):** collecting, validating and aggregating input and output data to quantify material use, energy use, environmental discharges, and waste associated with each life cycle stage.
3. **Life Cycle Impact Assessment (LCIA):** using impact categories, category indicators, characterization models, equivalency factors, and weighting values to translate an inventory into potential impact on the environment.
4. **Interpretation**: assessing whether results are in line with project goals, providing an unbiased summary of results, defining significant impacts, and recommending methods for reducing material use and environmental burdens.

This analysis adheres to the guidelines set forth in the International Organization for Standardization (ISO) 14044; however, it is focused solely on the raw materials extraction and acquisition portion of the life cycle.

Modeling Tools Used

The models in this study were constructed using SimaPro 7, a commercial LCA software product. The processes from the standard U.S. and European databases included with the software were used, with modification as needed.

Publicly available web-based MapQuest program was used to calculate truck shipping distance between cities where needed.

No allocation was needed for this study.

Data Categories & Life Cycle Impact Assessment

Summary of Data Categories

Impact Category	Unit	Source of Result
Greenhouse Gas (GHG)	kg CO2 Eqiv.	IPCC GWP 100a
Eutrification	kg N Equiv.	TRACI
Ozone Depletion	kg CFC-11 Equiv.	TRACI
Smog Formation	kg NOx Equiv.	TRACI
Metered Water	Kg	EPS 2000 V2.2
Acidification kg	H+ molecules	TRACI
Energy MJ-Equiv.		Cumulative Energy Demand 1.01

Table 1: Impact Assessment Method

Impact Assessment Limitations

There are some limitations of LCIA, including the following;

1. Spatial and temporal resolution is lost in an LCA. When emissions are normalized to a functional unit (e.g. 100 square feet of floor plating), all temporal and geographical characteristics which are needed to assess local environmental impacts are lost. LCA results do not distinguish between emissions released instantaneously and locally and those released over a large geographical area over a long period of time.
2. Threshold effects are lost in an LCA. LCA is based on linear extrapolation of mass loadings with the assumption that this loading contributes to an environmental effect. This is contrary to threshold-driven environmental and toxicology mechanisms. Thus, while a linear extrapolation of mass loading is a reasonable approach for more global and regional impact categories such as GWP (GHG) and acidification, it is not as appropriate a measure for human-health and toxicity-related impacts.

Results

DURADEK® vs. Steel Grating and Aluminum Grating

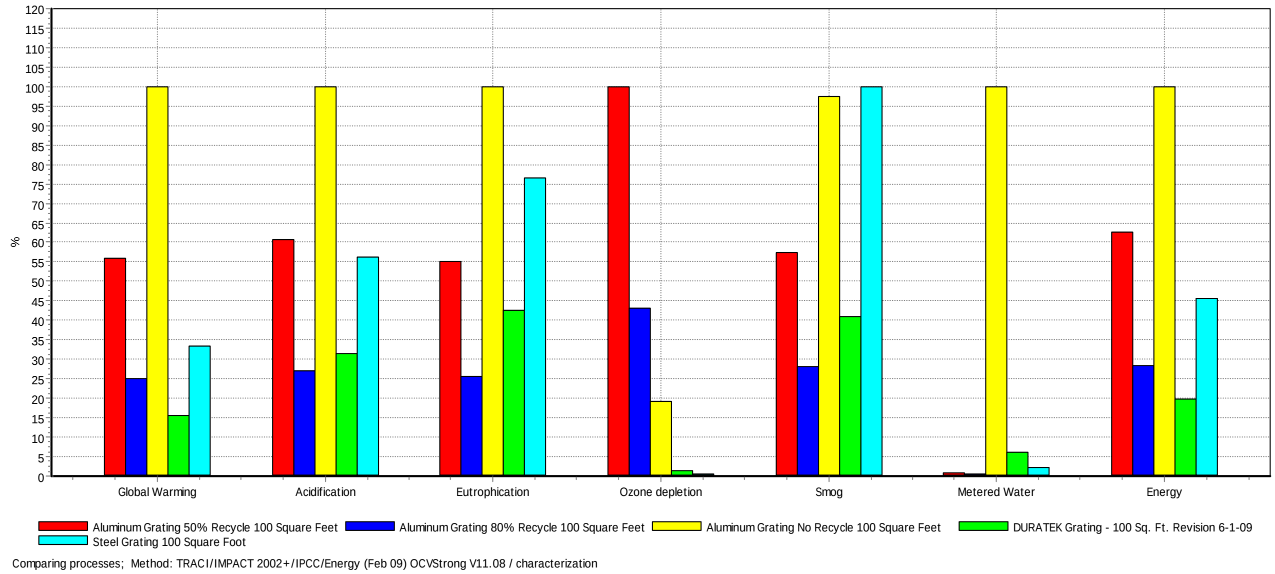

Figure 6: Impacts by Material Type for Grating

Title:	Comparing Processes for Gratings
Method:	TRACI/IMPACT 2002+/IPCC/Energy (Feb 09) OCVStrong V11.08
Indicator:	Characterization
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	Aluminum Grating 50% Recycle 100 Square Feet	Aluminum Grating 80% Recycle 100 Square Feet	Aluminum Grating No Recycle 100 Square Feet	DURATEK Grating - 100 Sq. Ft. Revision 6-1-09	Steel Grating 100 Square Foot
Global Warming	kg CO2 eq	1022.3732	459.78668	1826.1028	282.35199	612.65082
Acidification	H+ moles eq	320.2812	142.49761	528.16345	166.7845	296.90526
Eutrophication	kg N eq	0.10900725	0.05101498	0.19814229	0.08428409	0.15174252
Ozone depletion	kg CFC-11 eq	0.000324795	0.0001399	6.25E-05	4.13E-06	1.86E-06
Smog	kg NOx eq	1.6536951	0.80609973	2.8078751	1.1814648	2.8785404
Metered Water	kg	272.4276	199.89817	29338.268	1810.2361	620.95274
Energy	MJ-Eq	16420.019	7475.7648	26219.363	5219.3374	11949.755

Chart 2: Impacts by Material Type for Grating

SAFRAIL™FRP Handrail vs. Steel and Aluminum Handrail

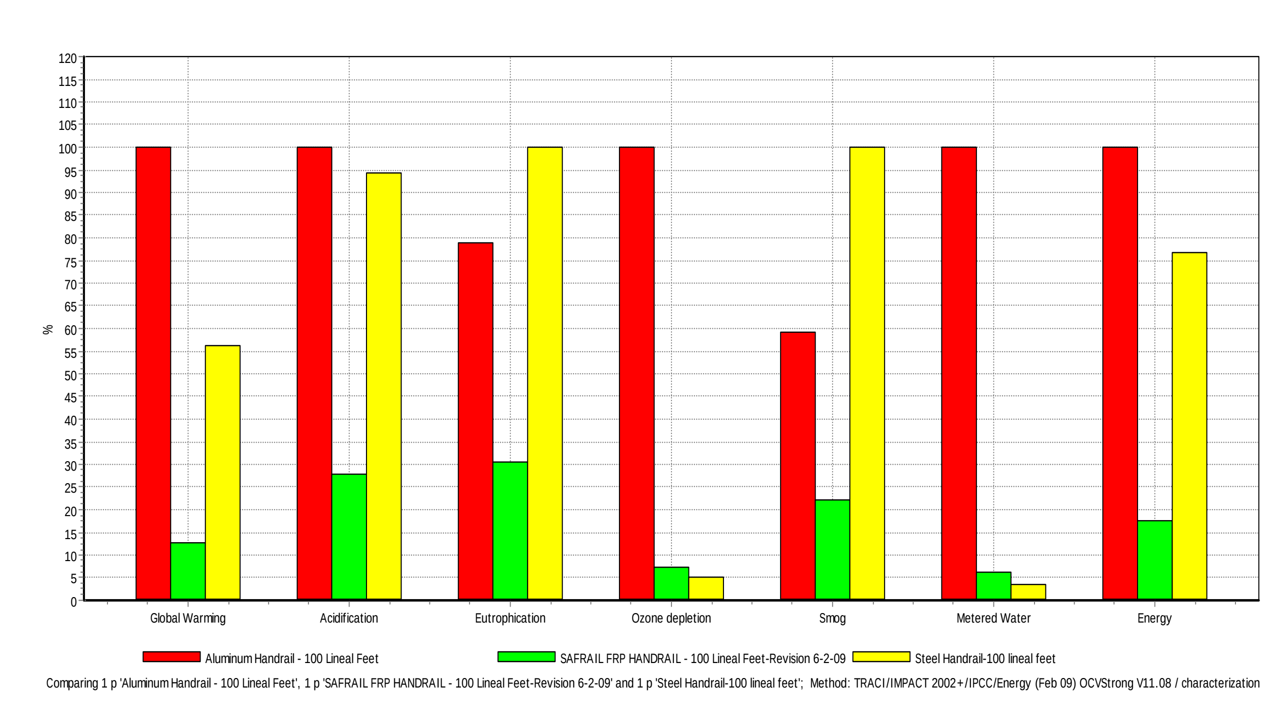

Figure 7: Impacts by Material Type for Handrail

Title:	Comparing 1 p 'Aluminum Handrail - 100 Lineal Feet', 1 p 'SAFRAIL FRP HANDRAIL, - 100 Lineal Feet-Revision 6-2-09' and 1 p 'Steel Handrail-100 lineal feet'
Method:	TRACI/IMPACT 2002+/IPCC/Energy (Feb 09) OCVStrong V11.08
Indicator:	Characterization
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	Aluminum Handrail - 100 Lineal Feet	SAFRAIL FRP HANDRAIL - 100 Lineal Feet-Revision 6-2-09	Steel Handrail-100 lineal feet
Global Warming	kg CO2 eq	2188.6774	280.85583	1229.1996
Acidification	H+ moles eq	632.56303	175.58965	596.25914
Eutrophication	kg N eq	0.2367617	0.09142527	0.30042656
Ozone depletion	kg CFC-11 eq	7.50E-05	5.48E-06	3.81E-06
Smog	kg NOx eq	3.346515	1.2487866	5.6559019
Metered Water	kg	35205.921	2145.3287	1276.3672
Energy	MJ-Eq	31426.952	5491.3782	24149.898

Chart 3: Impacts by Material Type for Handrail

EXTREN®525 Channel vs. Steel Channel

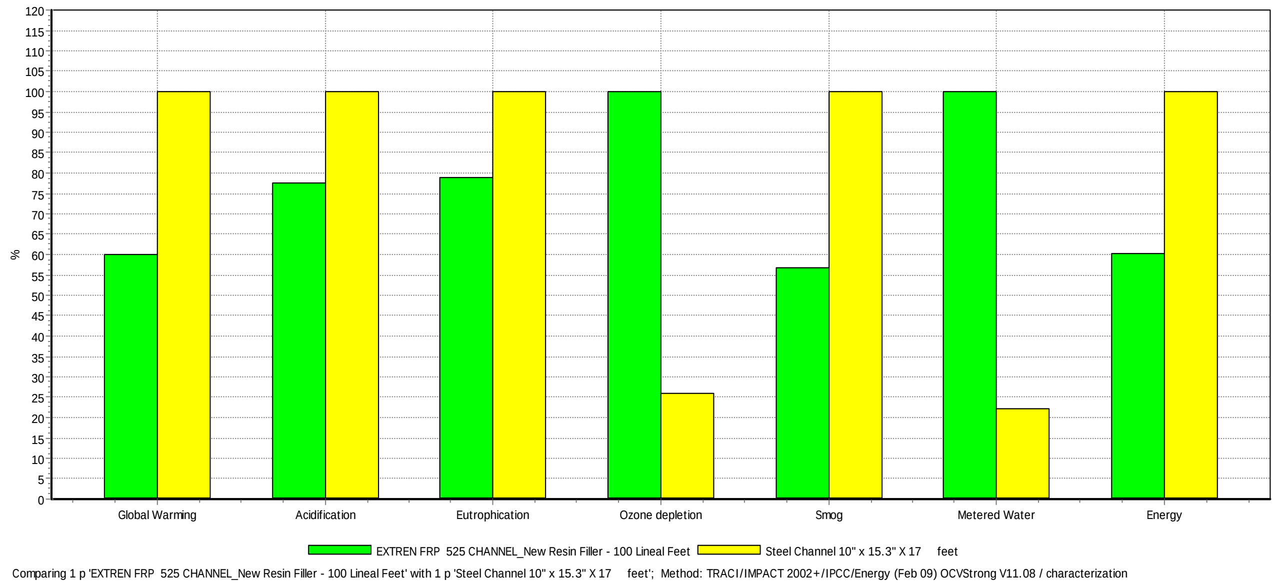

Figure 8: Impact by Material Types for Large Channel

Title:	Comparing 1 p 'EXTREN FRP 525 CHANNEL_New Resin Filler 100 Lineal Feet' with 1 p 'Steel Channel 10" x 15.3" X 17 foot'
Method:	TRACI/IMPACT 2002+/IPCC/Energy (Feb 09) OCVStrong V11.08
Indicator:	Characterization
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	EXTREN FRP 525 CHANNEL_New Resin Filler - 100 Lineal Feet	Steel Channel 10" x 15.3" X 100 foot
Global Warming	kg CO2 eq	514.89836	856.81513
Acidification	H+ moles eq	321.91249	415.23314
Eutrophication	kg N eq	0.16761147	0.21221761
Ozone depletion	kg CFC-11 eq	1.00E-05	2.60E-06
Smog	kg NOx eq	2.2894075	4.0257466
Metered Water	kg	3933.1027	868.42567
Energy	MJ-Eq	10067.472	16712.18

Chart 4: Impacts by Material Type for Large Channel

EXTREN®FRP Channel vs. Pine Framing

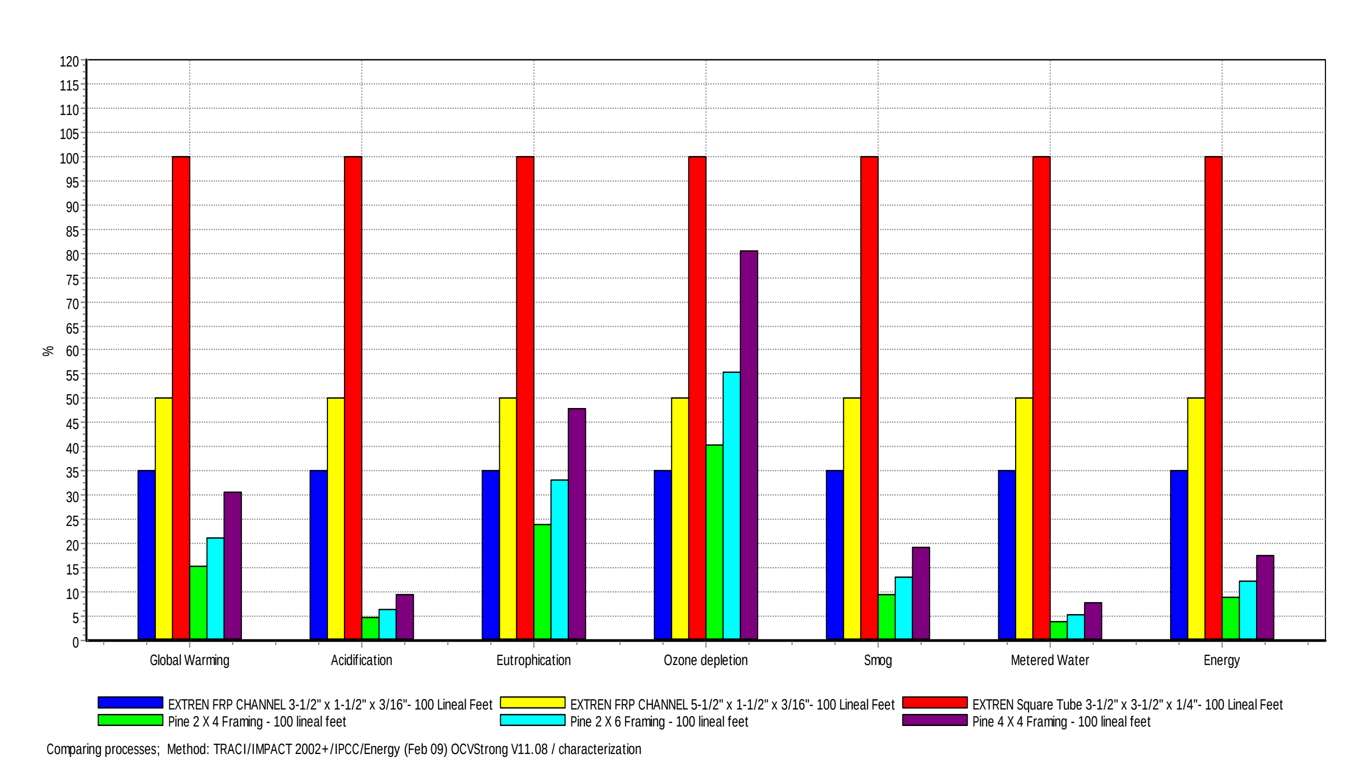

Figure 9: Impact of Material Types for Framing

Title:	Comparing processes
Method:	TRACI/IMPACT 2002+/IPCC/Energy (Feb 09) OCVStrong V11.08
Indicator:	Characterization
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	EXTREN FRP CHANNEL 3-1/2" x 1-1/2" x 3/16"- 100 Lineal Feet	EXTREN FRP CHANNEL 5-1/2" x 1-1/2" x 3/16"- 100 Lineal Feet	EXTREN Sq. Tube 3-1/2" x 3-1/2" x 1/4"- 100 Lineal Feet	Pine 2 X 4 Framing - 100 lineal feet	Pine 2 X 6 Framing - 100 lineal feet	Pine 4 X 4 Framing - 100 lineal feet
Global Warming	kg CO2 eq	84.254789	120.76661	240.59703	36.996844	50.870661	73.763002
Acidification	H+ moles eq	52.67598	75.502898	150.42049	7.0685939	9.7193166	14.093263
Eutrophication	kg N eq	0.027426833	0.039312334	0.078319911	0.01885803	0.02592978	0.03759839
Ozone depletion	kg CFC-11 eq	1.64E-06	2.36E-06	4.69E-06	1.89E-06	2.60E-06	3.77E-06
Smog	kg NOx eq	0.37461899	0.53696615	1.0697696	0.10267337	0.14117588	0.20470975
Metered Water	kg	643.59862	922.49136	1837.8316	71.134432	97.809844	141.82427
Energy	MJ-Eq	1647.3866	2361.2735	4704.2423	416.14006	572.19258	829.68671

Chart 5: Impact of Material Types for Channel

EXTREN®SAFPLATE vs. Steel and Aluminum Plate

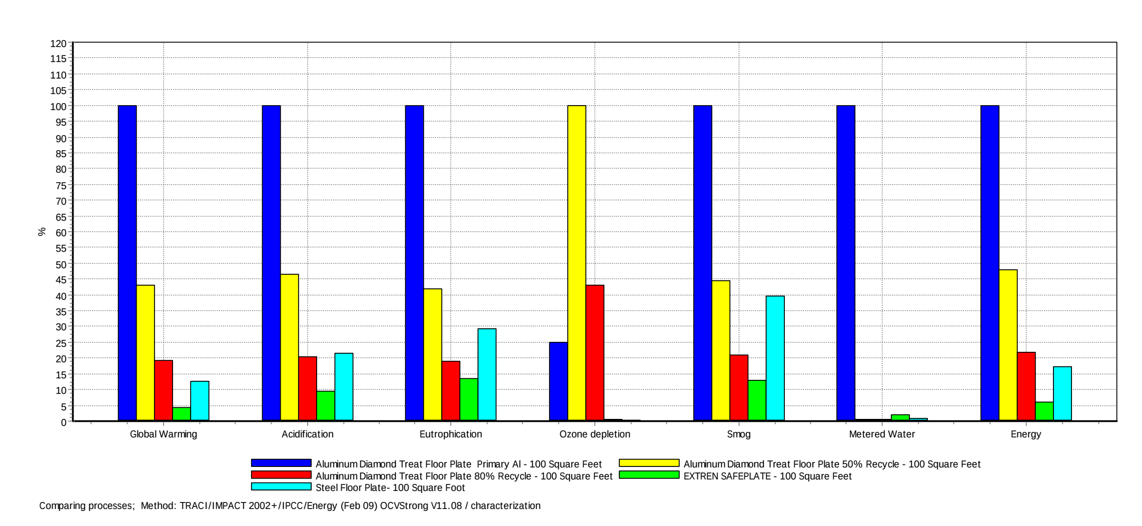

Figure 10: Impact by Material Type for Plating

Title:	Comparing processes
Method:	TRACI/IMPACT 2002+/IPCC/Energy (Feb 09) OCVStrong V11.08
Indicator:	Characterization
Skip categories:	Never
Relative mode:	Non

Impact category	Unit	Aluminum Diamond Treat Floor Plate Primary Al - 100 Square Feet	Aluminum Diamond Treat Floor Plate 50% Recycle - 100 Square Feet	Aluminum Diamond Treat Floor Plate 80% Recycle - 100 Square Feet	EXTREN SAFEPLATE - 100 Square Feet	Steel Floor Plate- 100 Square Foot
Global Warming	kg CO2 eq	4948.3211	2124.5843	947.89807	219.06441	630.57113
Acidification	H+ moles eq	1428.2116	663.46899	291.62307	136.95846	305.58988
Eutrophication	kg N eq	0.53230506	0.22274233	0.10144773	0.07131051	0.15618106
Ozone depletion	kg CFC-11 eq	0.000170034	0.000679323	0.0002926	4.27E-06	1.91E-06
Smog	kg NOx eq	7.4880891	3.3394036	1.5666029	0.97402636	2.962739
Metered Water	kg	79771.759	569.8	418.1	1673.3564	639.11589
Energy	MJ-Eq	71059.394	34154.632	15447.143	4283.232	12299.291

Chart 6: Impact by Material Types for Plating

Analysis of Embodied Energy

Part Composition: 61% Glass and 39% Resin

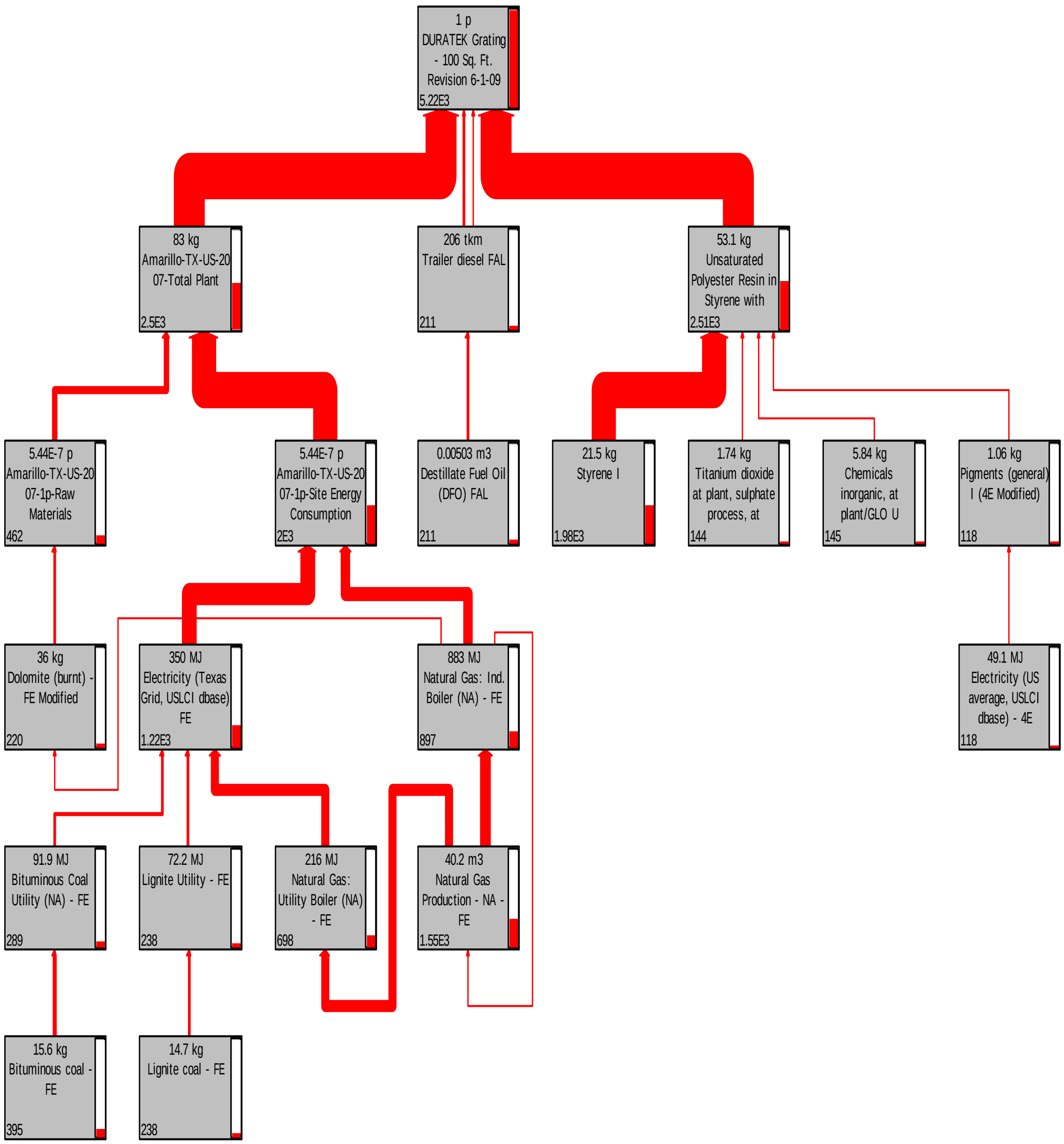

Figure 11: Embodied Energy Flow Map for Raw Materials-Grating

Part Composition: 55% Glass and 45% Resin

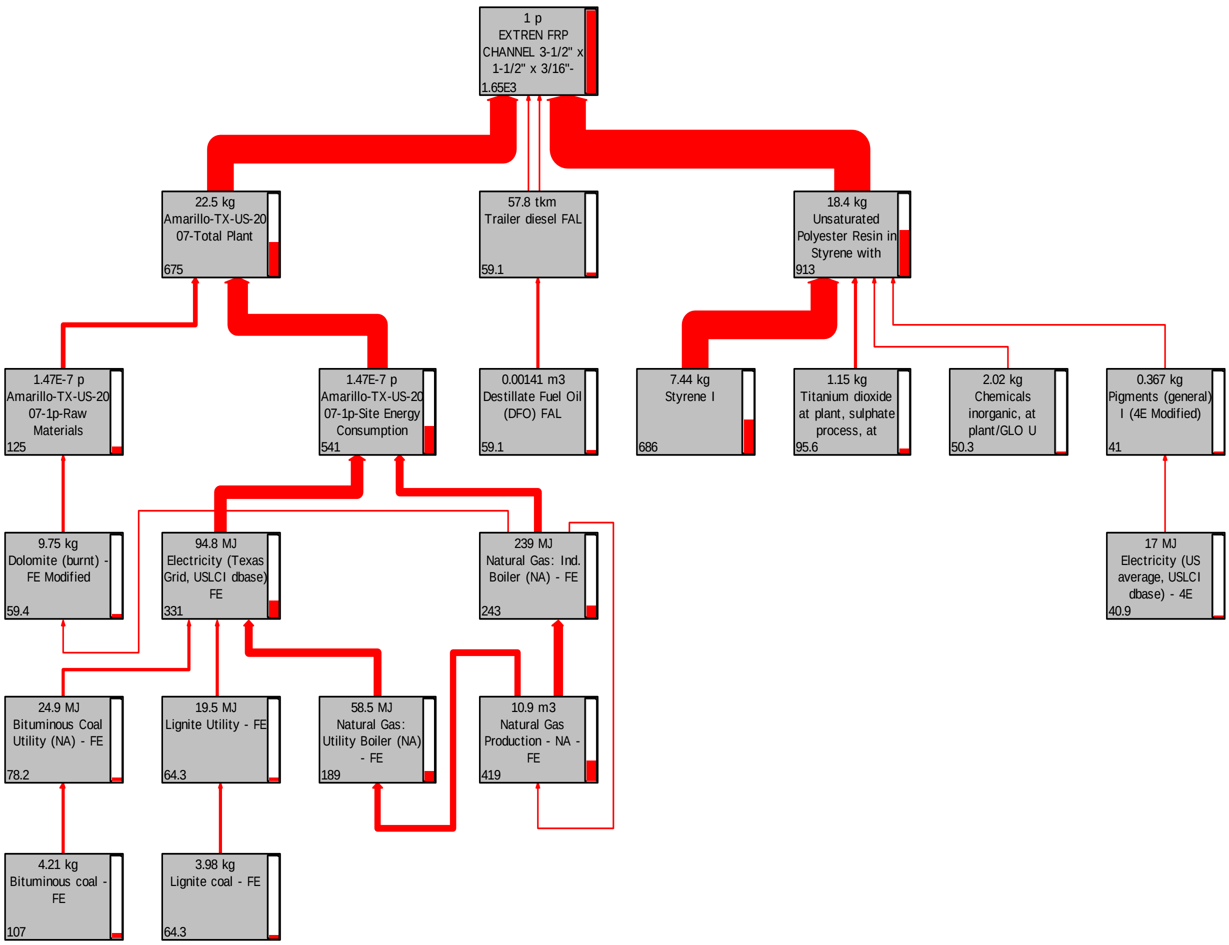

Figure 12: Embodied Energy Flow Map for Raw Materials-Composite Shapes

Embodied Energy Analysis

Based on the two formulations as provided, the cradle to grave energy of the raw materials increases as the percentage of resin increases in the component mixture. If the desire to make the product greener based on embodied energy of materials, increasing the ration of glass to resin would be an option. Another option is to reduce the amount of styrene used in the overall resin mixture

Conclusions

The primary purpose of this report was to examine the embodied energy of the raw materials used in making various industrial structural components. Materials of construction examined were composite glass with polyester resins, steel, aluminum (degrees of recycle content), and wood. Other impact assessment categories were included in the study for secondary impact considerations, which could result in a further LCA study. The report does not include any energy and/or environmental impacts in the actual manufacturing of the finished structural component, its transportation to customer, impacts due to use-life and end of life. A comparative LCA from cradle to grave would need to be performed in order to further identify additional impacts on the components.

The embodied energy for the major raw materials that are used in composite component manufacturing is less than the embodied energy of components made with aluminum that contains no recycle content. The data would suggest that aluminum can only be energy and environmentally comparative to composite glass structure as the recycle content approaches 100%. Product component weight for the composite part is very close to the weight for the aluminum part.

When comparing the embodied energy of raw materials in components made from steel (no recycle) versus the raw materials of components made from composite glass materials, the difference in their respective energy and environmental burdens are relatively smaller then when comparing composite glass to aluminum. The energy and environmental impacts are less for the composite glass components due to the greater weight of the component when made from steel instead of composite glass. As in the case of the aluminum comparison, it would be safe to assume that as recycle is added to the steel material, its energy and environmental footprint would be comparative to that of the raw materials used in composite components.

When the composite glass channel product is compared to the various wood products, wood has a consistent advantage in its environmental footprint. The embodied energy footprint for the wood product is one half (1/2) that of the composite glass materials.

Another means for reducing the embodied energy of composite parts could include reducing the amount of styrene used in resin (increase fillers), and/or increasing the glass to resin ratio on part manufacturing. Products with a glass/resin ration of 61%

to 39% have an embodied energy of 17.5 MJ/lb. Products using a glass/resin ratio of 55% to 45% have an embodied energy of 18.0 MJ/Lb.

Embodied Energy Ratios for materials by Component
(Ratio of MJ/MJ Energy)

Component A	l-v/Comp	Al80/Comp	Steel/Comp	Wood/Comp
Grating 5/1		1.42/1	2.3/1	N.A.
Handrail	5.7/1 N.A.	4.4/1 N.A.		
Channel 525	N.A.	N.A.	1.7/1	N.A.
Channel & Tube	N.A. N.A.	N.A.		1/3.9-5.7
Plate 16.3/1		3.5/1	2.8/1	N.A.

Chart 7: Embodied Energy Ratio of Materials by Component Application

Performing a full component comparative cradle to grave life cycle analysis would provide a full disclosure on the product impact assessments. Manufacturing processing difference for the final components can have a significant impact on the final energy and environmental burdens.

Manufacturing processes would include pultrusion for the composite glass part, slitting, cutting and bending for the steel parts and the aluminum parts are made from using the aluminum ingot, which is melted and extruded or formed into a final component. Additional processes for the metal type components could include galvanizing and anodizing, which utilize further energy and chemicals that can contribute to the environmental burdens in a life cycle assessment. The wood products could require a final coating treatment of paint or stains. These types of products were not included in the life cycle assessment burdens.

The use phase may be another advantage to a composite part over the other materials in this study. Life Expectancy of a component can have a major impact on the assessment results if the replacement ratios differ dramatically.

End of life assessments would be favorable to the aluminum and steel components due to there Recyclability and established processes to handle the recycled materials. Although wood products have an end of life fuel use, in most industrial operations, the demolition of these products would end up in a landfill. At this time, composite glasses would also end up in a landfill.