WHITE PAPER

ACMA Green Composites Committee

Proposal to Collect Life Cycle Inventory Data (rev. September 29, 2009)

Objective

Identify, evaluate, and compile life cycle inventory (LCI) data for composite raw materials and processes which could be used by ACMA members and end use markets to evaluate the "green" potential of composites products.

Executive Summary

Architects, engineers, and consumers are becoming more aware of the environmental impact that products and built facilities have on society. Requirements for "green" performance are steadily influencing standards and specifications. Architects and engineers are evaluating ways materials and products can be used to build more energy efficient structures by using life cycle assessment (LCA) tools to perform their design evaluations. Savvy consumers are changing their purchasing habits by considering products that are more energy efficient or have a lower carbon footprint. Other materials such as steel, concrete, aluminum, and wood have developed data that can be used to evaluate the carbon footprint of their respective materials. Currently, widely used LCA tools do not contain data on composites materials.

Today, some composites industry material suppliers are working to obtain LCA data that helps them understand the environmental impact of their products. There have been numerous requests of ACMA for data to evaluate the "green potential" of their products and support marketing their products. Coordination of stakeholders and compiling the data needs to be done.

NetComposites and BRE (UK's leading center of expertise on building and construction) authored a publication in 2004 titled *Green Guide to Composites*. The guide was developed based on a very comprehensive comparative LCA. European inventory data was developed from which life cycle impacts for twelve environmental measures and two socioeconomic measures were derived. The purpose of the guide was to allow composites manufacturers to choose environmentally preferable processes and materials. The report does not contain data on competing non-composite materials. The Network Group for Composites in Construction (NGCC) issued a Technical Sheet 07/07 – FRPs – environmental impact and embodied energy. A part of this technical sheet included a case study of a footbridge in the Netherlands with the replacement of a corroded steel structure. The case study concluded that FRP was the material of choice based on longevity. LCA has been performed on some composites products. At Composites & Polycon 2009, a technical paper was presented from a study performed by Stanford University comparing FRP and shotcrete for an aquarium tank. FRP was determined to have a lower carbon footprint than shotcrete. However few detailed examples exist for the composites industry.

A more comprehensive evaluation of composites carbon footprint and environmental impact would allow the composites industry to take advantage of the business opportunities available to composites. The basis for this is the development of LCI data, which can be used not only by the composites industry and end users, but would also be submitted to the Department of Energy's National Renewable Energy Laboratory database. NREL is DOE's principal research and development laboratory and repository of data used for LCA. Doing this will position composites on a level playing field with other materials. The importance of life cycle inventory data will position composites as a sustainable alternative that is backed up by data and not anecdotal stories.

Basic LCI data on composites would also be useful to ACMA advocacy efforts in an era of inevitable and aggressive regulation. For instance, under proposed CO2 cap & trade regulations the cost of energy is expected to rise. Comparison of the embedded energy (an LCI component) of composites vs. competing materials would indicate whether and under what conditions cap & trade might confer a relative cost advantage for composites. Advocacy might then be shaped around those conditions

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The development of life cycle inventory data for composites raw materials, processes and products is becoming increasingly important to the composites industry because this data can help the composites industry be more competitive versus other materials. Knowledge about composites carbon footprint and environmental impact can help grow the composites industry by showcasing the benefits of composites when competing with other materials. However, the multitude of materials and processes used by the composites industry makes this project very complicated. Active participation by all composites industry stakeholders, both material suppliers and manufacturers representing a wide variety of processes will be key to success.

Definitions

- **Carbon footprint**: the total GHG (greenhouse gas) emissions caused directly and indirectly by an individual, organization, event or product. The carbon footprint is a component of the total environmental footprint.
- **ENERGY STAR**: Is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy. It provides tools, resources, and guidance to thousands of organizations and includes a voluntary energy performance rating system.
- **Environmental footprint**: how much adverse impact an individual, organization, event or product has on the environment. For a product, the environmental footprint would be the output of an LCA on that product.
- **Green**: as often used, a rather vague term suggesting that a product or process is natural, carbon negative, non-toxic, or environmentally friendly, with no verification or certification. As used here, the term means relatively more sustainable (than less green alternatives) based on credible demonstration.
- **Green Globes**: Refers to a building environmental design and management tool developed by the Green Building Initiative (GBI). It provides an interactive online assessment protocol, rating system and guidance for green building design, operation and management. Green Globes is promoted by GBI as a more flexible and affordable alternative to LEED.
- **LEED**: Refers to The Leadership in Energy and Environmental Design Green Building Rating System, developed by the U.S. Green Building Council (USGBC) to provide a set of standards for environmentally sustainable construction.
- **Life Cycle Assessment (LCA)**: The compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system through its life cycle.
- **Life Cycle Inventory (LCI)**: A phase of life cycle assessment involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle.
- **NAHB GREEN**: The National Association of Homebuilders has developed a complete system relating to certification of homes that meet its ANSI approved ICC-700-2008 National Green Building Standard (NGBS) or its Model Green Home Building Guidelines. Builders may also attain Certified Green Professional status through a course of training offered by the NAHB.
- **Product life cycle**: the stages through which a product passes from development to its final disposition.
- **Sustainability**: The definition by the World Commission on Environment and Development: "the forms of progress that meet the needs of the present without compromising the ability of future generations to meet their needs."

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Background

Products impact the environment in many ways. In considering a product's life cycle (Fig 1), there are inputs and outputs at every step of making the product starting from the energy required to extract the ore or convert a natural resource to a raw material followed by manufacturing the composite product followed by transportation to deliver the finished goods to their location of use. The inputs of focus are energy, water, materials, and other resources. The outputs are wastewater, air emissions, and hazardous materials. Life Cycle Assessment (LCA) is the method by which the life cycle impacts of a product are compiled and evaluated

Fig 1 – Product Life Cycle

In the process of conducting an LCA, goal definition is important. Some possible goals are listed below and shown in Figure 2:

- Determine the environmental footprint (total or in part) on one or more products
- Develop a baseline footprint for a product, from which you will make improvements.
- Provide input for policy-making
- Image

ACMA members are mostly interested in LCAs that are used to determine whether and why Product A is greener than functionally equivalent Product B by comparing the environmental footprint of each. The parties interested in the answer - producer and/or consumer of product A/B - are the users who must conduct the LCA or sponsor the LCA. The information is important where the consumer or target market values environmental sustainability enough that it affects their choice of suppliers and/or materials. Market forces dictate the scope and depth of the LCA. For instance, only a limited LCA will be needed if consumers are only focused on carbon footprint. A full environmental footprint would also typically include emissions of all air pollutants, wastewater discharges, and solid wastes generated. Cost is not included, though a comparable life cycle cost assessment could be presented to decision makers along with the LCA.

LCAs are conducted by first specifying the project scope, then developing a product LCI consistent with that scope including not only direct impacts of processing by the producer but also embedded impacts due to downstream production of materials purchased by the producer. The party developing the LCA must develop the direct portion of the LCI which includes identifying available LCI data on embedded impacts of purchased materials or develop that information.

There are two basic classes of commercial tools available to facilitate such assessments. In the first class, commercial software systems such as SIMA-Pro or GaBi are used by LCA consultants to organize inventory data and convert it into LCAs. The second class includes “quick-LCA” systems that allow users with no technical expertise in LCA to make green product comparisons, based on an internal database of prior LCA information on generic products. An important example would be the Athena Institute Eco-Calculator for buildings, which we know both LEED and Green Globes will be adopting as part of their next-generation green building certification systems.

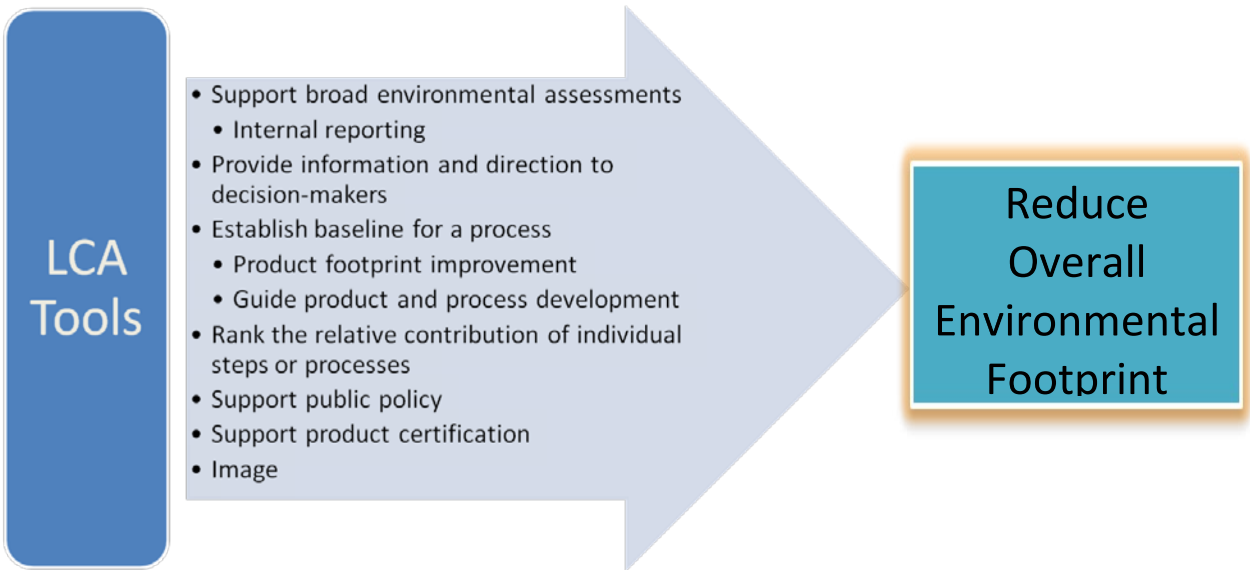

Fig 2 - Primary Goals of LCA Analysis

LCA systems include common databases of LCI information on basic materials already evaluated, which avoids the cost of reinventing the wheel. There is also a major initiative by the Department of Energy - NREL LCI inventory, which seeks to provide a common source for LCI data on US manufacturing processes. We have learned that composites and their component resin systems are poorly represented in these databases. This is not true of competing materials because "green" issues have been raised in the past on steel, concrete, wood, and aluminum. LCI data developed from past studies on these materials have been widely incorporated in commercial databases, and are included in the NREL inventory. Further, because corresponding LCA data are available, the competing materials are included in quick-LCA systems such as Athena, whereas composites are not.

Today, composites part manufacturers must work longer and pay more than their competitors to credibly demonstrate the sustainability of their products. A composites manufacturer developing an LCA in SIMA-Pro must first develop and input LCI data on both in-plant processes and embedded material impacts. Their competitors can tap into available embedded impact data and possibly some direct process data. Worse, consumers who base purchase decisions on LEED or Green Globes might not even recognize the benefits of composites, because they are not included in the Athena Calculator.

When we take the idea of a life cycle analysis one step further or look at ways to minimize what is consumed (inputs) and minimize the impact (outputs) of the product, we get to why we are interested in LCA which is “preserving our future”. There is a sustainable movement going on in the world which incorporates the use of LCA to identify ways in which the impact of a product is minimized. This movement presents an opportunity for composites as it opens the door for discussion on the alternative materials or products to use when one considers the impact of a product and the desire to improve an environmental footprint. Items that are considered for the environmental footprint are shown in Fig 3.

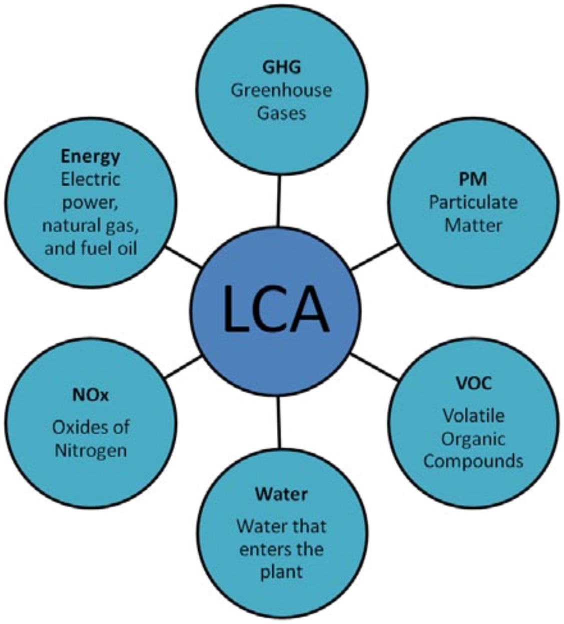

Fig 3 - Environmental Footprint

There are cases in which composites are the preferred choice over other traditional materials based on being the environmentally best option due to lower water and air pollution, improved longevity, better logistical solutions (transportation and the energy required or fuel used during operation of a product), and finally product improvement which can be useful as a marketing tool, a way to generate cost savings or a way to develop a product with more 'green' appeal. Longevity (corrosion resistance) and logistical solutions (lighter weight) are the pillars of the composites industry. LCA is a data-driven means to make that comparison or final decision and should provide a number of new opportunities to showcase the benefits of composites and ultimately grow the industry.

LCI, or population of composites LCI data is the first step in giving composites a proper say in this opportunity. Product improvement is a tool which can benefit the industry; driving towards better material inputs or process changes which can reduce costs and lower environmental impacts. It can also highlight areas in which the industry must band together and focus resources to solve challenging problems.

To participate in this emerging trend, we must focus on the lack of good data on the industry, whether you consider raw materials, processes or even final products. The fact that this trend is going on may represent an open door for composites into area where we have been previously barred. The second challenge is where to put efforts in this process, which is address later in this document.

Example of Focus Area

Our goal is to enable ACMA members to conduct LCAs at reasonable cost, using commercially available tools and free datasets, on parts they make for customers who value sustainability. Of particular value would be the ability to quickly and inexpensively pull together a limited or screening LCA, which often will suffice for the customer to select a greener product. For instance, a limited LCA might compare a traditional aluminum-framed window to one framed out of typical pultruded lineals. Inventory data on typical resins, typical reinforcement, and typical pultrusion methods would be sufficient, along with corresponding data on the competing product. But if the customer is choosing between two pultruded frame types, a detailed LCA would be required, based on inventory data for specific resins, reinforcements and processes used at the competing frame production plants.

Our industry benefits from having inventory data available for as many commonly employed resin systems, reinforcements, fillers, and production processes as possible. To illustrate what information would be needed, consider first a pultruded part made of unsaturated polyester resin filled with calcium carbonate and reinforced with fiber glass.

The first step in inventory development is scope setting. Here we are interested in impacts up to the pultrusion plant gate (cradle-to-gate), since post-gate impacts or final use are too part-specific to be generalized. We assume conventionally that the impact of producing capital goods (molds, mixers, pultrusion lines) can be safely ignored as having trivial impact on the footprint of a part. We will also assume here that because peroxide initiators are used in low quantities and are not emitted, their impact can be ignored. Finally, we ignore the impact of transporting raw materials to the production plant - these must be developed individually, if considered at all.

Next, Fig 4 shows a simplified in-plant process flow for pultrusion, based on the above-mentioned scoping assumptions.

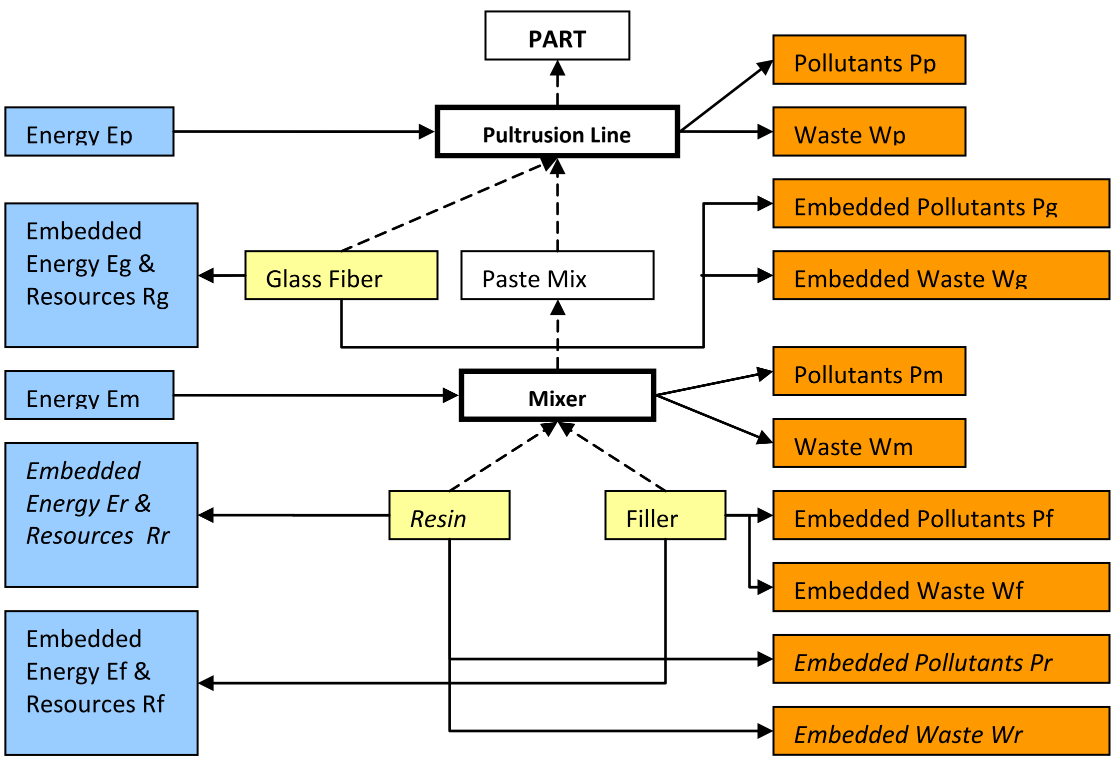

Fig 4 - Simplified in-plant process flow for pultrusion

Legend

- **Bolded Clear boxes** - The two in-plant processes
- **Unbolded clear boxes** - Products (intermediate and final).
- **Yellow boxes** - Purchased materials with usage quantities reflecting typical product formulations and material flow indicated by dashed arrows.
- **Blue and orange boxes** - Impacts to be inventoried. Impacts are either a *direct* consequence of in-plant processing, or *embedded* (embodied) within purchased materials. Embedded impacts are essentially inherited from production at material supplier plants.

The blue boxes are typical energy and resource (ex: water) usage. The orange boxes are pollutants and waste. Energy would include kilowatt-hours of electricity and BTU of natural gas, propane, oil, etc. Waste would include scrapped resin, saw waste, and cleanup solvents. Pollutants would include discharged wastewater and air emissions of VOC, particulates and individual hazardous air pollutants.

The total life cycle inventory for the pultrusion at the plant is the sum of the blue and orange boxes. The calculation is similar to the cost rollup of a multilevel manufacturing bill of materials. Embedded impacts from resin are italicized to indicate that we expect these must be "rolled up" by evaluating resin production processes at supplier plants, by the same method depicted here. Materials such as filler and fiber glass have limited data available in LCI databases and should be considered as well. In like manner, the most significant materials purchased by resin producers are widely used chemicals for which embedded impacts are likely to have already been evaluated. This should simplify inventory development at resin plants.

Development Plan

Part 1 - The first part of this strategy is to build relationships with academia and potential organizations that represent users of this information. We need to determine who the customer is. There needs to be collaboration between ACMA and with associations that represent the customer in order to create interest and need for information about composites. Examples of customer associations would be American Institute of Architects, Design Build Industry Association, ASTM, ISO, etc. We also need to develop relationships with the appropriate government agencies that provide oversight to the green market. In this case, Department of Energy is high on the list.

Part 2 - In a parallel effort, the second part of the strategy is to select a product(s) from growing or potential markets in which to focus the LCI study. ACMA has a number of working committees that is represented by Divisions, Alliances, and Councils. These groups can be given the opportunity to present recommendations to the Green Composites Committee for consideration. The recommendations must contain substantiation on why resources should be spent to evaluate the product(s). Selection should be based on products where data can be collected easily and on products that are used in multiple markets to provide the best opportunity for marketing composites to a broad audience. As a starting point, **Appendix A** provides an overview of the composites products used in commercial and residential construction and infrastructure type products versus the process used to manufacture the products. For the purpose of the LCI analysis, the approach would be to focus on those products that are manufactured using many processes while also taking into consideration which process is used most often. An analysis of this matrix gives the basis of the first processes to undertake and includes; Hand Lay-up, Spray-up, Vacuum Infusion, and Pultrusion.

Appendix B provides an overview of composites process versus materials. When compared to the results in Appendix A, we can conclude which materials to focus on for the LCI analysis. The materials to focus in include; Unsaturated Polyester Resin, DCPD resin, ATH (Aluminum Trihydrate), Low Profile additive, E-glass fiber reinforcement, and Calcium Sulfate. From this small list the LCI's for the above materials and processes will be developed as an initial start, noting that once completed a second round of materials and processes should be included. It is also recommended that four LCAs are included in this proposal and that the LCAs would represent a product from the above materials/process combinations (Appendix A). The LCAs would add further marketing value as well as understanding to the initial foray.

Part 3 - The third part of the strategy is to determine key leaders in the composites industry that represent critical sectors in reinforcements, resins, and manufacturing processes who are committed in sharing their knowledge and data to this program. This group would function as the advisory committee to collaborate with the designated consultant(s) who would perform LCA on composites. The Green

Composites Committee role is to search the industry and select people who can participate in this advisory group.

Part 4 - The fourth part of the strategy s to engage academia or LCI industry consultants that demonstrate a broad knowledge or experience in the field of LCA and have a basic knowledge of composites materials and can assist our industry in submitting the data to the appropriate organization so that the composites data can be added to the publically available database to conduct LCA.

Part 5 - The last part of the strategy is to review the data to determine if this best characterizes the composites industry. The Green Composites Committee in addition to the Advisory Committee must decide how the data can be used and authorize submission of the data to the appropriate group. Once the submission is made, contact must be made with the end user organizations to announce the availability of this data.

Proposed Timeline

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Project Start-up												
Part 1												
Part 2												
Part 3												
Part 4												
Part 5												

Resources

Staff

- Development relationships with customer industry groups
- Development relationships with academia
- Issue request for quote to industry consultants
- Project management - Monitor work of consultant
- Issue updates to GCC as needed

Green Composites Committee

- Identify key leaders in the composites industry that represent critical sectors in reinforcements, resins, and manufacturing processes who are committed in sharing their knowledge and data to this program
- Identify funding sources for project
- Develop project statement of work and request for quote for services
- Identify LCI industry consultants to perform work
- Evaluate proposals – select consultant
- Monitor progress of project – evaluate critical milestones
- Review / approve final work

Funding

- Consultant - TBD
- Staff travel – TBD

APPENDIX A.1 - Composite Product versus Process Matrix

Commercial and Residential Building Products	Open Molding - HLU	Open Molding - Sprayup	Gelcoating	Vacuum Infusion	Pultrusion	Compression molding	Casting - Closed Mold	Secondary bonding	Continuous Lamination	Filament Winding	Casting - Open Mold	RTM
1. Window lineals and envelope					X							
2. Doors and associated trim					X	X						X
3. Skylights and other light-transmitting panels	X			X					X			
4. Exterior trellises and sunscreens, sunrooms	X		X		X							
5. Roof structures - domes, cupolas, steeples, electronics housings	X		X	X	X							
6. Gutters/soffits		X			X	X						
7. Ornamental trim - posts/columns, railings, moldings, baseboard	X			X								X
8. Structural columns	X				X							X
9. Landscaping - fountains, sculpture, planters, porticos	X	X	X	X		X	X					
10. Handrails, stair steps	X				X	X						
11. Platforms, walkways				X	X	X						
12. Structural profiles (angle, channel, I, rod, plate, tube)	X				X	X				X		
13. Grating					X	X						
14. Utility vaults	X	X		X	X	X	X					
15. Storage tanks and piping for fuel, water, wastewater, runoff	X			X								X
16. Non-load bearing facades and curtain walls	X		X	X								
17. Roof panels	X			X		X			X			
18. Reusable formwork for poured-in-place concrete	X	X	X	X		X						
19. Corrugated FRP wall panels					X				X			
20. Cultured stone (cast polymer) countertops, wall panels, floor tiles											X	
21. FRP or cultured stone tub/shower enclosures, lavatories, vanities spas, pools	X	X				X					X	X
22. Fencing					X							
23. Signage	X			X		X			X			

APPENDIX A.2 - Composite Product versus Process Matrix

Infrastructure (typically corrosion resistant applications)	Open Molding - HLU	Open Molding - Sprayup	Gelcoating	Vacuum Infusion	Pultrusion	Compression molding	Casting - Closed Mold	Secondary bonding	Continuous Lamination	Filament Winding	Casting - Open Mold	RTM
1. Tanks: aboveground - atmospheric, pressurized							X			X		X
2. Tanks: underground - fuel, chemical storage, water/septic		X					X			X		X
3. Ductwork: round/rectangular duct and fittings, fire-retardant/low flame spread/low smoke ductwork, dampers and accessories	X				X	X						
4. Stacks: free standing, guyed, building, structure supported	X									X		
5. Air Pollution Scrubbers: wet scrubbers, high energy, educators, cyclones, dry /absorber, package systems	X			X		X				X		
6. Fans: centrifugal, axial, roof ventilators, in-line, high pressure	X			X	X	X						X
7. Pipe and fittings	X									X		
8. Trench and trench liners	X				X	X						X
9. Covers and hoods	X			X		X						X
10. Grating					X	X						
11. Handrails, platforms, stairs					X							
12. Structural products - rebar					X							
13. Marine structures - bulkheads, sheet pile, docks	X	X			X							
14. Infrastructure repair, replacement and improvement	X	X						X				
15. Liners												
a. process and effluent piping,	X									X		
b. abrasion resistant piping,	X			X						X		
c. storage vessels	X	X					X			X		X
d. process vessels,	X	X					X			X		X
e. stacks and chimney liners,	X			X						X		
f. duct systems	X			X								X
g. valves.	X											X
16. Cooling Towers and assemblies					X	X						
17. Electrical Generation and Transmission												
a. Flue gas desulfurization	X			X		X				X		
b. Conductor bars & covers					X	X						
c. Crossarms					X	X						
d. Conductor support brackets					X	X						
e. Guy Insulators					X	X						
f. Line Post Insulators					X							
g. Non conductive high voltage tools for transmission and power line installation and maintenance	X				X							X
h. Utility Poles and Towers					X					X		

18. Electrical												
a. Armature supports						X						
b. Cable Tray and Cable Tray Components					X							
c. Fuse tubes						X				X		
19. Highway Infrastructure												
a. Beams	X			X	X							
b. Bearing Piles					X					X		
c. Bridge Decks and Girders				X	X							
d. Dowel Bars for concrete pavements					X							
e. Pedestrian Bridges				X	X							
f. Highway delineators					X							
g. Rebar					X							
h. Road sign – custom panel, structural shapers - frame and posts	X				X	X			X			
i. Sheet Piling					X	X						
j. Snow Markers					X							
k. Structural Strengthening for Concrete and Masonry	X							X				
l. Structural Stay-in-Place forms for reinforced concrete decks – grating for internal reinforcement,	X			X								
20. Wind Power Generation & Transmission												
a. Blades	X			X	X							
b. Nacelles	X			X								
c. Tower Components	X			X		X						
21. Rail Transportation												
a. Capacitor Racks						X						
b. Pedestrian median barriers					X							
c. Shim Plates					X							
d. Third rail covers					X	X						
e. Track walkways					X							
f. Wind screens with benches					X	X						
22. Telecommunications												
a. Attachment hardware					X	X						
b. Cell Towers & Poles										X		
c. Coaxial cable					X							
d. Equipment Housing – structural profiles and panels				X	X	X						
e. Support frame and structure					X							
23. Water/Wastewater Treatment												
a. Cell Dividers, Components for Troughs and Gates	X			X		X						X
b. Floating docks – handrails, walkway	X			X	X							
c. Handrails, Ladders, Platforms					X							
d. Odor Containment Covers, Trench & manhole covers	X	X		X	X							X
e. Weir plates	X			X	X	X						

Appendix B – Process Versus Matierals

FRP Composites - LCI Priority Matrix

	Open Molding - HLU	Open Molding - Sprayup	Gelcoating	Vacuum Infusion	Pultrusion	Compression molding	Casting - Closed Mold	Secondary bonding	Continuous Lamination	Filament Winding	Casting - Open Mold	RTM
Relative Process Importance to Market	1	1	1	1	1	1	1	1	2	3	3	3
Material Importance to Process												
Styrenic Unsat Polyester	1	1	1	1	1	1	1	1	1	3	3	3
Low Profile additive					1	1						3
DCPD	2	1		3	3	3	1				X	X
Vinyl Ester	1	3	2	2	2	2	1			X		X
Phenolic	3				3	3				X		X
Urethane				3	2	3		2				X
Epoxy	3			2	3	3		1		X		X
E-glass	1	1			1	1			1	1		
S-glass & R-glass	3				3	3				X		
A-glass	3				3	2			X	X		
Aramid	3				3	3				X		
Carbon	3				3	3				2		
Alumina Trihrate		1			1	1	1					
Calcium Carbonate		2			1	1	1					
Calcium Sulfate		1			2	3	2					
Clay					2	2						
Nanoclay												

Suggested ranking scheme:

Importance Scores: 1-3, 1 = highest

Consider first only processes scored 1 for market importance

Within those proceses, consider only materials scored 1 for importance to process