Shell Eco Marathon 2024

Carbon Footprint Reduction Award

Cornell Electric Vehicles

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Overview and Motivation

Cornell Electric Vehicles, formerly Resistance Racing, has long been focused on sustainability through a lens of renewable energy. It's important that, in our journey to make the most efficient electric vehicle possible, we also focus on sustainability and reduction of waste throughout our design and manufacturing process. This paper will focus on an analysis of past and present manufacturing processes, as well as outline a plan to begin recycling carbon fiber and reduce waste when manufacturing future vehicles. Ultimately, the team plans to reduce waste while improving performance.

Analysis of Current Processes

The monocoque of the 2024 Urban Concept competition vehicle (which from here on out will be referred to as "UC '24," (or more affectionately, the "Chicken Coupe") is composed primarily of carbon fiber, interlayered with a high-density foam in large load-bearing areas. For the current vehicle iteration, upwards of 88 yards worth of carbon fiber was purchased. Throughout the manufacturing process, additional cuts worth of carbon fiber may be used for patching, or may be otherwise lost in the process. Aside from the material itself, infusion epoxy resin and plastic vacuum bagging are required for the layup process, neither of which can be recycled due to material properties. The resin in particular has a specific hardening life associated with it, making it difficult to use a can after opening it; however if the full volume is not needed, some of a can may be wasted. Of course, carbon fiber is not the only contributor towards carbon footprint; however, it is arguably the largest with other processes acting on a much smaller scale.

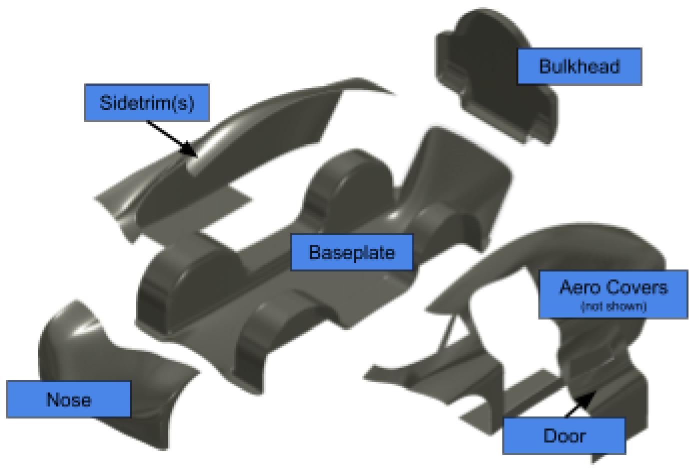

Figure 1: Chassis Breakdown

A breakdown of each component and the carbon fiber required is outlined in Table 1. Area, and thus volume, were approximated with CAD.

Part	**Thickness**	**Area (approx.)**	**Volume (approx.)**
Baseplate	0.5 in	19800 in^2	9900 in^3
Side Trim (x2)*	0.125 in	15940 in^2 (total)	1192.5 in^3
Door (x2)*	0.125 in	3030 in^2 (total)	378.75 in^3
Bulkhead	0.5 in	3086 in^2	1543 in^3
Bulkhead lip	0.5 in	392 in^2	196 in^3
Nose	0.125 in	3375 in^2	421.875 in^3
		Total Volume	11432.125 in^3

Table 1: Carbon Fiber Breakdown
*implies that window cutouts are not included in the estimate

It is worth noting that while this much carbon fiber is needed, some is eventually scrapped in order to make cutouts for the windshield and windows, again contributing to waste. Multiple sheets worth of fiber is needed for any given component, in order to layer them in 45-degree varying orientations for strength. Foam core is also used on the more structural components, adding strength but also potential sources of waste.

The current layup process, while successful in creating a functional and long-lasting monocoque, is highly conducive to producing waste. The workflow of a typical layup is outlined below, in Figure 2. The red diamonds highlight aspects of the process which are particularly wasteful.

For example, manufacturing of the molds themselves results in foam core scraps which are ultimately too small to reuse; sanding creates microscopic waste, as well. The Duratec, Wax, and Resin used, while reliable, are not particularly environmentally friendly. But ultimately, one of the biggest sources of waste is the scrap carbon fiber itself, both before and after layup. When sheets are cut to fit the mold, and when small portions of the finished monocoque get cut for features such as windows or wiring passageways, these fully-cured pieces end up being wasted and thrown away.

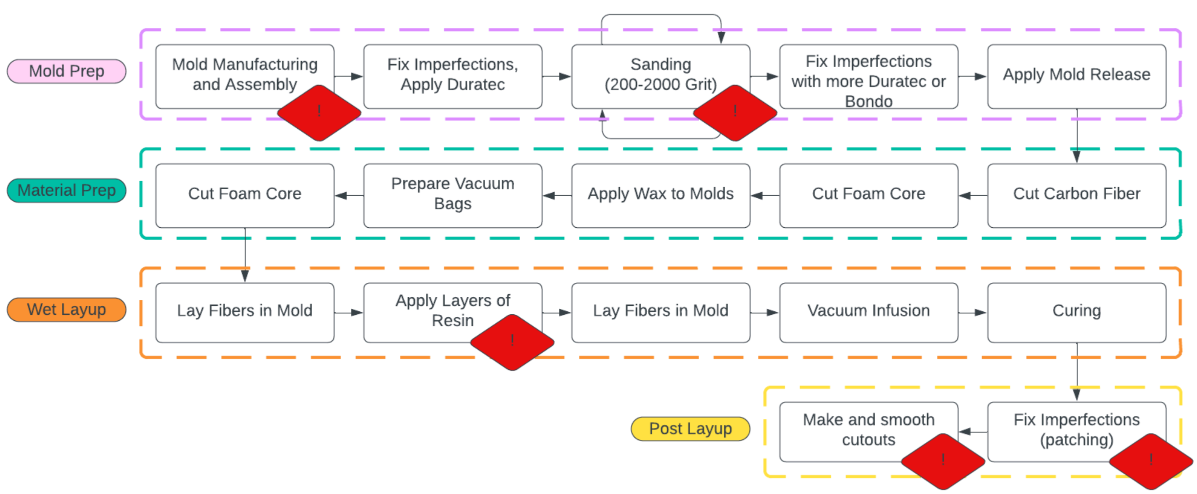

Figure 2: Current Carbon Fiber Production Process, with wasteful steps highlighted

Currently Implemented Methods for Carbon Footprint Reduction

As part of the layup process, the team designs several pieces of custom tooling board upon which the carbon fiber sets. One mold exists for each of the unique parts described in Table 1. These molds, often with various pieces to account for non-perpendicular geometries, are then made on a CNC.

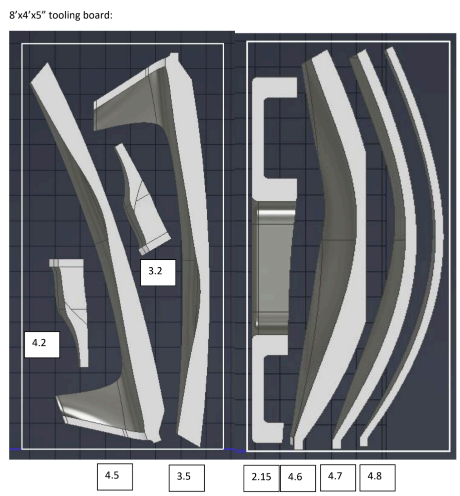

Figure 3: Tooling Board Optimization

The team has taken two main precautions to reduce waste during this process. The first is to fit as many individual mold pieces onto a single tooling board as possible, as shown in Figure 3. And, the second is to model new designs after old molds in order to reuse as much material as possible. For example, the next Urban Concept vehicle will use the same baseplate and bulkhead designs while changing the external aerodynamic properties; this will allow for the same molds to be used for those two integral pieces.

Proposed Improvements for Carbon Footprint Reduction

The team would like to introduce a carbon fiber recycling program for future designs. Carbon fiber scraps from previous and future iterations will be used to design new, custom carbon fiber rims. Not only will carbon fiber rims greatly improve vehicle efficiency and performance due to the material's extremely lightweight yet strong characteristics, it will also greatly reduce carbon fiber waste.

Research[1] shows that recycled carbon fiber is upwards of 67% as strong as fresh carbon fiber, depending on its preservation process. The best recovery came from thermal preservation via injection molding, with over 93% of the carbon fiber recovered. The most attainable form of recycling for this team would be the mechanical route, which involves shredding infused carbon scraps in order to separate it into carbon chips and resin pieces.

Rims, in particular, could be a good avenue for recycling carbon fiber, because they are composed of multiple conjoined components. While the barrel must end up being a continuous piece, the spokes of rims offer a unique opportunity to use recycled carbon fiber chips. Each spoke could easily go through the layup process and then be assembled together with the barrel and center cap. While the barrel may need new, continuous carbon fiber in order to better ensure stability, all other parts of the rim are feasible to make using recycled carbon fiber. Spokes are a key structural component of the rims, and using carbon fiber even if recycled will improve the overall strength and robustness of the vehicle as a whole.

[1] Source: A Review on Recycling of Carbon Fibres: Methods to Reinforce and Expected Fibre Composite Degradations (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9324376/#:~:text=Ref.&text=Recycled%20fibre%20type%20samples%20recorded,virgin%20version%20at%20139%20MPa)

Figure 4-5: Current (Aluminum) tires used for the 2024 SEM (left) vs example of a market carbon fiber rim, sold by ESE Carbon (right)

Two main avenues can be pursued to create a mold for the rims: 3D printed molds, or foam tooling board as the team's chassis layups currently use. Both involve non-biodegradable material, and thus alternatives are currently being researched. Regarding the former, several eco-friendly forms of PLA filament have recently entered the market, with a faster degrading time. That said, regardless of the mold materials eventually used, said mold will be reused for all four wheels and ideally for years to come, so as to reduce waste and thus carbon footprint over a long period of time.

There are of course, drawbacks to a potential custom rim design, the primary concern being the overall cylindricity and runout of the final product. Further research, along with prototyping, is necessary before committing to a full design, however prototyping with recycled materials will be aimed more towards perfecting the layup process than towards structural design changes, in order to prevent waste from multiple molds. A potential workflow is outlined below, taking the flaws outlined by Figure 2 and building upon them. The key is to collect any and all carbon fiber scraps- a benefit of carbon recycling is that the size of scrap is irrelevant towards the process, eliminating the need for any scrap filtering. Using a combination of heat and mechanical treatment, the team can then recycle this carbon fiber into wheel components.

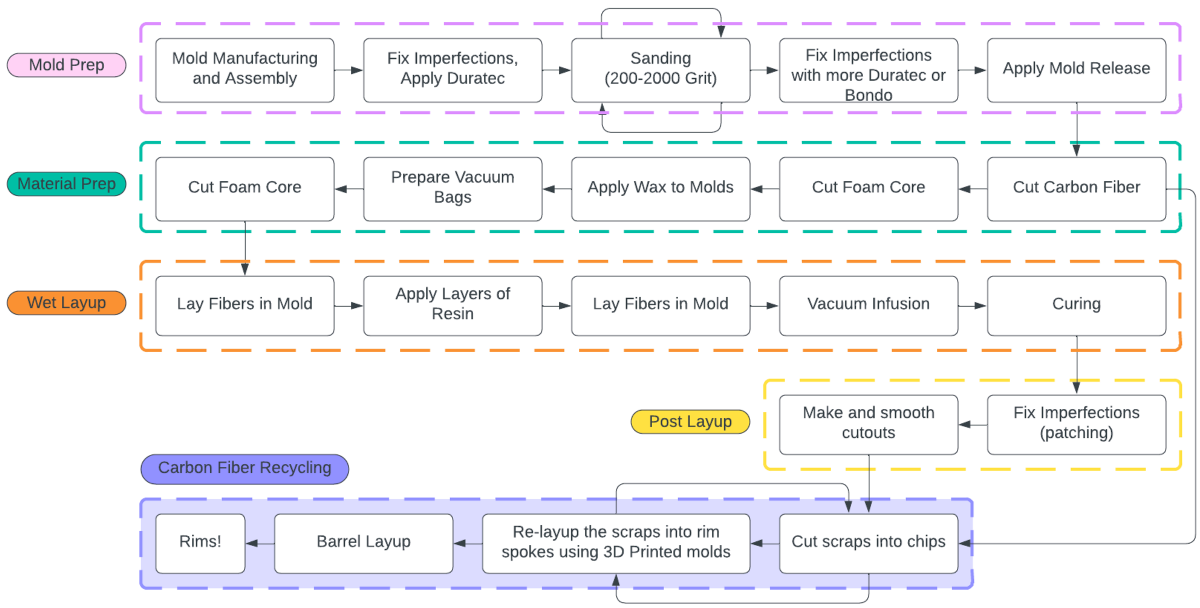

Figure 6: Proposed new manufacturing process involving carbon fiber recycling

Conclusion and Future Work

Ultimately, carbon fiber recycling has the potential to serve as a key method to reduce waste produced in the vehicle manufacturing process. New carbon fiber layups happen on a yearly basis, requiring large amounts of material and preparation. While CEV acknowledges that the layup process has its environmental downfalls, the plans outlined by this paper aim to optimize the wet layup process as much as possible, and introduce a recycling plan not just to this team, but to other organizations at Cornell as well. These recycled carbon fiber sheets and scraps can be compiled into new, smaller scale structural parts for future vehicles- in particular, carbon fiber rims would significantly increase overall efficiency thanks to its lightweight yet strong properties. As such, carbon footprint reduction has potential to be a winning strategy both for CEV and for the environment.