Recyclable Thermosets By Design
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Waste poses significant environmental and societal challenges all over the world. While some of the waste generated each year can be recycled or repurposed into new products, some materials are not currently recyclable. Consider plastics, which comprise 12% of waste generation in the U.S. The perception of plastic by the typical citizen is most likely that of thermoplastics, which is encountered in everyday life in the form out packaging, bottles, and casing materials, toys, etc. Little waste is created in the manufacturing of such consumer products because most common thermoplastics are recyclable, so for economic reasons, any manufacturing waste will be fed back into production. It is rather unfortunate that so many of these products, post-consumer, find their way into the environment.

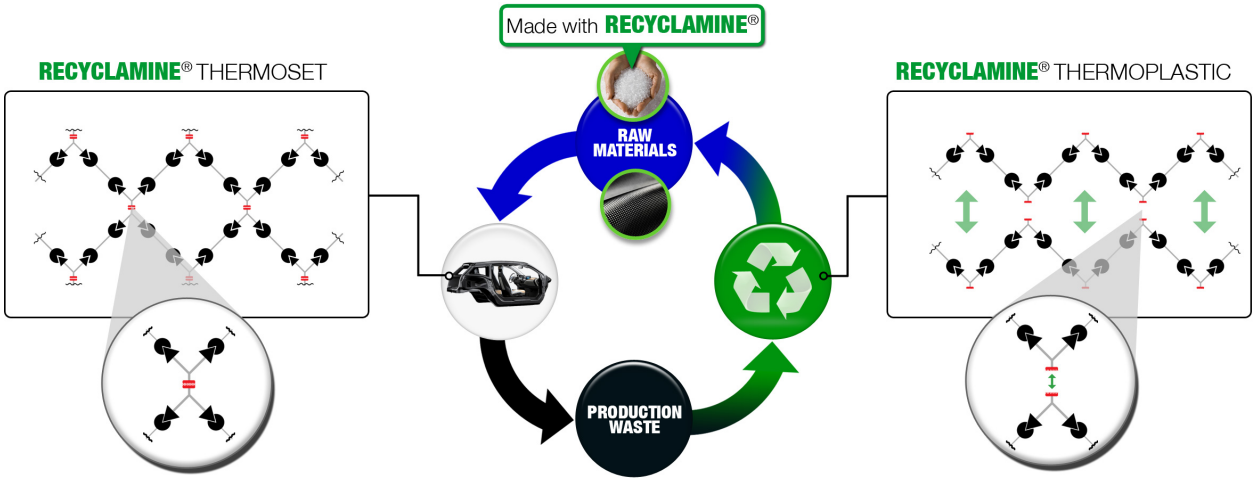

FIgure 1. Recyclable Thermosets - Connora's Recyclamine Technology enables the creation of recyclable carbon fiber composites. Importantly, the thermoset manufacturing waste can be recycled and re-integrated back into the manufacturing ecosystem.

There is a second category of high performance structural plastic called thermosetting plastics (or thermosets). While thermoplastics can be melted down from a solid and reshaped (thus recycled), thermosets are defined by an irreversible setting process. They are composed from two different liquid materials, a resin and a curing agent, which harden when mixed and heated. Once "set", thermoset materials, and products derived therefrom, cannot be melted and recycled as thermoplastics can. They can only be removed from the environment via incineration. The ordinary consumer is likely unaware about the fact that there still remains a non-recyclable class of plastic. This is understandable considering that, historically, thermosets have mainly been used for adhesive and coating applications. This is changing. Thermosets, such as epoxy, are now commonly used as the plastic matrix in performance composites, also known as fiber reinforced plastics (FRPs). Composites have the lightweight advantages of a plastic and the extra strength generated from the fiber reinforcement. As the cost of carbon fiber has dropped substantially, the prevalence of composites has increased dramatically. This is driven primarily by the push for implementation of lighter-weight alternatives to traditional structural materials such as steel and aluminum. Composites are now found in many familiar engineering applications, including automotive and aviation parts, wind turbine blades, structural supports in buildings, and high performance sporting equipment.

Thermoset composites are not recyclable because thermoset plastics were never designed to be recyclable in the first place. As the composite market continues to grow, the use of non-recyclable thermosets places the industry in a juxtaposition. On one hand, carbon composites are essential for meeting energy efficiency goals and café standards in the transportation industry, and on the other hand the materials required to make these products are not recyclable. While attention could clearly be focused on the fact that end-of-life products are not recyclable, the waste generated by composite OEMs is increasingly becoming both an environmental and economic burden.

The problem is perhaps best illustrated by Boeing's newest commercial jet model, the 787 Dreamliner. The Dreamliner represents a major transition in how Boeing constructs airplanes. Jet bodies have historically been constructed from metal, but the 787 is composed of 50% composite materials by weight, including a one-piece composite fuselage. The use of composites gives the Dreamliner revolutionary fuel efficiency, a key milestone toward reduction of in CO2 emission. At the same time, Boeing's manufacturing activities now produce large quantities of composite waste, estimated to be in the millions of lbs. Throughout the entire industry, between 10-30% of composite input raw materials in (i.e. thermoset + fiber) typically gets wasted during composite manufacturing. Unlike thermoplastic, thermoset plastic waste can not be re-integrated back into production. The lost economic value from the landfilling of thermoset composite waste is now in the $100s of millions. If just one car company switched from metals to composites, this number would be in the billions. One way or another, the lost material value and the disposal fees get passed on to the consumer and the wasted resources get passed on to the environment.

Connora Technologies (Hayward, CA) is an advanced materials startup solving the thermoset recycling problem for the industry by reengineering thermoset plastics using smart chemistry. Connora is in the process of commercializing a series of high performance epoxy curing agents, called Recyclamines®, enabling the manufacture of inherently recyclable thermoset composites. Recyclamine® is a drop-in replacement for standard thermoset composite manufacturing processes. This will enable OEMs to meet shifting regulatory end-of-life compliance, while also moving them toward "zero-landfill" operations via the recycle of manufacturing waste. Total composite recycling is achieved using a specific chemical recycling process, whereby the fibers and thermoset can be separated, recovered, and reused. Key to Connora's technology is the transformation of the thermoset into its thermoplastic counterpart. The recycled fibers maintain virgin quality and the reclaimed thermoplastic has unique performance characteristics, with mechanical properties similar to nylon and adhesive properties that parallel epoxy thermosets.

Connora has been engaged in development projects with leading brands & OEMs to prove that for the first time, the cradle-to-cradle life cycle is possible for thermoset products. For example, Recyclamine Technology enables complex products like skis & snowboards to be recyclable. All of the individual components used in product manufacturing can be recovered end-of-life through the thermoset recycling process (Figure 2). Importantly, all of the thermoset plastic wasted in the manufacturing process (commonly referred to as "flashing" in the ski & snowboard industry) can be recycled into an injection molding grade thermoplastic and used to make another plastic product such as a ski binding (Figure 2).

FIgure 2. Recyclamine thermoset technology allows manufacturers to design fully recyclable products, and recycle & repurpose thermoset manufacturing waste back into thermoplastic products.

The wide-scale adoption of composites for automotive applications will be contingent on effective cost-reduction strategies. The advent of High Pressure Resin Transfer Molding [HP-RTM] has helped move the thermoset composite industry towards this goal, enabling cycle times of minutes. This advanced processing technology has been integral to the development of BMW's I-Series, which is the first serial production carbon-fiber car. However, the cost of composites remains artificially high due to the fact that thermosets are not recyclable. Figure 3 shows fully recyclable carbon fiber panels made using HP-RTM made with Recyclamine® Technology. The carbon fiber lay-up remains fully intact and can be reused again to make another composite panels. Such efficient recycling and reintegration of composite waste can further reduce the cost of composites by 2.5-7.5%, depending on the amount of manufacturing waste generated.

FIgure 3. Recyclable carbon fiber composites made with Recyclamine® Technology. Automotive panels before & after recycling. Carbon fiber can be recovered and reused to make another panel (not shown).

While research and development on new molecules has all but stopped in large chemical companies, Connora Technologies was founded on the premise that smart molecules are key for the development of materials with fundamentally new performance. As Recyclamine Technology begins to take foot in the composite industry, Connora will look to transpose the same concept that drives thermoset recycling into other industries: Reverse, Remove, Release….Re-imagine.