Driving Sustainability: Advances in Waste Management for Green Graphene Synthesis and Lightweight Thermoplastic Manufacturing

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Recycling studies in the waste tires, waste plastics, and waste carbon fiber reinforced composites industries play a crucial role in advancing sustainable waste management practices, reducing environmental impact, and fostering a circular economy mindset. Instead of traditional recycling processes, it is possible to produce high value-added carbon nanomaterials by using a rich hydrocarbon source in plastics and rubbery materials which are also primary source for graphene. Also, sustainable green graphene enhanced compounds can be produced by gathering different waste sources and providing suitable compatibilization with sizing solutions and functionalized additives in compounding process. In addition, stringent regulations in the automotive sector mandate a minimum of 25% recycled materials, including 25% post-consumer waste, in compositions, aiming for net-zero emissions. At this point, upcycling is a significant concept to bring an end to the life cycle of materials and open various new application routes for graphene production and its sustainable plastic materials. The present work provides an insight into the importance of green synthesis methods in graphene nanomaterials synthesis by combining recycling and upcycling technologies. It is observed that different plastic wastes based on their aromaticity and alifaticity and thermoset wastes and biomass can lead to the formation of different dimensional graphene structures such as 2D plates/sheets and 3D spheres. The produced graphene materials are used for the design of lightweight composite structures for automotive and plastic industry by reducing adverse environmental impacts and adopting energy-efficient manufacturing technologies. Furthermore, responsible management of carbon fiber waste through recycling and reuse initiatives is imperative for sustaining the carbon fiber industry and mitigating its environmental footprint. The widespread use of carbon fiber reinforced composites (CFRP) and the anticipated growth in consumption have led to substantial CFRP waste accumulation. Through the development of graphene derived from waste, compound formulations are devised using recycled polymer sources (e.g., PP and PA), natural fibers (such as hemp and flax), and recycled carbon fibers, aiming to replace glass fiber reinforced plastic in commodity products. Additionally, Life Cycle Assessment studies integrate into raw materials and parts, fostering circular economy models. Consequently, this multidisciplinary work ensures significant innovation potential of graphene in the field of thermoplastic-based composites and overcomes the needs by addressing greenhouse gas emissions with sustainable designs.