Mechanical recycling of Thermoplastic Composite waste: A Life Cycle Assessment

The debate over thermoplastic composite (TPC) waste management continues to cycle without resolution. While TPC initially gained traction for its recyclability, in practice, it often meets the same fate as thermoset (TS) composites—piling up in landfills or incinerated despite its theoretical reusability. Adding to the concern, the production of TP resins like PA6, PEEK, and PPS is typically more CO_2-intensive than the epoxy resins commonly used in TS composites. If TPC is to remain a sustainable alternative, addressing these challenges is crucial.

By directly addressing the supply and demand challenges of the TPC industry, SPIRAL offers a straightforward, effective solution to close the loop on TPC waste. Starting from the collection of material, we make sure it is efficiently recycled and suitably processed for a wide range of manufacturing technologies, including injection molding, additive manufacturing, and other hybrid processes.

Figure 1. SPIRAL's solution of open loop recycling of TPC waste

SPIRAL's recycling process; Low energy consumption, high throughput rates

To validate our process, we conducted a comparative Life Cycle Assessment (LCA) in accordance with the ISO 14044 and ISO 10440 standards. The analysis was performed using the Sphera LCA software suite, using its connected databases to ensure robust and accurate data coverage.

The results indicate that SPIRAL's recycling process has a significantly lower greenhouse gas (GHG) impact compared to the production of virgin materials. Notably, the recycling process even has a lower environmental impact than the incineration of the same material. Furthermore, when comparing the energy efficiency of the granulation process, SPIRAL's mechanical grinding process consumes 85% less energy than the reported number in the Sphera databases.

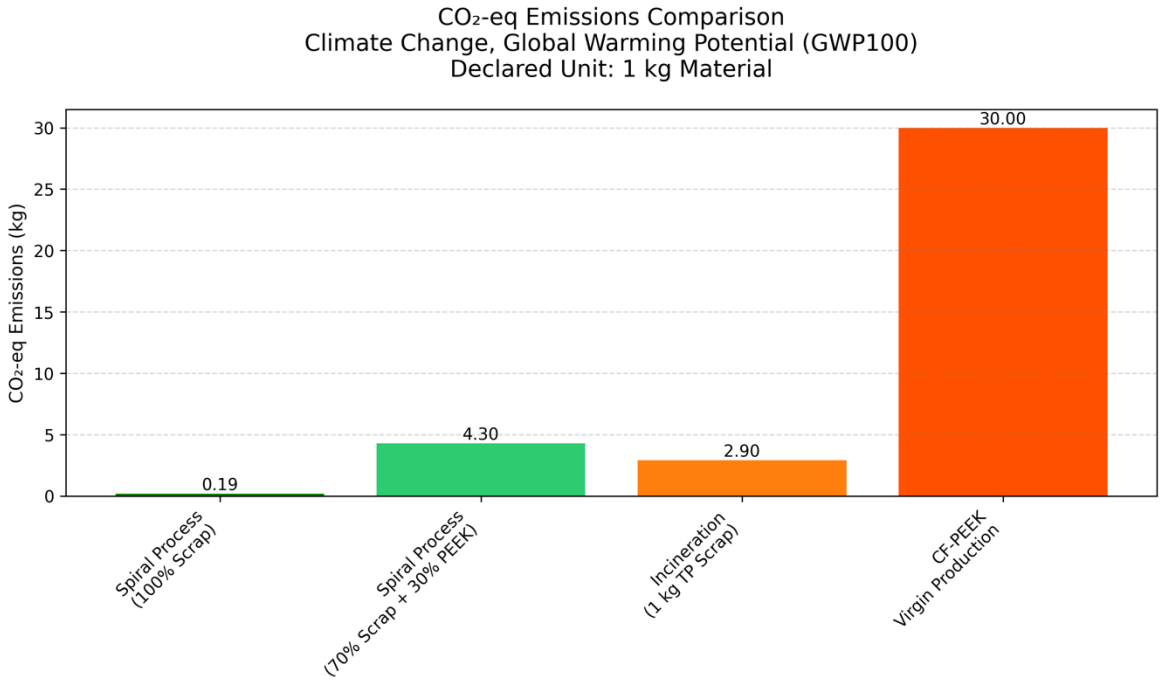

Figure 2. Environmental impacts of different material scenarios. [1]

To further illustrate the added value of SPIRAL´s closed-loop process, a cascading scheme according to ecochain´s methodology was simulated.[2] The total emissions of 1 kg TPC/PEEK granulate (as was calculated in scenario 2 of figure 2) over the amount of lifecycles was extrapolated and is shown in Figure 3. Assuming no additional virgin PEEK or CF are used for recycling after the first lifecycle, the global warming potential drops exponentially until it reaches the value of the added emissions related to the SPIRAL recycling process, which is below 0,2 kg CO2.eq per kg.

Although this LCA is simplified and does not contain a sensitivity analysis for the sources, it clearly illustrates the immediate potential environmental benefits of SPIRAL´s recycling technology.

[1] **Carbon emissions and plastic waste: Incineration's impact on the environment.** Retrieved from QMRE.

[2] **Approaches to recycled content allocation in LCA.** Retrieved from Ecomatters (Cut-off approach 100:0.

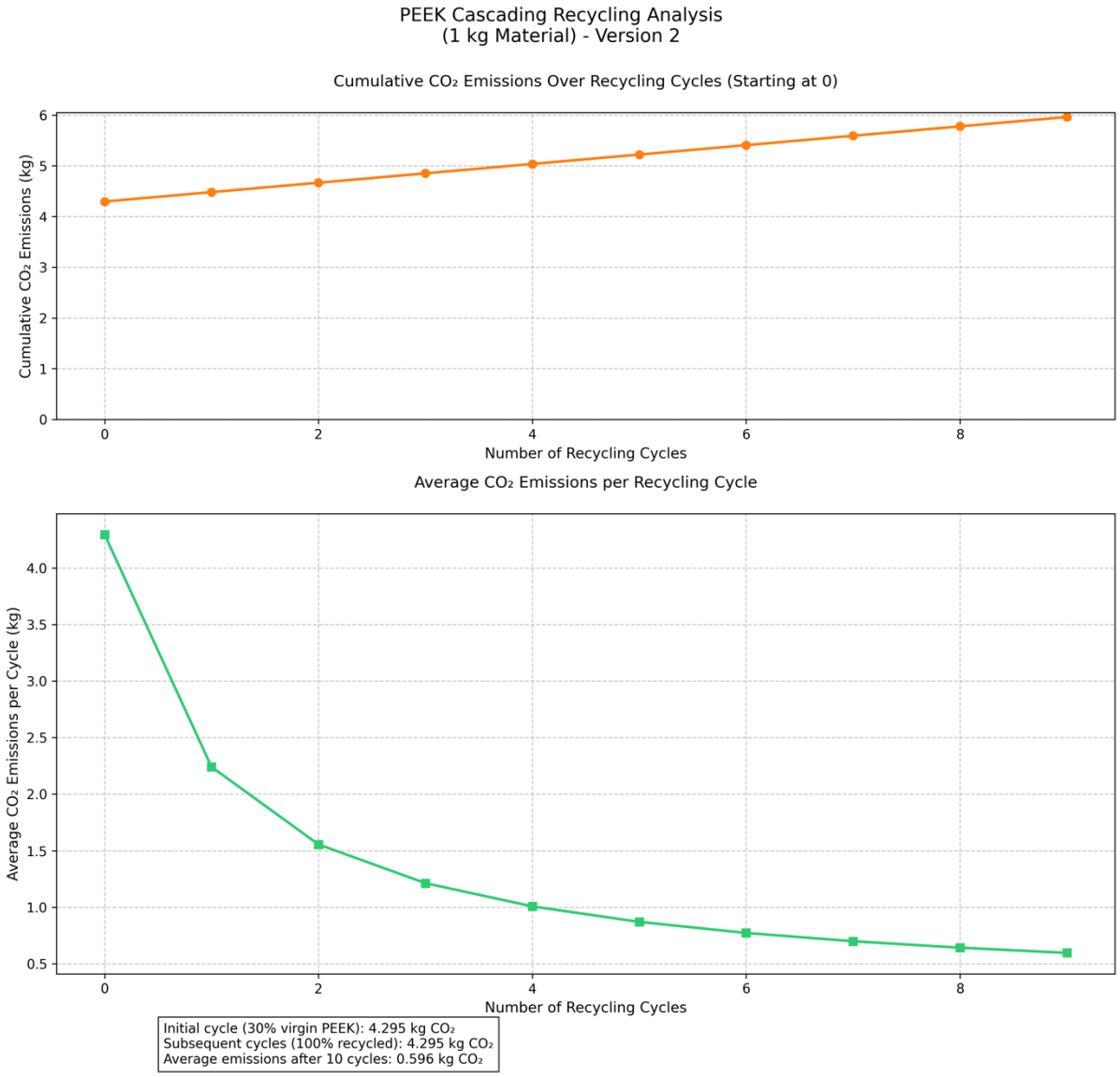

Figure 3. Global Warming Potential of TPC/PEEK granulate. Top image shows the cumulative emissions for 0-10 life cycles. On the x-axis the amount of closed loop cycled are projected. The y-axis shows the cumulative emissions. The bottom image shows the Average emissions per life cycle. The x-axis again shows the number of cycles. The y-axis shows the emission per kg material.

Conclusion

While regulatory incentives for TPC recycling remain limited, SPIRAL's mechanical recycling process offers a compelling solution for reducing the environmental impact of thermoplastic composites. Our process retains maximum material value with minimal energy consumption, providing an eco-friendly alternative to landfilling or incineration. Moving forward, establishing a robust secondary value chain through collaboration and innovation will be crucial for accelerating the transition to a circular economy. Finally, we extend our gratitude to our partners for their contributions: **DLR Institute of Lightweight Systems** for providing expert information on LCA and composite, and **TPRC** for laboratory measurements and expert insights on TPC recycling.