# Plastic Recycling-Value Preservation and Carbon Avoidance

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## Abstract

Plastic recycling is a complex issue that requires a systematic analysis of the issue. PEP Review 2019-15 *Plastic Recycling- a Process Economics Framework* [1] proposed a quantitative way of examining various recycling options, including mechanical (physical) recycling back to polymers, chemical recycling to monomers, molecular recycling to feedstocks, and energy recycling. Each recycling option will have a different re-entry point in the circular economy with impact on future demand of prime materials at plastic, monomer, feedstock, and natural resource level, respectively. At each level of recycling, we identified three key factors that will determine the future growth of each recycling option: (1) recyclate quality; (2) comparative production economics; and (3) relative carbon footprint of recycled versus competing prime material.

While the most urgent goal for plastic recycling is to reduce pollution to the environment, PEP Review 2019-15 indicated that there is a need to examine the issue holistically from the value preservation and sustainability perspectives. Not all recycling technologies are created equal, hence quantitative measures are required to compare the relative merits of each proposed recycling technology. This review introduces two quantitative yardsticks: value preservation (VP) and carbon (emission) avoidance (CA) to assess the relative sustainability of each level of recycling.

The goal of each recycling option is to bring back a post-consumer plastic to reusable polymer. The total circular economics need to be considered, which are defined as the total cost of the recycling step plus all the process costs required to bring the recyclate back to the polymer state. For example, chemical recycling to monomer(s) needs to include additional costs of converting monomers back to polymer. Likewise, molecular recycling to feedstock needs to include all additional steps and associated costs of converting feedstocks back to monomers and then to polymers. The circular economics are then compared with the integrated economics of prime polymer—from natural resource(s) to feedstock(s), to monomer(s) and then to polymer. Value preservation (VP) is defined as:

VP= product value per ton of prime plastic – product value of recycled product

Product value is defined as the total production cost + 15% ROI (return of investment). Product value is a measurement of the product's worth to a producer on a per ton basis. To produce one ton of product by any process, a producer must be able to cover all production costs plus a reasonable rate of return, which PEP assumes to be 15%. Value preservation (VP) is trying to answer the question that when one ton of plastic is recycled to replace one ton of prime plastic production, how much value does it preserve? Value preservation measures the economic sustainability of a recycling process.

The environmental sustainability of each level of recycling should be taken into consideration as well. The accumulated carbon footprint of each recycling option back to polymer is a good yardstick for comparison. Apart from the fact that carbon footprint impacts climate change and every company is

trying to reduce it, carbon footprint is heavily related to the energy (fuel and electricity) consumption of a process and thus, a good measure of sustainability. The accumulated carbon footprint of each recycling option is then compared with the accumulated carbon footprint of integrated prime polymer production from natural resources up to polymer production. The environmental sustainability can be measured by carbon (emission) avoidance (CA), which is defined as:

> CA= (cumulative carbon footprint of integrated prime polymer production - accumulated carbon footprint of recycling option

CA is trying to answer the question that when one ton of plastic is recycled to replace one ton of prime plastic production, how much carbon emission does it avoid?

To develop the two yardsticks, this review first presents the integrated economics and carbon footprint of prime PET, HDPE, LLDPE, and LDPE as benchmarks, with each plastic starts from either ethane or wide-range naphtha steam cracking to produce ethylene. The review then presents the circular economics and accumulated carbon footprint of PET and HDPE mechanical recycling, PET chemical recycling, and mixed-polyolefin molecular recycling to feedstock to be compared with corresponding integrated-prime polymer production using VP and CA as metrics.

Other than recycling back to polymer, converting waste plastic to electricity and heat in an incinerator are other options. In this review, we also compare the value preservation and carbon emission per ton of waste PET, HDPE, and mixed olefins with three monetization options: recycling to reusable plastic, converting to heat, and generating electricity.

The comparison is made based on USGC location first, and then the comparison is extended to Germany and China based on the production economics and carbon footprint of the same recycling and prime plastic processes in each region.

Recently, there have been a large number of new recycling processes proposed and a flurry of investments by major plastic producers in incipient new recycling processes. The VP and CA expounded in this review are good yardsticks for all players to quantitatively measure the merit of each recycling process before making major investment decisions.

# Contents

# Tables

# Figures



 

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