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Plastic Recycling and Sustainability—a Process Economics Framework

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Abstract

Recycle of plastic wastes is a war that our industry and global community must win. The Earth is groaning "I cannot breathe" due to the bulging landfills, and marine creatures are crying "you are killing me" with all the plastic litter in our riverways and oceans. Plastic recycling and sustainability must be a high priority for the petrochemical industry, environmental groups, non-profit organizations, and government regulators. In 2018, global production of five major plastics (PE, PP, PS, EPS, and PET) for packaging was around 112 million tons, which is expected to grow at 3.7% per year to reach 174 million tons by 2030 [1]. Yet, only about 14–18% was collected for recycle [2]. The unfortunate consequence is that the plastic waste will continue to pile up the landfills and pollute our water ways and oceans if the rate of plastic recycling does not increase dramatically and quickly.

In a recent study by IHS Markit titled "A Sea Change: Plastics Pathway to Sustainability [3]," the report identified the following major impediments to achieving higher recycle rate:

- Economics have not been established to enable viable recycling
- The plastic recycling industry is too fragmented and underdeveloped industry structure to allow more effective waste collection
- There are too few recycling processes that are robust, scalable, and economically viable
- There is not enough unbiased data to define the problem and measure progress

This review examines plastic recycling and sustainability from a process economics viewpoint to examine ways to remove barriers for significantly lifting the future recycle rates. We start by presenting a clear process economics framework to enable full analysis of plastic production and recycle value chain. Plastic recycling should be viewed as a proactive way to recover value, not only as a passive environmental pressure to reduce waste. To produce one ton of plastic, each step requires raw materials, energy, labor, and capital investment to convert a lower value feedstock to the highest value consumer products. Then due to poor waste collection infrastructure and lack of efforts or technologies to effectively and economically recycle plastics, most of the post consumer products end up in landfills or pollute our waterways and oceans. This is tremendous waste of resources and value that the chemical industry must try to recover for achieving circular economy.

To effect value recovery, we first examine all recycle options, including physical (mechanical) recycle to polymers, chemical or biological recycle to monomers or feedstocks, and energy recycle and discuss their relative merits. A significant increase in recycle rate can only be achieved if recycle economics are favorable and quality of recycled material is comparable to the virgin plastic. We select a few cases to compare economics of recycling plastic waste to polymers or monomers with production economics

of corresponding virgin materials. And if the recycle economics is not favorable, what changes in recycle infrastructure or what improvement in technology are needed to make it favorable in each case.

As the recycling rate and demand of recycled plastic picks up, it is going to reduce the demand of virgin plastics. We have derived a set of equations and create an Excel template to estimate the impact of future plastic recycling acceleration rate on demand growth rate of virgin plastic, which mainly depends on three parameters: 1) future total demand growth rate, 2) current recycle ratio, and 3) future plastic recycling acceleration rate. The template can be used to estimate the impact of recycling on future demand growth of all plastics regionally and globally under various scenarios. The template can also be used to estimate how much the recycling rate needs to be accelerated in order to achieve a government or industry recycle target. The same template also allows an estimate of leakage to the environment which is important to the regulators. In this review, we use PET recycling in the United States to demonstrate how the template can be used to estimate the impact of PET package recycling acceleration rate on the future demand of virgin PET and leakage to the environment under three scenarios: 1) a zero recycling growth rate scenario, 2) an EPR (enhanced producer responsibility) 30% recycle by 2030 scenario, and 3) ACC (American Chemistry Council) 100% recycle by 2040 scenario.

The economics framework and quantitative analysis provided in this review will facilitate an on-going discussion of plastic recycling leading to a more effective solution for the industry.

Contents

Tables

Figures

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