EXECUTIVE SUMMARY

Environmental Assessment of Full Brightmark Products

Independent Evaluation of

BRIGHTMARK
PLASTICS RENEWAL

October 2021

Summary

Brightmark's plastics renewal technology is a significant environmental improvement compared to manufacturing plastics from virgin fossil resources. Brightmark's plastics renewal technology:

1. Saves 82% of natural resource energy
2. Saves 39% of carbon footprint (CO_{2eq}) based on U.S. waste management
3. Saves 139% of carbon footprint (CO_{2eq}) based on regions with 50% incineration
4. Saves 46% water loss

This document summarizes a Life Cycle Assessment report produced by Environmental Clarity, Inc. for Brightmark in March 2021. The information herein has been third-party reviewed in April 2021 and concluded to be detailed, verifiable, and compliant with ISO 14041 and 14044.

Overview

Brightmark has developed technology to meet important needs of our society for the management of potentially reusable polymers (or plastics). Brightmark's plastic renewal goal is to divert 8.4 million metric tons of plastic from landfills by 2025. "Simply put, the life cycle analysis shows that products created by plastics renewal require 17% the amount of fossil fuels as the same family of hydrocarbon plastics made from virgin petroleum," said Matthew Realff, Professor at Georgia Tech. "These improvements are significant when comparing technologies to make these products from virgin resources.

A detailed, quantitative life cycle analysis of Brightmark's plastics renewal technology was conducted by Environmental Clarity, Inc., specialists in life cycle analysis and developers of one of the largest life cycle databases. This Executive Summary describes the assumptions, framework, and key findings related to quantifying the environmental improvements of plastics renewal. Overall, there are three groups of activities included in the environmental life cycle analysis: plastics renewal and supply chain; the resulting avoided waste management system because of recycling; and the cradle-to-gate production of equivalent chemical products that would have to be made if recycling of waste plastics did not occur. The activities included in the life cycle boundary are shown in Figure 1.

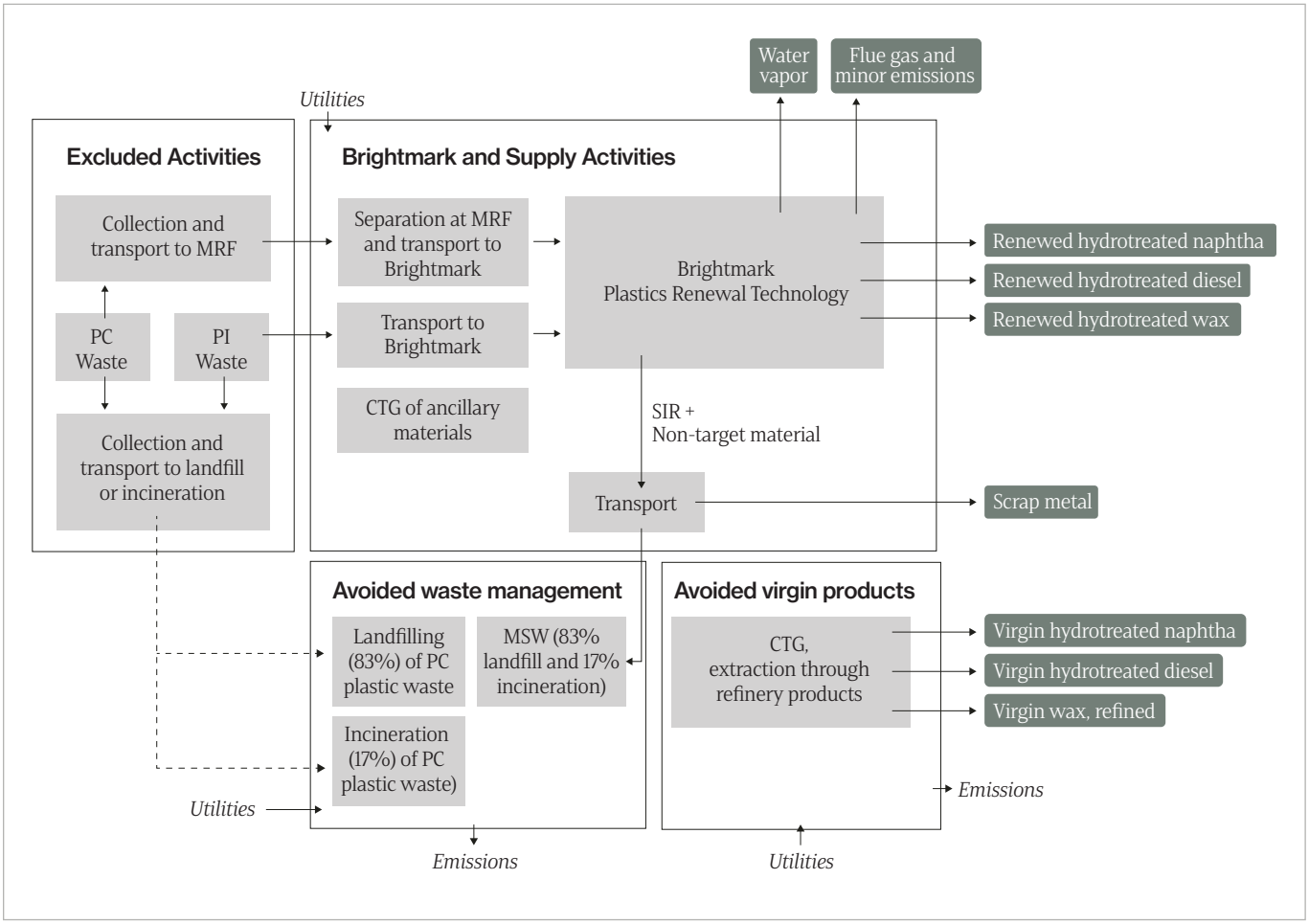
For the first group, Brightmark begins with post-consumer waste plastic arriving at a materials recovery facility (MRF) or post-industrial (PI) plastic arriving at the point of collection, and the process continues to three distinct saleable products going to the marketplace (naphtha, diesel, and refined wax). An additional smaller product is fuel gas that is harvested to supply the thermal needs of Brightmark's plastics renewal facility. Meanwhile, a small amount of solid inert residue (SIR) is removed and sent to the landfill alongside sorting reject, and recovered metals are sent to a recycler.

The second group is the set of systems governments have set up to manage waste plastics at the end of life when these plastics are not recycled, namely a mix of incineration and landfill. Thus, this group is referred to as avoided waste management.

The third group is the industrial production of these same three products, beginning with fossil natural resources in the earth and then converting these to equivalent end materials. These are commonly referred to as virgin products (that is, not from recycled materials) or avoided virgin production.

Plastics renewal is combined with the avoided waste management activities to produce a cradle-to-gate impact of 1 metric ton of Brightmark total saleable products (total Brightmark system). This is compared to the cradle-to-gate impact of the virgin production to produce the equivalent products, and the difference is the net benefit from the Brightmark process.

FIGURE 1:
Brightmark Plastics Renewal Technology Activities Included In LCA



All three of these life cycle assessment activities are measured with the same metrics to allow consistency and overall assessment, covering energy/fossil resources, air, and water systems. These metrics are:

1. **Fossil energy resources are extracted to produce both materials and energy (electricity and heat), referred to as the natural resource energy total (NREt), (MJ high heat value)**

2. **Carbon footprint (kg CO_{2eq}), one measure of global atmospheric environmental impact,** *and*

3. **Water used that is not treated to quality standards and returned to aquatic systems (known as water loss).**

Results

Plastics Renewal Technology and Supply Chain

Plastics renewal is an integrated process beginning with the life cycle assessment of the waste plastics plant inputs from two main sources: MRFs, and PI. The incoming waste plastics are preprocessed to remove about 17% of weight, of which about 1.5% is metal that is recycled elsewhere. The remaining targeted waste plastics are input to a vessel at high temperatures then cooled to produce a mixed product for further processing (the fuel gas previously described) and SIR, which is 7.5% of the weight of the pyrolysis input. The pyrolysis oil is then processed and separated into saleable products, which is 26% naphtha, 52% diesel, and 22% refined wax, as well as some additional fuel gas for the pyrolysis reactor.

For the purposes of this analysis, energy was measured as total natural resource energy (NREt), which is composed of fossil fuel energy combusted (NREc) to produce process heat, electricity needs, and natural resource energy for materials (NREm). In Brightmark's case, the fuel use for materials includes the supply chains for natural gas and to manufacture the solvents for wax purification. The boundary includes the MRF and transport of both PC and PI materials to the Brightmark facility. The NREt for plastics renewal is added to the avoided waste management in Table 1. Using carbon footprint (or global warming potential, GWP) as another environmental life cycle metric, and the same boundary as that used for energy use, the plastics renewal accounts for 830 kg CO_{2eq} per metric tons of saleable products. This carbon footprint is generated 63% from the actual process emissions and 37% from energy use emissions. Water use was found to be 1,360 kg per metric ton of saleable products.

Avoided Waste Management

The second activity in the life cycle analysis is avoided waste management, also known as the end-of-life (EOL) direct benefit of plastics renewal, namely the fact that the waste plastics are no longer a part of the waste management system of landfill and incineration. In 2019, the United States landfilled 83% of non-recycled polymers and incinerated the remaining 17%. Incineration produces significant CO_2, emissions, but some electricity and or heat are recovered. In this study, we assumed that only electricity was recovered at 17% efficiency. Because waste management is avoided, this impact is subtracted from the Brightmark system in this analysis. Therefore, the incineration-direct avoided CO_2 emissions are a negative value and generated electricity is a positive value in Table 1. Generated electricity offsets a portion of the direct CO_2 emissions, but the net CO_2 from avoided incineration is a large negative value.

The avoided waste management and Brightmark plastic renewal activities are combined in Table 1. The avoided waste management carbon footprint depends strongly on whether the prevailing waste management is incineration or landfill. In Europe, the fraction that is incinerated is estimated to be 40-60%, which is significantly higher than that of the United States (17%). A sensitivity analysis with an incineration ratio more typical of Europe (50% landfill and 50% incineration) was also included. For the boundary of municipal solid waste from collection to landfill/incineration, the avoided EOL for plastics renewal is -410 kg CO_{2eq} per metric ton of Brightmark saleable products. In the European-related scenario, it is -1,140 kg CO_{2eq} per metric ton of Brightmark saleable products. The third metric for avoided EOL activities is 740 kg water use per metric ton of saleable products.

Avoided Virgin Products

The third activity in the life cycle assessment derives from avoiding products comparable to Brightmark saleable product that are instead made from virgin fossil resources., including hydrotreated naphtha, hydrotreated diesel, and refined paraffin wax. The life cycle analysis of these avoided virgin products uses a boundary beginning with natural resource extraction, and includes transportation and refining into the hydrocarbon materials equivalent to one metric ton of the Brightmark saleable products. Thus, the NREt for equivalent Brightmark saleable products is 55,600 MJ HHV Table 1. The total GWP for one metric ton of this mix of virgin products is 690 kg CO_{2eq}, with 3,890 kg of water use.

Net Benefit of Brightmark Plastics Renewal Technology

The cradle-to-gate environmental impact of plastics renewal technology includes the impact of the Total Brightmark System (activity 1) to make one metric of saleable products plus the impact of activity 2, the avoided waste management. This Total Brightmark system is compared to activity 3, which is the cradle-to-gate manufacturing of the same mix of virgin materials. The net benefit from switching from virgin production to the plastics renewal is activity 3 minus the sum of activities 1 and 2, and this is expressed as a percentage of cradle-to-gate virgin production in Table 1. In the U.S. 2019 scenario, the greatest benefit from plastics renewal is 82% NREt savings, followed by 46% water use savings and a 39% reduction in carbon footprint. The carbon footprint benefit in geographical regions where incineration is higher (50%) gives a larger carbon footprint benefit (139%). These improvements are significant when comparing technologies to make chemical products either from virgin resources or waste plastics.

TABLE 1:

Environmental life cycle analysis of Brightmark's plastics renewal technology per 1000 kg of Brightmark or equivalent products

Metric	Total Brightmark System*	Cradle-to-gate Measure of Virgin Equivalent Products	Total Brightmark Savings**
Energy Use: Natural Resource Energy Total, NREt, MJ HHV	10,100	56,600	82%
U.S. Carbon Footprint: kg of CO_{2eq}	420	690	39%
Europe Carbon Footprint: kg of CO_{2eq}	-270	690	139%
Water Use: kg	2,100	3,890	46%

*Total Brightmark System = Brightmark renewal technology plus avoided waste management due to recycling

**Total Brightmark Savings are calculated as (virgin cradle-to-gate – total Brightmark system)/virgin cradle-to-gate. A negative value means CO_2 emissions were prevented.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