Technical white paper

Life Cycle Environmental Impact Assessment

Virgin PET vs. recycled PET used in HP ink cartridges

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Acronyms and Definitions

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

PET: Polyethylene terephthalate, a strong, lightweight plastic that makes up the majority of the mass of Hewlett-Packard (HP) ink cartridge bodies and lids

RPET: The term used in this study to refer to the recycled content PET in cartridges, and is made up of CPET, RBR, and other additives (glass fiber, etc.)

RBR: Recycled bottle resin

CPET: “Closed-loop PET”, or the recovered PET coming directly from cartridges and made into new HP cartridges

EitB: “Envelope in the Box” program, a former HP Planet Partners program aspect

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Executive summary

Hewlett-Packard's (HP) environmental programs help create a more sustainable world. From products designed for the environment, extensive return and recycling programs, and technical innovations, HP is committed to reducing our environmental impact—and yours. Some of the key milestones in HP's history of manufacturing and recycling ink cartridges include:

- In 1991, HP began Planet Partners, a worldwide program to provide customers with a free and convenient way to recycle their empty Original HP ink and LaserJet print cartridges. Through the HP Planet Partners program, HP collects, sorts, and disassembles ink cartridges. Recovered plastic, metals, and other materials are recycled for reuse. Over time, the HP Planet Partners program expanded and now serves 49 countries for ink cartridge recycling.[1]
- Polyethylene terephthalate (PET), a strong, lightweight plastic, is the primary material in most HP ink cartridge bodies and lids. In 2005, HP began to produce ink cartridge lids and bodies with recycled PET. Some of the RPET comes from HP Planet Partners program. Cartridges are collected, sorted and shredded as part of the HP Planet Partners program, and recovered PET from ink cartridges and other pre- and post-consumer products goes into new ink cartridges. The RPET from spent ink cartridges that goes into new cartridges is referred to as "closed-loop."
- In 2010, HP's design of a disassembly tool that helps reduce energy and water use and recovers a higher percentage of PET than earlier processes was deployed.[2]

In 2010, HP commissioned Four Elements Consulting to perform an environmental Life Cycle Assessment (LCA) to quantify and highlight the environmental benefits of using RPET in its ink cartridges. Since RPET is a direct replacement to virgin PET, the production of these was compared. Production of RPET incorporates the HP Planet Partners take-back program, transportation logistics, and the various process routes through which the cartridges go in order to get to cartridge-ready RPET. Cartridge-ready virgin PET is produced through conventional chemical manufacturing routes.

In October 2013, HP commissioned Four Elements to update the 2010 study to recalculate the environmental benefits of the recycled content cartridges produced to date. The update incorporates the latest data and statistics on HP Planet Partners worldwide program, ink cartridge recycling facilities, and LCA databases. The HP Planet Partners program encompasses primarily North America (NA) and Europe, Middle East and Africa (EMEA). The update evaluated the environmental performance in these geographies from two viewpoints:

1. Cumulatively, accounting for a snapshot of the total benefits of using open- and closed-loop recycled content PET in cartridges from 2005 through fiscal year 2013 (FY13). This information enabled HP to understand the total environmental benefits of the world-wide Planet Partners ink program since 2005, and use metrics to quantify and communicate information regarding the HP Planet Partners program, including total savings due to the use of recycled content PET in HP ink cartridges.
2. As a snapshot of the Program today, the study modelled the FY13 HP Planet Partners program logistics and infrastructure. This information enabled HP to understand the environmental benefits of the current world-wide HP Planet Partners ink program, identify strong and weak points of the program, assess areas for improvement both with logistics and technological changes, and highlight the potential environmental benefits of using RPET vs. virgin PET in ink cartridges.

Results summary

Based on the data and assumptions from the LCA study, the replacement of virgin PET for RPET in HP cartridges shows a clear advantage for eight of the impact categories. The results tables on page 5 show that for most of the categories, RPET performs better than or on par with virgin PET. RPET is less than 75% of virgin PET for six of the impact categories, including water depletion, freshwater eutrophication, fossil fuel depletion, total energy, climate change, and human toxicity. The least performing RPET category was freshwater ecotoxicity (approximately 3.7 times worse than virgin PET in the cumulative model and 3 times worse in the 2013 model). This was primarily due to the management of waste ink and Polyurethane (PUR) through the incinerator. The data used to model incineration at the recycling facilities were based on LCA data sets on solvent and PUR incineration, which may or may not be representative of the incinerators used by the Planet Partners recyclers. Thus, these ecotoxicity results might be different if data from the HP Planet Partners incinerators were used instead.

[1] Program availability varies. Original HP cartridge return and recycling is currently available in more than 49 countries, territories and regions in Asia, Europe, and North and South America through the HP Planet Partners program. For more information, visit hp.com/recycle.
[2] Beginning in 2010, the recycled PET produced by Lavergne contained no virgin PET.

Overall results: Cumulative model

Impact category	Unit	RPET (Cumul Model)	Virgin PET	RPET as % of Virgin	Use of recycled plastics vs. virgin plastic
Climate change	kg CO2 eq	2.04	3.06	67%	33% less
Ozone depletion	kg CFC-11 eq	1.1 E-07	1.1 E-07	102%	2% more
Terrestrial acidification	kg SO2 eq	0.01	0.01	88%	12% less
Freshwater eutrophication	kg P eq	2.7 E-04	7.5 E-04	36%	64% less
Human toxicity	kg 1,4-DB eq	0.31	0.44	72%	28% less
Photochemical oxidant formation	kg NMVOC	0.01	0.01	101%	1% more
Particulate matter formation	kg PM10 eq	4.5 E-03	5.5 E-03	82%	18% less
Terrestrial ecotoxicity	kg 1,4-DB eq	2.1 E-04	2.0 E-04	104%	4% more
Freshwater ecotoxicity	kg 1,4-DB eq	2.3 E-03	6.3 E-04	372%	272% more
Water depletion	m3	1.45	5.76	25%	75% less
Fossil depletion	kg oil eq	0.70	1.51	46%	54% less
Cumulative energy demand	MJ	33.91	72.27	47%	53% less

Overall results: 2013 model

Impact category	Unit	RPET (2013 Model)	Virgin PET	RPET as % of Virgin	Use of recycled plastics vs. virgin plastic
Climate change	kg CO2 eq	2.06	3.06	67%	33% less
Ozone depletion	kg CFC-11 eq	1.2 E-07	1.1 E-07	106%	6% more
Terrestrial acidification	kg SO2 eq	0.01	0.01	93%	7% less
Freshwater eutrophication	kg P eq	2.5 E-04	7.5 E-04	33%	67% less
Human toxicity	kg 1,4-DB eq	0.32	0.44	72%	28% less
Photochemical oxidant formation	kg NMVOC	0.01	0.01	102%	2% more
Particulate matter formation	kg PM10 eq	4.7 E-03	5.5 E-03	85%	15% less
Terrestrial ecotoxicity	kg 1,4-DB eq	2.0 E-04	2.0 E-04	96%	4% less
Freshwater ecotoxicity	kg 1,4-DB eq	1.9 E-03	6.3 E-04	302%	202% more
Water depletion	m3	1.38	5.76	24%	76% less
Fossil depletion	kg oil eq	0.69	1.51	46%	54% less
Cumulative energy demand	MJ	33.80	72.27	47%	53% less

The results tables shown above should be read across so that impact categories are treated as distinct and independent from one another. The overall results tables present the impacts to produce 1 kilogram (kg) of RPET in a cartridge and 1 kg of virgin PET in a cartridge. The fifth column in the tables presents RPET's percentage of the virgin results, where a lower percentage is more favorable for RPET. The sixth column presents the difference in each category when using RPET instead of virgin PET.

This document is intended for public use. A more detailed, confidential version of this report is on file with HP.

See Appendix 1—Detailed results for more information.

Methodology

This study was conducted in strict accordance with the International Standards Organization (ISO) guidelines for conducting LCA including the ISO principles and framework specified in ISO 14040, as well as the guidelines specified in ISO 14044.[3] LCA is a tool for the systematic evaluation of the environmental impacts of a product through all stages of its life cycle, which include extraction of raw materials, manufacturing, transport and use of products, and end-of-life management (e.g., recycling, reuse, and/or disposal).

The preceding RPET vs. virgin PET study underwent a rigorous external peer review by Brian Glazebrook, an LCA expert with NetApp. He based his review on credibility and objectivity of the data and results, as well as conformance with ISO 14040 and 14044 standards on LCA. It should be noted that his review does not represent an endorsement by NetApp of the intent or existence of the study. For the review process, he ensured the following:

- "The methods used to carry out the LCA are consistent with this International Standard,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent."

Because this study follows the same methodology and modeling approach and only data are updated, another peer review has not been performed.

Description of the systems

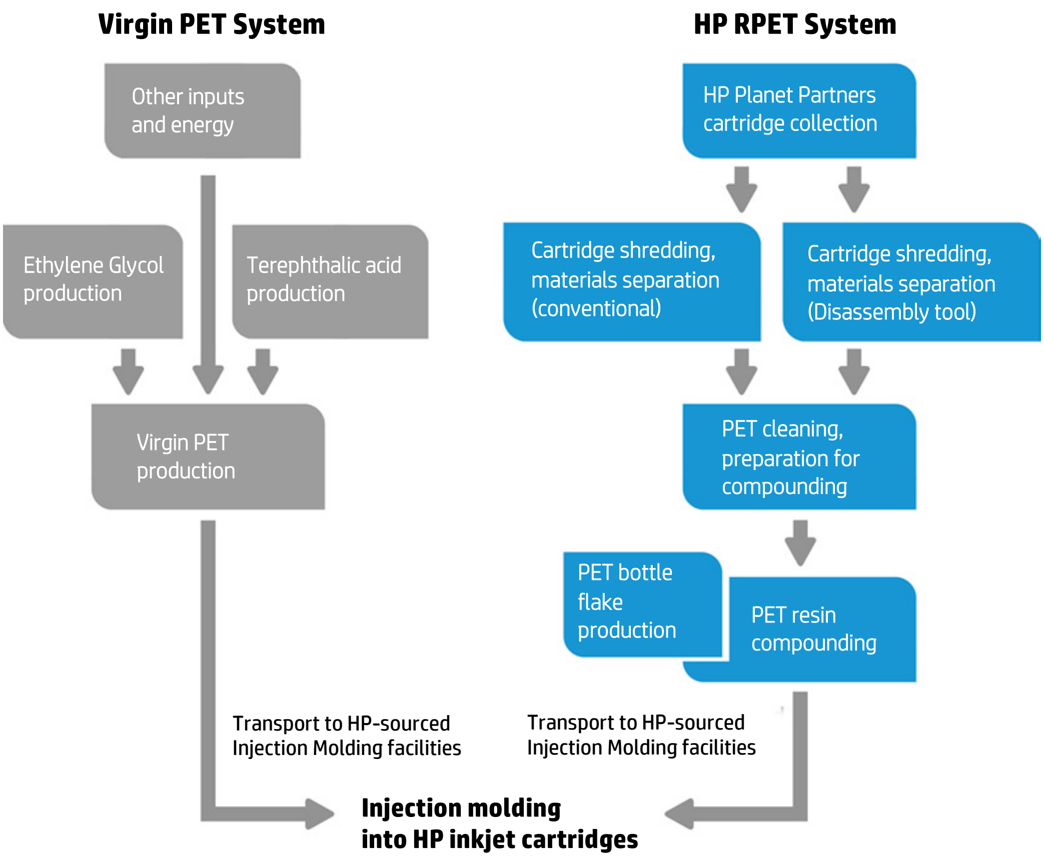
This study compared the production of HP's RPET (through the HP Planet Partners program) to the production of virgin PET used in HP ink cartridge manufacturing. The materials are functionally equivalent and are replaceable on a one-to-one basis, supported by the following:

- The RPET recovered by HP from used HP cartridges is blended with reclaimed PET bottles and additives, resulting in an RPET of sufficient quality to replace virgin PET in the production of cartridge lids and bodies. HP has rigorously tested the RPET material and formally qualified it for production of cartridge lids and bodies.
- RPET has been verified as a 1:1 replacement for PET on a mass basis (i.e., the body walls do not need to be thicker to make the RPET perform the same, etc.).
- The injection molding equipment uses the same quantity of incoming resin and the same process energy, regardless of a pure virgin PET or a blended PET.

Figure 1 on page 7 presents the overall study boundaries for the two materials compared.

[3] ISO 14044:2006, Environmental management—Life cycle assessment—Requirements and guidelines.

Figure 1. Simplified study system boundaries



The virgin PET system represents the cradle-to-gate of the sourced PET in HP ink cartridge manufacturing plants worldwide. This system starts at the production of PET precursors and manufacturing of PET resin, and continues through the distribution of the PET resin to injection molding facilities near final cartridge manufacturing.

The RPET system starts at collection of the spent cartridge from the consumer and ends with RPET at injection molding facilities near final cartridge manufacturing. The RPET system includes the worldwide HP Planet Partners operations and HP RPET production. As mentioned previously, in order to understand the global impacts of the RPET system, the comparison is evaluated both cumulatively (since 2005) and as a current snapshot of the RPET production operations. The next system boundary figures (Figure 2, page 8 and Figure 3, page 9) represent more detailed breakdowns of the HP systems.

There are several categories of recycled content PET materials in this study, defined as follows:

- CPET ("closed-loop PET"): the recovered PET coming directly from cartridges and made into new HP cartridges
- RBR: recycled bottle resin blended with CPET and other additives to make RPET
- RPET: the term used in this study to refer to the recycled content PET in cartridges, and is made up of CPET, RBR, and other additives (glass fiber, etc.)

Description of HP Planet Partners program and "Cumulative" and "Current" models

When ink cartridges were first incorporated into the HP Planet Partners program, collection was done through "Envelope in the Box" (EitB), in which U.S. postal-paid return envelopes were provided inside HP original equipment manufacturer (OEM) ink cartridge packaging. Over the years, EitB has been replaced by a web-based envelope request program and recycling centres in order to reduce shipping material required for recycling returns and to streamline the return process. The web-based return method includes single- or multiple-cartridge envelopes and bulk collection boxes ordered by the customer through hp.com. Special cartridge incentive programs, such as Instant Ink or PurchasEdge can utilise web-based returns. The vast majority of cartridge returns are also collected at Staples, Office Max, Office Depot, and Walmart—HP's retail recycling partners (hereinafter referred to as HP's "retail partners"). While still available to consumers, the web-based program has dwindled to a small percentage of cartridge returns.

Figure 2 presents the global view of the production of HP RPET in the cumulative program. It starts with various consumer return routes in NA and EMEA, which include collection at retail drop-off centres, return via EitB and the web, and collection of manufacture scrap to recycling facilities. The cartridges collected in NA are sent for conventional shredding, material separation/reclamation and cleaning, or to the new Disassembly Tool, a state-of-the-art cartridge shredder and material recovery system. The conventionally shredded PET is sent to two facilities for further processing and compounding into RPET resin. The PET from the Disassembly Tool is then sent for further processing and compounding into RPET resin. The cartridges in EMEA, plus scrap from one of HP's Asian facilities, are sent for conventional shredding, material separation/reclamation, and cleaning, and then the finished RPET resin material is sent to HP-sourced injection molding facilities located very near HP manufacturing facilities in Asia-Pacific and Europe. An additional recycled content PET feed is also sent to the Europe facility.

Figure 2. Overall system boundaries: Cumulative HP Planet Partners RPET program

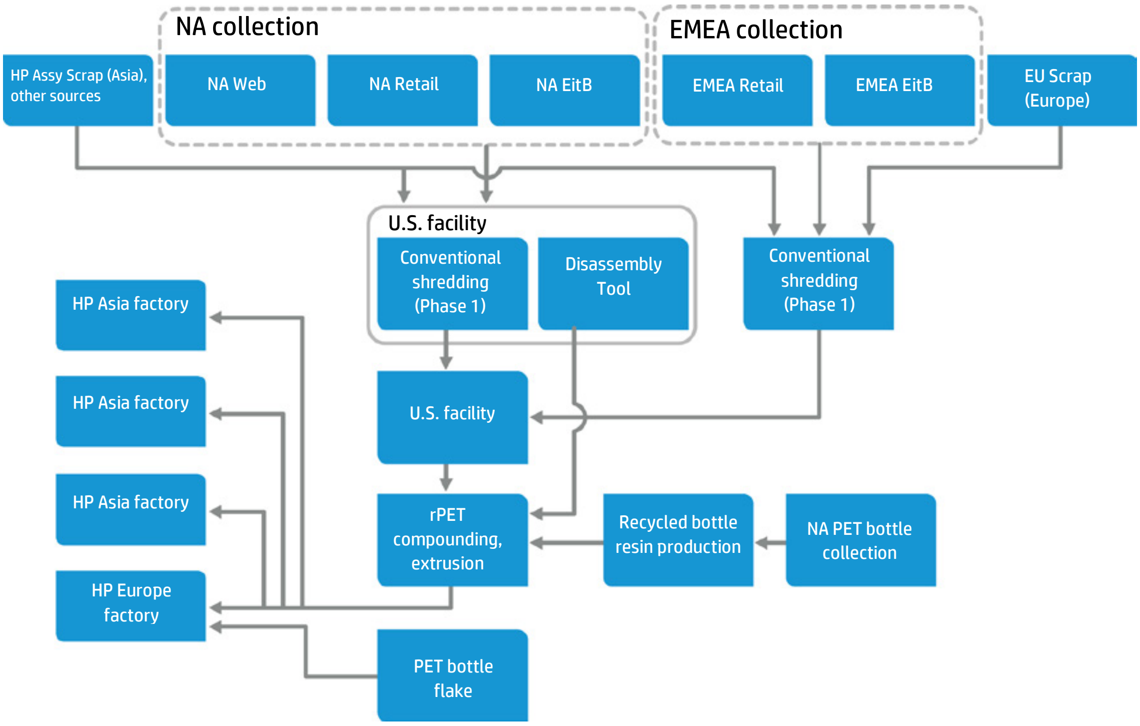
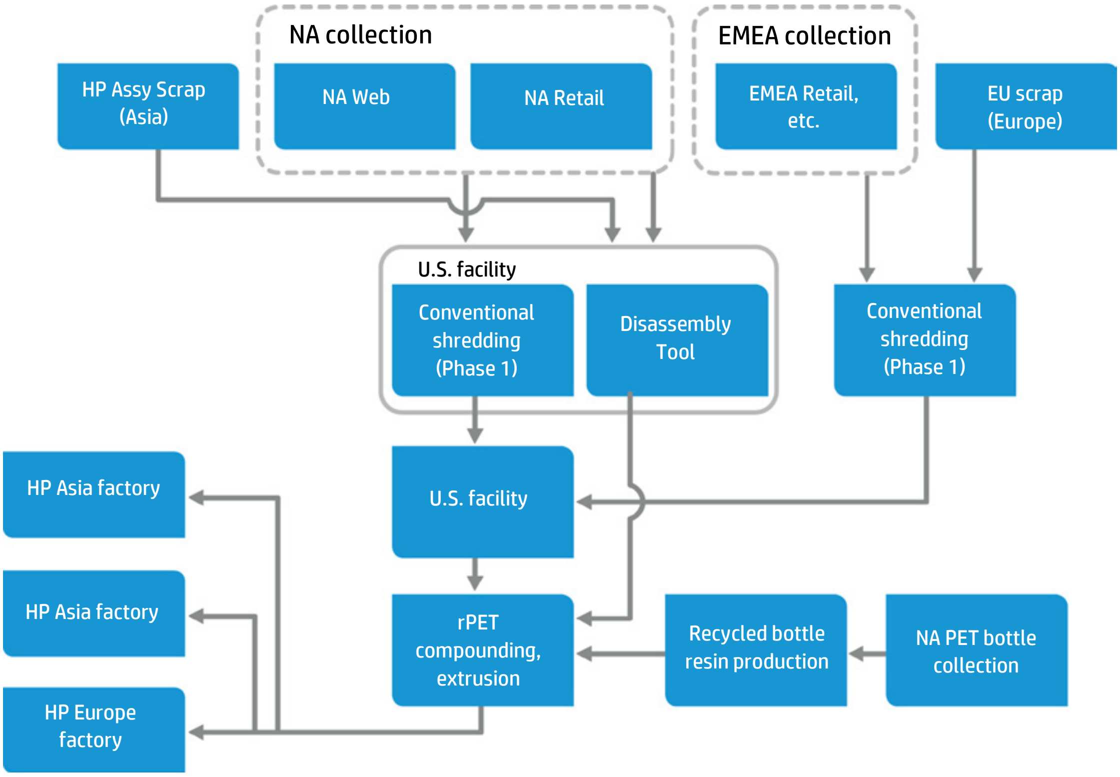


Figure 3, shown on page 9, presents the global view of the 2013 production of HP RPET which starts with consumer returns at retail drop-off centres and the web program. The cartridges collected in NA are sent for conventional shredding, material separation, reclamation, and cleaning, or to the Disassembly Tool. The conventionally-shredded PET is sent for further processing and compounding into RPET resin. The PET from the Disassembly Tool, which includes the Asia Pacific manufacture scrap, is sent directly for further processing and compounding into RPET resin. The cartridges in EMEA are sent for conventional shredding, material separation and reclamation and cleaning, and then the finished RPET resin material is sent to HP-sourced injection molding facilities located very near HP manufacturing facilities in Asia-Pacific and Europe.

Figure 3. Overall system boundaries: 2013 RPET program



Exclusion of data from the system boundaries

In LCA, it is typical to exclude some aspects within the set boundaries of the LCA. The manufacturing of the cartridge, distribution to consumers, and use are excluded from the system boundaries since the PET and RPET are functionally equivalent. Modeling these portions would be identical for both systems so these need not be included when evaluating net differences.

While the study boundaries include some human-related aspects, i.e., consumer drop-off to retailers and postal delivery, the study excludes impacts for other human activities, such as manufacturing/reclamation plant employee travel to and from work. This latter activity is almost always excluded from LCAs since the data vary widely (number of employees, mode and distance of transportation) and are not specific to any particular industry.

Functional unit

The function of this study system is production of PET and RPET for HP ink cartridge lids and bodies. The function of the study does not include injection molding into bodies but does include delivery of the materials to injection molding plants. The unit to which all results are normalised and reported is 1 kg, which can subsequently be converted into the use of these resins in any number of cartridges defined by HP. Impacts were calculated to look at 1 kg of PET and RPET for both the cumulative and current systems. The "savings" in impacts potentially generated due to the use of RPET is the net difference between the PET and the RPET.

Cut-off criteria

ISO 14044 requires a cut-off criterion to be defined for the selection of materials and processes to be included in the system boundary. Several criteria are used in LCA practice to decide which inputs are to be studied, including mass, energy and environmental relevance. The mass criterion was applied, and at least 99.5% of inputs, based on mass, were covered in the analysis.[4]

Detailed information on the inputs of the system was gathered and every effort was made to perform a comprehensive analysis on the production of these materials. Despite the defined mass criteria, an attempt was still made to collect all materials and energy involved in the material systems, regardless of mass contribution, in order to capture all materials that may be environmentally relevant.

[4] Mass was selected as the criteria for determining which inputs were included in the analysis. Mass was selected in preference to alternatives—energy and environmental relevance—because there was greater certainty in specifying and defining mass. However, an attempt was made to collect all materials and energy involved in order to capture all aspects that might be environmentally relevant, regardless of mass contribution.

Data types

Both primary data (collected from a manufacturing plant) and secondary data (publicly-available, literature sources) can be used for LCAs, and it is common to see a mix of both data types. For this study, primary data on HP Planet Partners program logistics were collected from HP and HP suppliers (the cartridge separation and PET reclamation facilities). All other data were based on the best available secondary data.

Software used

The commercially-available SimaPro LCA software was used to model the systems.[5]

[5] PRé Consultants: *SimaPro 8.0 LCA Software*. 2013. The Netherlands.

Appendix 1—Detailed results

Overall, the 2013 results for RPET are comparable to the cumulative model. In some of the categories, the results are slightly higher; in others, the results are slightly lower. There are some real differences between the models, such as a significantly higher proportion of closed-loop PET (CPET) through the disassembly tool in 2013 and the different mix of HP Planet Partner collection programs. Many factors may have affected the results. For example, the benefits of using the more streamlined disassembly tool may have been offset by the impacts of the high percentage of the retail collection route, which was found to be a fairly significant impact to the RPET systems.

It should be noted that due to inherent margins of error in LCA studies, for values within 10% (+/-) of each other, one system is not conclusively better than another; instead, the results can be considered to be "on par with one another." See discussion on general LCA limitations in the Methodology section.

Table 1. Overall results: Cumulative model

Impact category	Unit	RPET (Cumul Model)	Virgin PET	RPET as % of Virgin	Use of recycled plastics vs. virgin plastic
Climate change	kg CO2 eq	2.04	3.06	67%	33% less
Ozone depletion	kg CFC-11 eq	1.1 E-07	1.1 E-07	102%	2% more
Terrestrial acidification	kg SO2 eq	0.01	0.01	88%	12% less
Freshwater eutrophication	kg P eq	2.7 E-04	7.5 E-04	36%	64% less
Human toxicity	kg 1,4-DB eq	0.31	0.44	72%	28% less
Photochemical oxidant formation	kg NMVOC	0.01	0.01	101%	1% more
Particulate matter formation	kg PM10 eq	4.5 E-03	5.5 E-03	82%	18% less
Terrestrial ecotoxicity	kg 1,4-DB eq	2.1 E-04	2.0 E-04	104%	4% more
Freshwater ecotoxicity	kg 1,4-DB eq	2.3 E-03	6.3 E-04	372%	272% more
Water depletion	m3	1.45	5.76	25%	75% less
Fossil depletion	kg oil eq	0.70	1.51	46%	54% less
Cumulative energy demand	MJ	33.91	72.27	47%	53% less

Table 2. Overall results: 2013 model

Impact category	Unit	RPET (2013 Model)	Virgin PET	RPET as % of Virgin	Use of recycled plastics vs. virgin plastic
Climate change	kg CO2 eq	2.06	3.06	67%	33% less
Ozone depletion	kg CFC-11 eq	1.2 E-07	1.1 E-07	106%	6% more
Terrestrial acidification	kg SO2 eq	0.01	0.01	93%	7% less
Freshwater eutrophication	kg P eq	2.5 E-04	7.5 E-04	33%	67% less
Human toxicity	kg 1,4-DB eq	0.32	0.44	72%	28% less
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Water depletion	m3	1.38	5.76	24%	76% less
Fossil depletion	kg oil eq	0.69	1.51	46%	54% less
Cumulative energy demand	MJ	33.80	72.27	47%	53% less

Based on the data and assumptions set out in this report, the replacement of virgin PET for RPET in HP cartridges shows a clear advantage for eight of the impact categories. For both models, RPET performs better than or on par with virgin PET for six of the impact categories, including water depletion, freshwater eutrophication, fossil fuel depletion, total energy, climate change, and human toxicity. Key findings in the results tables include:

- RPET is less than 75% of virgin PET for half of the impact categories.
- The best performing categories are water depletion, freshwater eutrophication, fossil fuel depletion, and total energy.
- For climate change (67% of virgin PET), using RPET instead of virgin PET in ink cartridges saves 1 kg CO2-eq for every kg RPET.

The story of recycling, especially the ability to track and use closed-loop material, is a powerful one. It keeps material out of the landfill and, in the case of RPET, uses less fossil resources and energy and contributes to a lower carbon footprint.

Appendix 2—Indicator descriptions

The analysis included a comparison of a broad and comprehensive spectrum of environmental indicators including those known to be of interest to consumers.

Climate change measures the greenhouse gas emissions which have been generated by the processing of virgin PP and recycled PP (RPP). The "greenhouse effect" refers to the ability of some atmospheric gases to absorb energy radiating from the earth, trapping the heat and resulting in an overall increase in temperature. Climate change is also called Global Warming Potential or the "carbon footprint." Carbon dioxide released from burning fossil fuels for energy is the main greenhouse gas contributing to the climate change impact in this analysis. Climate change is reported in kilograms (kg) of carbon dioxide-equivalents.

Ozone depletion quantifies ozone depleting gases in product systems. These may include chlorofluorocarbons (CFCs or freons), halons, carbon tetrachloride, and trichloroethane. A decline in the ozone layer allows more harmful short wave radiation to reach the Earth's surface, potentially causing damage to human health, plants, and changes to ecosystems. Ozone depletion is reported in kg of trichlorofluoromethane equivalents.

Terrestrial acidification quantifies acidifying gases that may dissolve in water (i.e., acid rain) or fix on solid particles and degrade or affect the health of vegetation, soil, building materials, animals, and humans. Acidification is measured in terms of kg of sulfur dioxide-equivalents.

Eutrophication potential quantifies nutrient-rich compounds released into water bodies, resulting in a shift of species in an ecosystem and a potential reduction of ecosystem diversity. A common result of eutrophication is the rapid increase of algae, which depletes oxygen in the water and causes fish to die. Eutrophication is measured in phosphorous equivalents.

Toxicity categories. Human toxicity provides an indication of the risk to human health, while terrestrial ecotoxicity and freshwater ecotoxicity results provide indication of the risks of damage to ecosystems on land and in fresh water bodies, respectively. All three are reported in terms of 1, 4 dichlorobenzene equivalents. There is more controversy among LCA practitioners about how toxicity affects should be quantified, than for other measures, because toxicity impacts are usually limited to a local area rather than widely spread.

Photochemical oxidant formation quantifies the potential for smog-forming gases that may produce photochemical oxidants. This is reported in kg of non-methane volatile organic compounds (NMVOC).

Particulate matter formation quantifies particles in the air generated by use of fuels for manufacturing, transportation, and materials handling. Inhaling these particles may result in health issues such as asthma and other respiratory illnesses. This impact category is reported in kg PM10-eq (particulate matter of size less than or equal to 10 micrometers).

Water depletion measures the use of water from all water bodies and includes not only water to process RPP and upstream activities but also the water required to generate the electricity used. Water is reported in liters.

Fossil fuel depletion is the measure of the use—or depletion—of fossil fuels and is measured in oil-equivalents. Fossil fuel depletion tracks use of fossil fuels for energy as well as fossil fuels embedded in products made up of hydrocarbons, such as plastics.

Cumulative energy demand is reported in Megajoules and includes not only energy to process RPP but also the energy required to produce or extract upstream materials and transport all materials. Total energy encompasses fuel energy, including fossil and non-fossil fuels such as nuclear power, hydropower, and biomass, and embodied energy, such as hydrocarbons in plastics.

Appendix 3—Data quality and limitations

Data quality as applied to this study

Overview

Overall, the consultant believes the data quality to be very good. The HP Planet Partners program suppliers provided primary data. These data sets were checked for mass and energy balances, and we believe that 99% of the inputs and energy were provided. The data on RBR is very complete, based on a comprehensive, recent study on cradle-to-gate of PET bottle recycling in North America. The virgin PET production, while secondary, is based on very good quality data provided by a reputable data source (EcoInvent data,[6] based directly on comprehensive LCA data from Plastics Europe[7]). The sourcing and transportation logistics are quite detailed, and wherever necessary, sensitivity analyses were performed. For secondary data, the best data available at the time of the study was evaluated. Data came from primarily the EcoInvent and U.S. LCI databases.[8]

Representativeness

Temporally, the data used for the study are largely representative. The primary data are based on 2013 operations and program logistics. The secondary data are based on data from the mid- to late-2000's. A couple data sets come from early 2000's or late 1990's. Geographically, the data are representative, with the data coming from North America and Europe. Technologically, the data are largely representative. The secondary data are based on typical and sometimes average technologies. The primary data for HP Planet Partner facilities are based on state-of-the-art technologies.

Consistency

Consistency is a qualitative understanding of how uniformly the study methodology is applied to the various components of the study. Consistency was maintained in the handling of the comparisons of materials. The models for all materials were built consistently, and methodological decisions were consistent across all products.

Reproducibility

The level of detail and transparency provided in this report allow the results of this study to be reproduced by another LCA practitioner as long as the production datasets are similar.

Precision

Precision represents the degree of variability of the data values for each data category. The return route data categories (mail distances, retail partners transport distances, consumer drop-off) were based on percentages that were estimated but believed to be representative. Where we could not get precise data and thought there could be significance in the model, we performed sensitivity analysis.

We received comprehensive primary data on RPET processing, so believe there is not much data variability there. Two facilities provided less precise data so there may be more variance there, but these processes proved to be insignificant in the overall life cycle. The RBR data is quite precise and we feel confident about its application and representativeness. Transportation logistics (i.e., ports used, modes of transportation), were well-defined.

Completeness

ISO 14044 section 4.2.3.6 defines completeness as the "percentage of flow that is measured or estimated." The models in this study are fairly complete since data were carefully evaluated for all aspects of the HP Planet Partners program and virgin PET sourcing. Overall percentages of cartridges returned in the HP Planet Partners program had been calculated estimates based on program information. These data were cross-checked with the mass balance data calculated from facility inputs/output data and the numbers corroborated.

Also, very precise data were obtained on program aspects that HP owns or controls such as the EitB envelope BOM, transportation routes, and virgin PET sourcing, but some of the data from PET reclamation plants was estimated, including precious metal recovery.

[6] Ecoinvent Centre, *Ecoinvent data v3.0* (Dübendorf: Swiss Centre for Life Cycle Inventories, 2013). Found at: www.ecoinvent.org.
[7] PlasticsEurope, The Plastics Portal. Found at: www.plasticseurope.org/plasticssustainability/eco-profiles/browse-by-list.aspx.
[8] National Renewable Energy Laboratory (NREL): U.S. Life-Cycle Inventory Database. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

Limitations and uncertainty

The LCA, like any other scientific or quantitative study, has limitations and is not a perfect tool for assessing exact environmental impacts and attributes associated with product systems. While LCA is a good tool to assess relative differences between systems, there is still inherently some margin of error in the results. LCA results are based on models in a software using datasets of varying quality. As described above, data sets often cover a broad range of technologies, time periods, and geographical locations, increasing the uncertainty of the results. The exclusion and/or unavailability of potentially relevant data could also increase the uncertainty.

Both primary and secondary data are used in modeling the materials. Because the quality of secondary data is not as good as primary data, the use of secondary data becomes an inherent limitation to the study. However, from a practical standpoint, it is impossible to collect actual process data for each of the hundreds or thousands of unit processes included in a complete life cycle model, so the use of secondary data in an LCI is normal and necessary.

Because hundreds of data sets are linked together and because it is often unknown how much the secondary data used deviate from the specific system being studied, quantifying data uncertainty for the complete system becomes very challenging. It is well-understood in the LCA community that a margin of error could be as great as 30%. While it is not possible to provide a reliable quantified assessment of overall data uncertainty for the study, some uncertainty can be assessed quantitatively, and this has been done by way of sensitivity analysis in areas that may have been identified as potentially significant.

It should be added that, wherever possible, this LCA used the best data that were available at the time of the study, including the HP Planet Partners infrastructure, PET reclamation processes, and energy, fuels, transportation, and basic materials from data available in the latest versions in the LCA software database.

Appendix 4—Life Cycle Assessment analyst

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Anne Landfield Greig, Life Cycle Assessment Certified Professional (LCACP), is the principal and owner of Four Elements Consulting, LLC. Four Elements specialises in Life Cycle Management (LCM) and Life Cycle Assessment (LCA) services to help corporations, government and non-governmental organisations find valuable environmental and cost management solutions for their products and operations. Four Elements also carries out Environmental Product Declarations and their corresponding LCAs, as well as product- and corporate-wide greenhouse gas (GHG) assessments and carbon footprints. Anne Greig is an advisor on life cycle issues for CarbonFund's Carbonfree™ certification program. She is on the American Center for LCA certification committee and a member of the International Council on Mining & Metals LCM Working Group. Anne holds a Bachelor of Science in Geology from Boston College and a Master of Science in Environmental Management from Duke University.

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