Life Cycle Assessment comparison of virgin PET vs. recycled PET in HP Ink cartridges

Summary report

February 2018

Prepared for

HP Inc.

By

Four Elements Consulting, LLC

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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 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 cartridge return method

Executive summary

In 2010 and again in 2014, 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 worldwide 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.

HP has commissioned Four Elements to perform an update of the 2014 study to model the environmental benefits of the recycled content cartridges produced in 2017. The update is intended to incorporate the latest data and statistics on HP's worldwide HP Planet Partners programs, ink cartridge recycling facilities, and LCA databases. The worldwide HP Planet Partners program encompasses primarily North America (NA) and Europe, Middle East, and Africa (EMEA).

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 out of the ten results categories. As shown in the results on page 8, RPET is lower than or on par with virgin PET in all categories. The best-performing categories are fossil resource scarcity and cumulative energy demand. Global warming potential is more favorable for RPET, at 58% of virgin PET.

Introduction

Polyethylene terephthalate (PET), a strong, lightweight plastic, is the primary material in some HP ink cartridge bodies and lids. In 2005, HP began to produce ink cartridge lids and bodies with recycled PET ("RPET"). Some of the RPET is sourced from the HP Planet Partners program, an ink and LaserJet print cartridge recycling program that provides consumers free and convenient ways to return their empty cartridges. 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" PET.

Peer review

The 2014 RPET vs. virgin PET study underwent a rigorous external peer review. This review was based on the credibility and objectivity of the data and results as well as conformance with the International Organization for Standardization (ISO) standards on LCA.

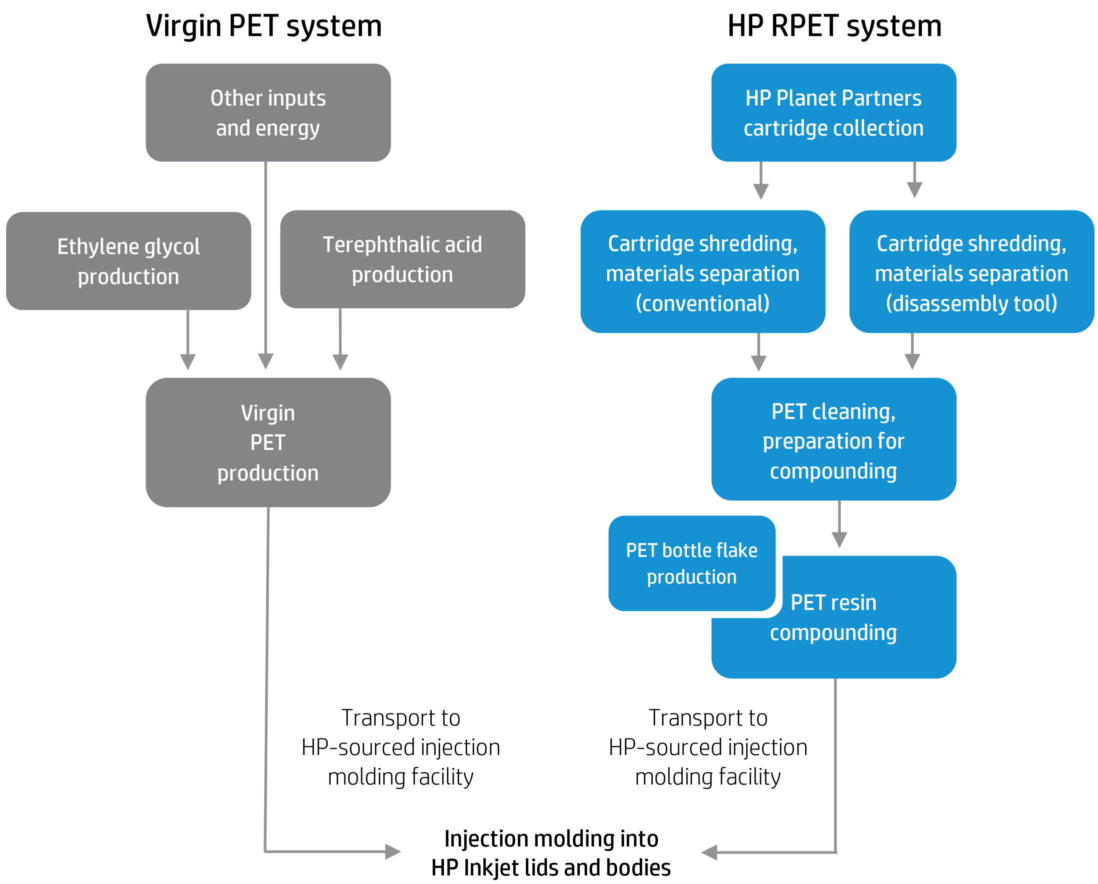
Because this study follows the same methodology and modeling approach and only data have been updated, another peer review has not been performed.

System boundaries

System description and overall system boundary

The figure below presents the overall study boundaries for the two materials being compared.

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. Figure 2 on page 5 represents a more detailed breakdown of the HP RPET system.

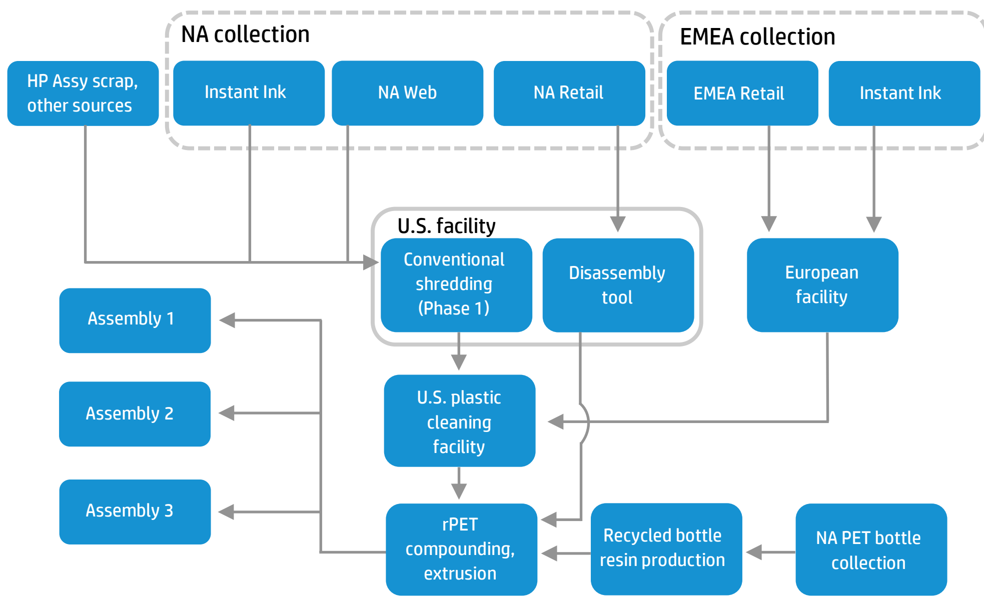
Description of HP Planet Partners Program

When ink cartridges were first incorporated into the HP Planet Partners program, only “Envelope in the Box” (EitB) collection was used, in which postal-paid return envelopes were provided inside HP OEM ink cartridge packaging. Over the years, EitB has been replaced by a web-based envelope request program and retail drop-off programs in order to reduce shipping material required for recycling returns and to streamline the return process. The web-based return method includes multiple-cartridge envelopes and bulk collection boxes ordered by the customer through hp.com. Special cartridge incentive programs such as HP Instant Ink or HP PurchasEdge can utilize envelope or box returns.

Figure 2 presents the global view of the production of HP RPET in 2017. It starts with various consumer return routes in NA and EMEA, which include cartridge scrap from manufacturing, collection at retail drop-off centers, return in envelopes and boxes via the web, and through the Instant Ink program. The cartridges collected in NA are sent for (a) conventional shredding, material separation/reclamation and cleaning or (b) to the Disassembly tool, a state-of-the-art cartridge shredder and material recovery system. The conventionally-shredded PET is sent out for further processing and compounding with recycled bottle resin (RBR) into RPET resin. The PET from the Disassembly tool is sent for further processing and compounding with RBR into RPET resin. The cartridges in EMEA are sent for conventional shredding, material separation/reclamation and cleaning. The finished RPET resin material is sent to HP-sourced injection molding facilities located very near HP manufacturing facilities.

Modeling for this study included all collection programs and cartridge/plastic processing operations described above and additionally reclaimed PET bottle recycling and all transportation logistics from the collection programs through to the HP-sourced injection molding facilities.

Figure 2: Overall system boundaries: HP Planet Partners RPET program—2017



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.

Functional unit

In order to conduct a proper LCA under the ISO guidelines, all flows within the system boundaries must be normalized to a unit summarizing the function of the system. This allows for the comparison of different product systems that perform the same function. Once this shared function is defined, a functional unit, or reference flow, has to be chosen in order to calculate the systems on the same quantitative basis.

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 normalized and reported is 1 kg of PET and RPET, which can subsequently be converted into the use of these resins in any number of cartridges defined by HP. The "savings" in impacts potentially generated due to the use of RPET will be 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. A cut-off criterion based on mass was applied for the modeling of the system, and a cut-off goal of 99.5% of inputs has been defined. Detailed information on the inputs of the system has been gathered and every effort has been 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.

Results categories

HP is interested in a number of environmental impact indicators, including water consumption, water emissions, the carbon footprint (or global warming potential), and cumulative energy demand. The first outcome of an LCA is the Life Cycle Inventory (LCI), i.e., the quantification of all elementary flows into and out of the systems studied. The LCI results are then classified into impact categories, that is, categories in which a set of related flows may contribute to impacts on human or environmental health. ReCiPe[1] was used for this study; it is a reasonable and sound methodology to use because it:

- Is considered scientifically and technically valid.
- Has a broad set of impact categories. This is important since, in general, ISO recommends that the Life Cycle Impact Assessment (LCIA) "shall employ a sufficiently comprehensive set of category indicators."[2]
- Has a recognized and accepted methodology to ensure a level playing field for the systems studied.
- Has the latest iteration of Intercontinental Panel on Climate Change (IPCC) data on global warming potential.
- Has been used for recent HP LCA studies, including the externally peer reviewed earlier RPET study, so maintains consistency amongst HP LCAs.

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[1] Huijbregts M.A.J., Steinmann Z.J.N., Elshout P.M.F., Stam G., Verones F., Vieira M., Zijp M., Hollander A., van Zelm R. ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level. Int J Life Cycle Assess (2017) 22: 138: https://link.springer.com/article/10.1007/s11367-016-1246-y. It was first made available in Fall 2009 and has been fully updated in 2016. The default version for the midpoint method, the "Hierarchist," was used. Please see www.pre.nl for more information.

[2] ISO 14044, Section 4.4.5.

ReCiPe offers two "levels" of results categories: midpoint and endpoint. Midpoint can be thought of as the potential impact to human or environmental health that gives information on potential damage to humans or the environment but does not quantify or specify the damage. Damage, or endpoint, categories go beyond midpoint categories by modeling causes and effects to estimate actual damages (damage to humans, damage to vegetation, etc.).[3]

For this study, the midpoint set of categories is used since they address some of the issues important to HP, including the carbon footprint. Also, as there is generally less uncertainty with midpoint categories and there is good consensus on the derivation of weighting factors for midpoint categories, using midpoints is more advantageous than endpoint categories. The table on page 7 presents the midpoint categories within ReCiPe and other impacts to be used in the results. The energy category comes from the cumulative energy demand (CED) methodology.[4]

Table 1: LCIA categories

Impact category	Units
Global warming	kg CO_2 eq
Water consumption	Cubic meters
Fossil resource scarcity	kg oil eq
Cumulative energy demand	MJ

Data and software

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.

The commercially-available SimaPro LCA software was used to model the systems.[5] Background data, or the data sets that support the LCA model, came from the ecoinvent[6] and U.S. LCI[7] databases.

Results

Table 2 presents the impacts to produce 1 kg RPET (Total RPET) for a cartridge and 1 kg virgin PET (Total virgin PET) for a cartridge, for each impact category. The fourth column of numbers in the table presents RPET's percentage of the virgin PET for that category. The last column describes how much lower or higher the RPET is relative to the virgin PET. The units of savings are those corresponding with each category. Impact categories are distinct and independent from one another, so the results should be read line by line.

Where RPET is less than 90% of virgin PET (or more than 10% lower), the result is in green. Where RPET results are within 90% and 110% of virgin PET (within 10% +/- of each other), the result is in yellow. Due to inherent margins of error in LCA studies, for values within 10% (+/-) of each other, one system is not conclusively better than another, so we can say the results are on par. See discussion on general LCA limitations on page 9.

The best-performing categories are fossil resource scarcity and cumulative energy demand. Global warming potential (previously called Climate change) is more favorable for RPET, at 58% of virgin PET.

[3] For more information, refer to detailed documentation provided by Pre on these methods, at www.pre.nl.
[4] CED is based on EcoInvent version 2.0 and has been expanded to include elements from the SimaPro database. See www.pre.nl and www.ecoinvent.org for more information.
[5] PRé Consultants: *SimaPro 8.5 LCA Software*. 2013. The Netherlands.
[6] ecoinvent centre, ecoinvent data v3.0 (Dübendorf: Swiss Centre for Life Cycle Inventories, 2013), retrieved from: ecoinvent.org.
[7] National Renewable Energy Laboratory (NREL): U.S. Life-Cycle Inventory Database. 2005. Golden, CO. Retrieved from nrel.gov.

Table 2: RPET vs. Virgin PET Comparison: 2017[8]

Impact category	Unit	Total RPET	Total virgin PET	RPET as % of virgin	Use of recycled vs. virgin plastics
Global warming	kg CO_2 eq	1.6 E+00	2.8 E+00	58%	42% lower
Water consumption	m^3	2.1 E-02	3.4 E-02	62%	38% lower
Fossil resource scarcity	kg oil eq	4.9 E-01	1.4 E+00	36%	64% lower
Cumulative energy demand (CED)	MJ	2.5 E+01	6.7 E+01	37%	63% lower

Data quality requirements and evaluation

Overview

This LCA adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results. The following aspects of the study's data quality are described in accordance with ISO 14044:

- Representativeness of the data in the study, which includes an assessment of the temporal, geographical, and technological coverage of the model
- Consistency—the qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis
- Reproducibility—the qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study
- Precision—the measure of the variability of the data values for each data category expressed
- Completeness—the percentage of flow that is measured or estimated
- Uncertainty of information

Data quality as applied to this study

Representativeness

Representativeness includes how old the primary and secondary data are, their geographical coverage, and their technological coverage. Overall, representativeness is very good. The HP Planet Partners program North American suppliers provided primary data for 2016-2017 operations where there were significant updates from 2014. These data sets were checked for mass and energy balances, and an estimated 95% of the inputs and energy were provided. Technologically, these are modern recycling facilities, and the Disassembly tool is considered state-of-the-art. The data for the NA Planet Partner facilities were used as proxy for the European facilities – see the Limitations section for more information. The data on PET bottle recycling is complete and precise, based on a comprehensive LCA study on North American PET bottle recycling. The virgin PET production, while secondary, is based on very good quality data provided in ecoinvent and based directly on comprehensive LCA data from Plastics Europe. The sourcing and transportation logistics are based on current Planet Partners HP-internal market data. The background data on energy and electricity, materials, and transportation are primarily based on the 2010s and some 2000s time frame. Energy and electricity grid data were customized to North American and European conditions. Almost all data in databases such as ecoinvent are regularly checked and updated for technological and other overall data improvements.

[8] For a full list of categories and results, email sustainability@hp.com.

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. For the 2014 study, 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 we believe there is not much data variability there. As we received less precise data from two facilities, there may be more overall variance, 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 (see for example Figure 2). These numbers were checked with the mass balance data calculated from facility inputs/output data, and the numbers seemed to corroborate.

Also, very precise data were obtained on items that HP owns or controls such as the return envelope bill of materials, transportation routes, and virgin PET sourcing.

Limitations and uncertainty

General use limitations

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 better at assessing 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. 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. *Should claims or assertions be made on the environmental performance of a product, the public should be informed of these inherent limitations.*

Study limitations

While the European recycling facility and US recycling facility are similar facilities, there may be a considerable amount of variability between the two. The facilities employ the same technology, but feedstock of cartridges and other material brought in may be very different, yielding different quantities of PP, PET and other plastics, coproducts/byproducts, and waste products. Also, treatment of the waste may be very different. Different electric grids for the two facilities have been accounted for, but the aforementioned differences have not been addressed in the model. Still, the European recycling facility (and the European market) currently plays a relatively small role in this model.

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 (secondary may cover a broad range of technologies, time periods, and geographical locations). 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.

Conclusions

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 from an environmental life cycle standpoint. In almost all categories evaluated, RPET performs better than or on par with virgin PET.

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Acronyms and definitions

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

PP: Polypropylene, a durable thermoplastic polymer used for a wide variety of applications including HP ink cartridge bodies and lids.

RPP: the term used in this study to refer to the recycled-content PP in cartridges, and is made up of closed loop HP cartridge PP (CPP), recycled clothes hangers, and other additives.

CPP: "closed-loop PP", or the recovered PP coming from HP cartridges and HP manufacturing (as scrap) and made into new HP cartridges.

Executive summary

In 2014, HP commissioned Four Elements Consulting to perform an environmental Life Cycle Assessment (LCA) quantifying the environmental impacts and highlighting the environmental benefits of using RPP in its ink cartridges. Since RPP is a direct replacement to virgin PP, the production of these was compared. Production of RPP incorporates the worldwide 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 RPP. Cartridge-ready virgin PP is produced through conventional chemical manufacturing routes.

HP has commissioned Four Elements to perform an update of the 2014 study to model the environmental benefits of the recycled content cartridges produced in 2017. The update is intended to incorporate the latest data and statistics on HP's worldwide HP Planet Partners programs, ink cartridge recycling facilities, and LCA databases. The worldwide HP Planet Partners program encompasses primarily North America (NA) and Europe, Middle East, and Africa (EMEA).

Results summary

The replacement of virgin PP for RPP in HP cartridges shows a clear advantage for cumulative energy demand, fossil resources scarcity, and water consumption. The results are nearly equivalent for global warming.

In other environmental categories, the recycling system is not so favorable, unlike what was seen for RPET vs. virgin PET. This is due partly to the production of virgin PP, which has lower environmental impacts relative to virgin PET.

Despite the mixed results for RPP, the story of recycling, especially the ability to track and use closed-loop material, is a powerful one. Recycling cartridges keeps material out of landfills, and in the case of RPP, uses less fossil resources, energy, and water.

Introduction

Polypropylene (PP) is a durable thermoplastic polymer used for a wide variety of applications including HP ink cartridge bodies and lids. In 2013, HP replaced virgin PP ink cartridge lids and bodies with recycled PP (RPP) lids and bodies. Some of the total RPP in the cartridges comes from HP's Planet Partners program, an ink and LaserJet print cartridge recycling program that provides consumers free and convenient ways to return their empty cartridges. Cartridges are collected, sorted and shredded as part of the HP Planet Partners program, and recovered PP from ink cartridges, PP clothes hangers, and other pre- and post-consumer products go into new HP ink cartridges. The RPP from spent ink cartridges that goes into new cartridges is referred to as "closed-loop" PP, or CPP.

Peer review

The 2014 RPP vs. virgin PP study underwent a rigorous external peer review by Brian Glazebrook, an LCA expert then with NetApp. He based his review on credibility and objectivity of the data and results as well as conformance with the International Organization for Standardization (ISO) standards on LCA. Because this study follows the same methodology and modeling approach and only data have been updated, another peer review has not been performed.

System boundaries

Systems studied

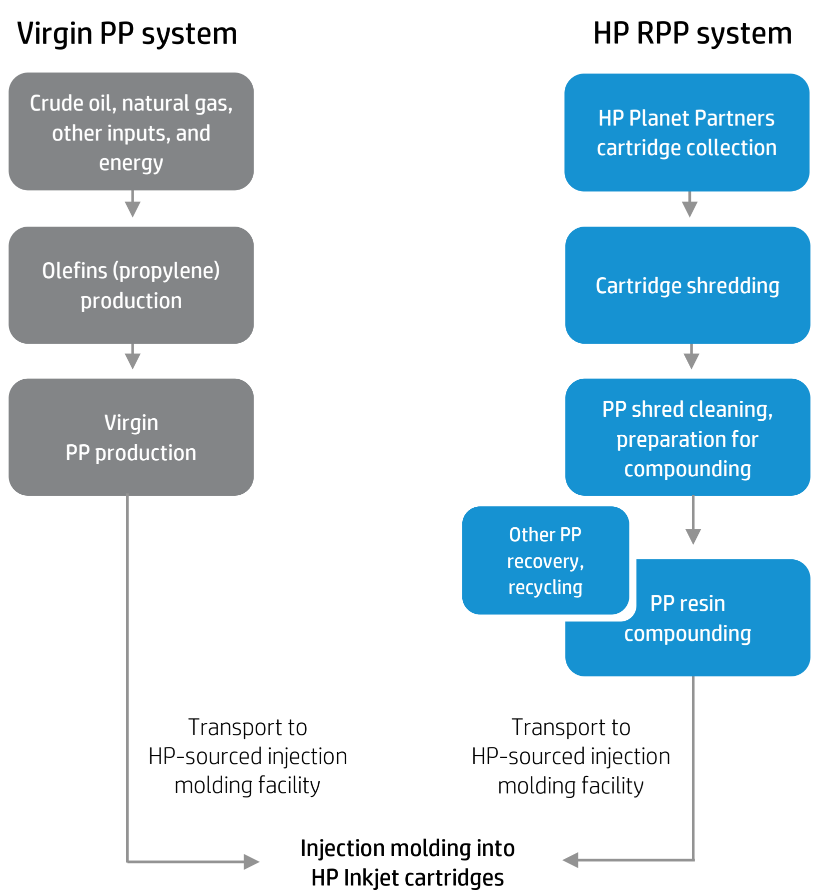
This study compares the production of HP's RPP (through the HP Planet Partners program) to the production of the virgin PP that had been used in HP cartridge manufacturing. The materials are functionally equivalent and are replaceable on a one-to-one basis, based on the following:

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

System description and overall system boundary

The figure below presents the overall study boundaries for the two materials being compared.

Figure 1: Simplified study system boundaries



The virgin PP system starts at the production of PP upstream materials and manufacturing of PP resin and continues through the distribution of the PP resin to injection molding facilities near final cartridge manufacturing.

The RPP system starts at collection of the spent cartridge from the consumer and ends with RPP at injection molding facilities near final cartridge manufacturing. The RPP system includes the worldwide HP Planet Partners operations, which include HP RPP resin production. Figure 2 presents a more detailed breakdown of the HP system.

Description of HP Planet Partners Program

When ink cartridges were first incorporated into the HP Planet Partners program, only an "Envelope in the Box" (EitB) program was used, in which U.S. postal-paid return envelopes were provided with HP OEM ink cartridge packaging. Over the years, EitB has been replaced by a web-based envelope request program and retail drop-off programs in order to reduce shipping material required for recycling returns and to streamline the return process. The web-based return method includes multiple cartridge envelopes and bulk collection boxes ordered through hp.com. Special cartridge incentive programs such as HP Instant Ink or HP PurchasEdge can utilize envelope or box returns.

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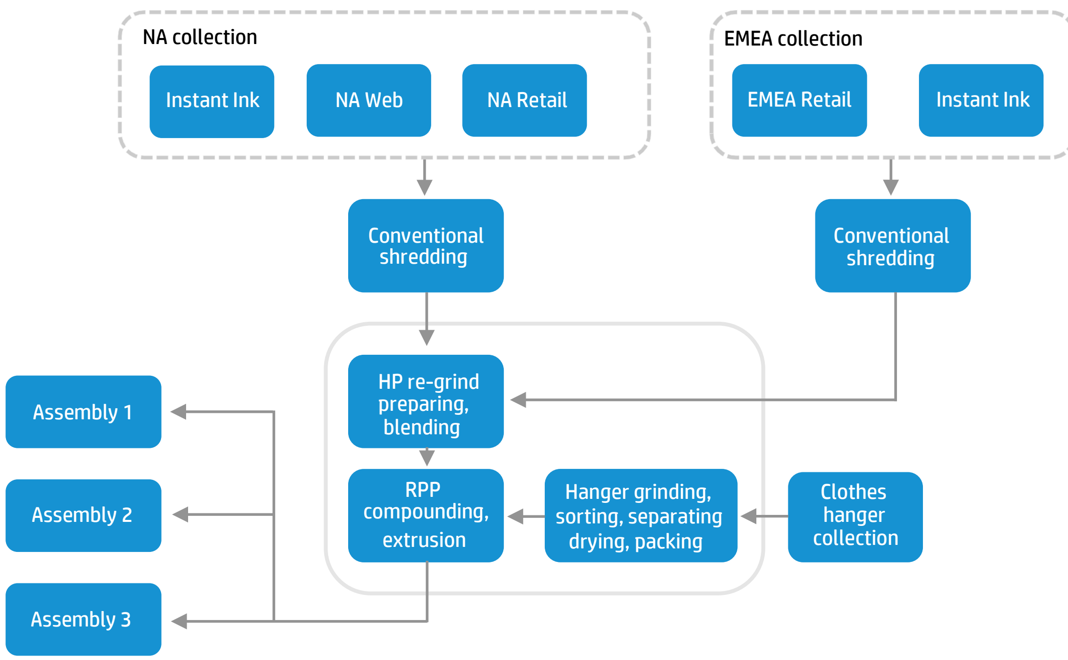
Modeling for this study included the collections systems across NA and EMEA, Planet Partners cartridge/plastic processing operations, all transportation logistics from the collection programs through to the HP-sourced injection molding facilities, and additional essential processes such as recycling of PP clothes hangers.

Figure 2: Overall system boundaries: 2017 RPP program



Reference notes for Figure 2:

- The horizontal dashed boxes defined by "NA" and "EMEA" represent the HP Planet Partners collection programs
- The assembly boxes on the left are the HP manufacturing facilities who use the RPP

Exclusion of data from the system boundaries

In an 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 PP and RPP are functionally equivalent and modeling these portions would be identical for both systems. These additional processes 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.

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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. A cut-off criterion based on mass was applied for the modeling of the system, and a cut-off goal of 99.5% of inputs has been defined. Detailed information on the inputs of the system has been gathered and every effort has been 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.

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The commercially-available SimaPro LCA software was used to model the systems.[8]

Results

Table 2 presents the impacts to produce 1 kg RPP for a cartridge (Total RPP) and 1 kg virgin PP for a cartridge (Total virgin PP), for each impact category. The fourth column of numbers in the table presents RPP's percentage of the virgin PP for each category. The last column describes how much lower or higher the RPP is relative to virgin PP for each category. The units of savings are those corresponding with each category. Impact categories are distinct and independent from one another, so the results should be read line by line.

Where RPP is less than 90% of virgin PP (or more than 10% lower), the result is in green. Where RPP results are within 90% and 110% of virgin PP (within 10% +/- of each other), the result is in yellow. Due to inherent margins of error in LCA studies, for values within 10% (+/-) of each other, one system is not conclusively better

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[3] For more information, refer to detailed documentation provided by Pre on these methods, at www.pre.nl.

[4] CED is based on EcoInvent version 2.0 and has been expanded to include elements from the SimaPro database. See www.pre.nl and www.ecoinvent.org for more information.

[5] PRé Consultants: *SimaPro 8.5 LCA Software*. 2013. The Netherlands.

[6] ecoinvent centre, ecoinvent data v3.0 (Dübendorf: Swiss Centre for Life Cycle Inventories, 2013), retrieved from: ecoinvent.org.

[7] National Renewable Energy Laboratory (NREL): U.S. Life-Cycle Inventory Database. 2005. Golden, CO. Retrieved from nrel.gov.

[8] PRé Consultants: *SimaPro 8.5 LCA Software*. 2013. The Netherlands.

than another, so we can say those results are on par. See discussion on general LCA limitations in the Limitations and uncertainty section on page 9.

As shown in the results, fossil resource scarcity and water consumption are very favorable compared to the virgin alternative (48%, 47%, and 59%, respectively, of virgin PP). For cumulative energy demand and fossil resource scarcity, the difference in results is partially based on the savings of the energy and fossil-based hydrocarbons embodied in the virgin PP. For the global warming category, RPP and virgin PP are essentially equivalent to one another.

Table 2: Overall results—2017[9]

Impact category	Unit	Total RPP	Total virgin PP	RPP as % of virgin	Use of recycled vs. virgin plastics
Global warming	kg CO_2 eq	2.09 E+00	2.16 E+00	97%	3% lower
Water consumption	m^3	9.25 E-03	1.58 E-02	59%	41% lower
Fossil resource scarcity	kg oil eq	7.37 E-01	1.56 E+00	47%	53% lower
Cumulative energy demand (CED)	MJ	3.68 E+01	7.60 E+01	48%	52% lower

This set of results is not as favorable as the results for the HP RPET vs. virgin PET LCA. This is due in part to the production of virgin PP which has lower environmental impacts relative to virgin PET. Other factors contributing to lower environmental favorability for the RPP include:

- Greater impacts found in the cartridge collection infrastructure, including customer transport to retail stores
- Impacts found in other PP recycling (i.e., PP clothes hangers), plus other inputs needed to prepare the recovered PP for usable high-quality RPP
- Large transport distances of CPP material through the HP Planet Partners system, including from Europe to the shredding facility in the U.S., then to resin compounding in Montreal, Canada, then to resin production in Asia

Data quality requirements and evaluation

Overview

This LCA adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results. The following aspects of the study's data quality are described in accordance with ISO 14044:

- Representativeness of the data in the study, which includes an assessment of the temporal, geographical, and technological coverage of the model
- Consistency—the qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis
- Reproducibility—the qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study
- Precision—the measure of the variability of the data values for each data category expressed
- Completeness—the percentage of flow that is measured or estimated

[9] For a full list of categories and results, email sustainability@hp.com.

- Uncertainty of information

Data quality as applied to this study

Representativeness

Representativeness includes how old the primary and secondary data are; their geographical coverage; and their technological coverage. Overall, representativeness is very good. The HP Planet Partners program North American suppliers provided primary data for 2016-2017 operations where there were significant updates from 2014. These data sets were checked for mass and energy balances, and an estimated 95% of the inputs and energy were provided. Technologically, these are modern recycling facilities. The data for the NA Planet Partner facilities were used as proxy for the European facilities—see the Limitations and uncertainty section on page 9 for more information. The virgin PP production, while secondary, is based on data provided in the most current version of ecoinvent and based directly on comprehensive LCA data from PlasticsEurope. The sourcing and transportation logistics are based on current Planet Partners HP-internal market data. The background data on energy and electricity, materials, and transportation are primarily based on the 2010s and some 2000s time frame. Energy and electricity grid data were customized to North American and European conditions. Almost all data in databases such as ecoinvent are regularly checked and updated for technological and other overall data improvements.

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 RPP system in terms of methodological decisions.

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/available.

Precision

Precision represents the degree of variability of the data values for each data category. The return route data categories (mail distances, retail partner 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 most of the RPP processing facilities so believe there is not much data variability there. As we received less precise data from a couple of the facilities, there may be more overall variance, but these processes proved to be insignificant in the overall life cycle in contribution analyses. While the PlasticsEurope virgin PP data are precise, they are not current temporally, and to an extent, technologically. This is discussed in more detail in the Limitations section.

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 PP sourcing. Overall percentages of cartridges returned in the HP Planet Partners program had been calculated estimates based on program information. These numbers were checked with the mass balance data calculated from facility inputs/output data, and the numbers were corroborated. Some of the primary data from PP reclamation plants was estimated.

Limitations and uncertainty

General use limitations

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 an LCA is better at assessing 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. 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. *Should claims or assertions be made on the environmental performance of a product, the public should be informed of these inherent limitations.*

Study limitations

With the exception of the different electricity grids to account for geographical differences, the European recycling facility and US recycling facility have been modeled as replicas of one another, while in reality there may be a considerable amount of variability between the two. Without more specific data from the European recycling facility, the level of uncertainty is unknown. Still, the European recycling facility (and the European market) currently plays a relatively small role in this model.

While the PlasticsEurope virgin PP data are precise and based on a representative set of manufacturer-specific data, they are not temporally current. Because the data are based on processes in the late 1990s to early 2000s, one might assume that the process could be more environmentally-friendly. The extent to this is unknown, however, given the available data.

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 (secondary may cover a broad range of technologies, time periods, and geographical locations). 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, PP reclamation processes, and energy, fuels, transportation, and basic materials from data available in the latest versions in the LCA software database.

Conclusions

Based on the data and assumptions set out in this report, the replacement of virgin PP for RPP in HP cartridges shows a clear advantage for cumulative energy demand, fossil resources scarcity, and water consumption. The results are nearly equivalent for global warming.

In other environmental categories, the recycling system is not so favorable, unlike what was seen for RPET vs. virgin PET.

Despite the mixed results for RPP, the story of recycling, especially the ability to track and use closed-loop material, is a powerful one. Recycling cartridges keeps material out of landfills, and in the case of RPP, uses less fossil resources, energy, and water.