Life Cycle Environmental Impact Assessment

Recycled vs virgin plastic used in manufacturing Original HP ink cartridges

Prepared for:

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EXECUTIVE SUMMARY

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 Planet Partner Program, HP collects, sorts, and disassembles ink cartridges. Recovered plastic, metals, and other materials are recycled for reuse. Over time, the Planet Partners program expanded and now serves 46 countries for ink cartridge recycling. Beginning in 2005, HP began to use the cartridge plastic (Polyethylene terephthalate or PET) collected through Planet Partners directly in the production of new Original HP ink cartridges in a "closed loop" recycling process. PET recovered from the Planet Partners program, other post-consumer recycled PET (plastic bottles), and HP's manufacturing scrap is used in place of virgin PET.

HP commissioned Four Elements Consulting, LLC to perform an environmental Life Cycle Assessment (LCA) to quantify the environmental benefits of the use of recycled PET (rPET) from HP's Planet Partners programs, and other sources, in the production of HP ink cartridges compared to the use of virgin PET. The study covered use of the cartridges collected through HP's Planet Partners programs in North America (NA) and Europe. The analysis compared the impact of the collection, transportation, and processing of used cartridges and other recycled PET to the extraction and processing of oil and production of virgin plastic.

The details of the Planet Partners program vary by region and have been enhanced over time to continually improve the program's efficiency and thus further lower the environmental impact of the program. This LCA quantified the advantage, on average, of producing ink cartridges with recycled plastic recovered via the Planet Partners program, and other sources, from 2005 through 2010 worldwide. The study also quantified the environmental performance of the program as it is currently structured in 2010.

Results summary

Overall, HP's production of recycled plastic for use in manufacturing HP ink cartridges had a lower environmental impact than producing virgin plastic. Using recycled plastic resulted in a significant environmental benefit in all 12 of the indicators measured. Key findings included:

- Use of recycled plastic resulted in a reduction in the environmental impact for several key measures: carbon footprint, water use, and fossil fuel depletion.
  - Carbon footprint using recycled plastic was up to 33% smaller.
  - Water use was up to 89% lower.
  - Fossil fuel depletion was up to 62% lower using recycled plastic.
- HP's use of recycled plastic also provided an advantage over use of virgin plastic on a broad set of measures of water and air pollution.
- Total energy use for producing recycled plastic, including the embedded energy in plastic, was up to 60% lower.
- Planet Partners program enhancements over time have improved the efficiency of the program, continually lowering its environmental impact.

Overall Results—Use of Recycled Plastics vs Virgin Plastic

See Appendix 3 for illustrations of the 2005-2010 programs and the 2010 program.

Environmental Impact	2005-2010 Programs Average	2010 Program	Improvement
Climate change "Carbon Footprint", greenhouse gas emissions	22% less	33% less	11 percentage points
Ozone depletion Ozone depleting gases	15% less	59% less	44 percentage points
Human toxicity	11% less	12% less	1 percentage point
Photochemical oxidant formation Smog forming gases	37% less	55% less	18 percentage points
Particulate matter formation Particles in the air due to use of fuels	25% less	39% less	14 percentage points
Terrestrial acidification Acid rain	20% less	34% less	14 percentage points
Freshwater eutrophication Nutrients released in freshwater bodies with potential species shift	63% less	74% less	11 percentage points
Terrestrial ecotoxicity Potential for damage to ecosystems on land	18% less	41% less	23 percentage points
Freshwater ecotoxicity Potential for damage to ecosystems in freshwater bodies	34% less	40% less	6 percentage points
Total water use	69% less	89% less	20 percentage points
Fossil fuel depletion	50% less	62% less	12 percentage points
Total energy Energy from all sources to produce and transport PET and extract, produce and transport all upstream materials. Includes 'embedded energy' in plastic.	49% less	60% less	11 percentage points

The environmental impact of using recycled PET in HP ink cartridges was found to be significantly less than that of virgin PET in the areas of climate change, water use, and fossil fuel depletion.

- The reduced carbon footprint of recycled PET was a function of less overall energy required to produce rPET compared with virgin PET.
- Lower water use for rPET was driven by lower water and electricity use throughout the production process. Electricity generation requires significant water.
- Fossil fuel depletion was lower for rPET both because extraction of additional raw materials—crude oil and natural gas—required to manufacture virgin PET was avoided and less energy was required to manufacture rPET.

The key drivers of improvement over time, as shown in the comparison between 2005-2010 average and 2010, were:

- Increased percentage of recycled content. In 2010 HP's rPET contained no virgin PET.
- Development of more efficient methods for collecting cartridges from consumers.
- HP's design of a disassembly tool that reduces energy and water use and recovers a higher percentage of PET than earlier processes.

2010 is the first year the newly designed disassembly tool has been deployed. As the tool is employed for a greater proportion of the recycled HP cartridges, the environmental performance of HP's recycled PET is expected to be even more favorable than shown for the 2010 program above.

See Appendix 1 for more detail on results.

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. [1] 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/waste management—recycling, reuse, or disposal. For this study, a broad spectrum of environmental indicators was evaluated.[2] The study has undergone an external peer review process to ensure the credibility and objectivity of the data and results, as well as conformance with ISO 14040 and 14044 standards on LCA. See Appendix 7 for the peer review letter.

The analysis covered the resources necessary to produce virgin PET material and recycled PET from HP cartridges, and other sources, ready for use in injection molding. Recycled PET recovered through Planet Partners is blended with reclaimed post-consumer PET bottles and additives to produce a material functionally equivalent and interchangeable in quality to virgin PET in HP cartridge manufacturing.

The process studied begins with extraction, in the case of virgin PET, and consumer recycling, in the case of recycled plastic. This is a "cradle to gate" analysis. The process studied ends with delivery of plastic to injection molding manufacturing facilities. From injection molding forward the steps are identical for each alternative.

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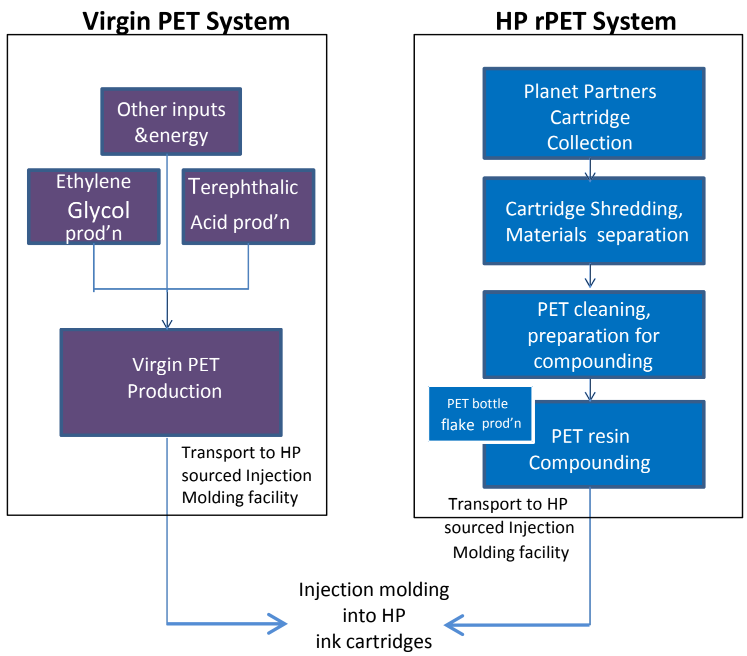
[1] ISO 14040:2006, the International Standard of the International Standardization Organization, Environmental management. Life cycle assessment. Principles and framework. ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.
[2] ReCiPe was created by the RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen, and CE Delft. It was first made available in fall, 2009. Please see www.pre.nl for more information.



The flows of plastic both over the life of the Planet Partners program (2005 through 2010) and for the current 2010 program were modeled. A variety of methods have been available through the Planet Partners program for the consumer to return used cartridges for recovery of the plastic. Initially, consumers received a postage-paid envelope for return with each new cartridge purchased. Over time, more efficient return options have been introduced. These include web-based return and authorized retail recycling locations which allow streamlined return processes and require fewer shipping materials. Once the cartridges are collected, several suppliers are involved in the cartridge disassembly, shredding, cleaning, and further processing of the returned cartridges into recycled PET. [3] Finally, recycled PET is sent to various HP manufacturing sites worldwide for injection molding to produce new Original HP ink cartridges.

Consumer collection models and PET processing suppliers have differed over time and between North America and Europe. Each of the various consumer return flows and PET processing flows were modeled in proportion to their occurrence over the life of the program.

The analysis includes:

- Modeling the collection of used cartridges from consumers—including consumer travel.
- Preparation of cartridges and other recovered plastic for reuse by Planet Partners processing suppliers (depackaging, separation, shredding, and cleaning)

[3] In addition to the processing of cartridges returned via the Planet Partners program, production scrap is shipped from the HP manufacturing sites to HP's PET processing suppliers for reclamation. Other post-consumer PET recycled content, plastic bottles, is also used in the production of rPET.

- Recycled bottle resin production from collection through delivery to HP processing partners.
- Extraction, processing, and production of virgin PET and shipping to HP injection molding facilities.
- Transportation of recycled plastic from collection sites to and between processing partners and to HP injection molding facilities.

While the scope and boundaries included some human activities—consumer drop-off of cartridges at retailers and postal delivery—the study excluded impacts for other human activities, such as employee travel to and from work.

At least 99.5% of inputs, based on mass, were covered in the analysis.[4]

See Appendix 3 for more detail on process flows.

Detailed quantitative and qualitative primary data on Planet Partners program logistics were collected from HP and the key HP suppliers who provide cartridge separation and PET reclamation services: Sims Metal Management, Butler-MacDonald, and The Lavergne Groupe.[5] All other data was based on the best available secondary data. The virgin PET production data, while secondary, is based directly on comprehensive LCA data from Plastics Europe.[6] Data for consumer travel behavior and other transport associated with recycling used cartridges and plastic bottles were based on two externally peer-reviewed Franklin Associates LCA studies.[7] [8] Data available from LCA software databases were evaluated and the best data available at the time of the study were applied. Data from the EcoInvent, U.S. LCI, and SimaPro databases were used.[9] [10] [11] Energy use calculations were based on the Cumulative Energy Demand methodology.[12]

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[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.

[5] Other suppliers, PDR Recycling GmbH Co + KG, and a European recycled plastic producer, did not provide data. Data gathered from suppliers using the same processes were used, with customization of the electricity grid.

[6] Published by EcoInvent; original data is housed at: http://www.plasticseurope.org/plastics-sustainability/life-cycle-thinking.aspx.

[7] Franklin Associates, a Division of ERG, 2009. LCA of Drinking Water Systems: Bottle Water, Tap Water, and Home/Office Delivery Water, prepared for Oregon DEQ, found at http://www.deq.state.or.us/lq/sw/wasteprevention/drinkingwater.htm.

[8] Franklin Associates, April 2010. **Life Cycle Inventory of 100% Post-Consumer HDPE and PET Recycled Resin from Post-Consumer Containers and Packaging**, performed for American Chemistry Council, Inc., et al.

[9] EcoInvent Centre, *EcoInvent data v2.0* (Dübendorf: Swiss Centre for Life Cycle Inventories, 2007), www.ecoinvent.org.

[10] U.S. LCI Database, hosted by National Renewable Energy Laboratory. Found at http://www.nrel.gov/lci/database/default.asp.

[11] PRé Consultants: *SimaPro 7.0 LCA Software*. 2005. The Netherlands (SimaPro v.7.2.3 used for this analysis).

[12] 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.

In any LCA, there is an inherent margin of error due to various limitations such as data quality differences or the lack of availability of potentially relevant data. Where publicly available data were used, and several data sets were available, data points were checked for sensitivity. Sensitivity analyses were also performed to test the robustness of key assumptions. Generally, the sensitivity analyses did not change the overall direction of the result.[13] All data sources used in the study were evaluated for temporal, geographical, and technological coverage.

For further detail on data sources, see Appendix 4.

[13] In one sensitivity analysis, the result for one of the 12 categories evaluated was sensitive. With greater consumer travel to recycle cartridges, the human toxicity result was better for virgin PET than recycled PET. For the other categories evaluated, with increased consumer travel, results for recycled PET were still better than for virgin PET.

APPENDIX 1—DETAILED RESULTS

The overall results tables below present the environmental impacts of producing 1 kg recycled PET or virgin PET and the impact of recycled PET as a percentage of the impact of virgin PET. Due to the margin of error inherent in LCA studies, values within 10% (+/-) of each other can be considered comparable. For all impact categories evaluated, the study concluded that replacement of virgin PET with rPET in HP ink cartridges has a “clear advantage” from an environmental lifecycle standpoint.

Overall Results: 2005-2010 average, 1kg PET produced

Impact category	Unit	Recycled PET	Virgin PET	Recycled PET as a % of Virgin PET	Use of recycled Plastics vs Virgin Plastic
Climate change	kg CO_2 eq - kilograms of carbon dioxide equivalents	2.12	2.73	78%	22% less
Ozone depletion	kg CFC-11 eq - kg of trichlorofluoromethane equivalents	1.15 E-07	1.35 E-07	85%	15% less
Human toxicity	kg 1,4-DB eq - 1,4 dichlorobenzene	0.78	0.88	89%	11% less
Photochemical oxidant formation	kg NMVOC - non-methane volatile organic compounds	4.8 E-03	7.7 E-03	63%	37% less
Particulate matter formation	Kg PM10-eq - particulate matter size </ 10 micrometers	2.5 E-03	3.3 E-03	75%	25% less
Terrestrial acidification	kg SO_2 eq - sulfur dioxide	8.1 E-03	1.0 E-02	80%	20% less
Freshwater eutrophication	kg P eq – phosphorus	2.7 E-04	7.4 E-04	37%	63% less
Terrestrial ecotoxicity	kg 1,4-DB eq - see above	1.65 E-04	2.0 E-04	82%	18% less
Freshwater ecotoxicity	kg 1,4-DB eq - see above	8.6 E-03	1.3 E-02	66%	34% less
Total water used	Liters	17.92	57.45	31%	69% less
Fossil Depletion	kg oil equivalents	0.78	1.57	50%	50% less
Total energy (based on CED)	MJ – Megajoule	37.60	73.53	51%	49% less

Overall Results: 2010 program, 1kg produced

Impact category	Unit	Recycled PET	Virgin PET	Recycled PET as a % of Virgin PET	Use of recycled Plastics vs Virgin Plastic
Climate change	kg CO_2 eq - kilograms of carbon dioxide equivalents	1.82	2.73	67%	33% less
Ozone depletion	kg CFC-11 eq - kg of trichlorofluoromethane equivalents	5.6 E-08	1.4 E-07	41%	59% less
Human toxicity	kg 1,4-DB eq - 1,4 dichlorobenzene	0.77	0.88	88%	12% less
Photochemical oxidant formation	kg NMVOC - non-methane volatile organic compounds	3.5 E-03	7.7 E-03	45%	55% less
Particulate matter formation	Kg PM10-eq - particulate matter size </ 10 micrometers	2.0 E-03	3.3 E-03	61%	39% less
Terrestrial acidification	kg SO_2 eq - sulfur dioxide	6.7 E-03	1.0 E-02	66%	34% less
Freshwater eutrophication	kg P eq – phosphorus	1.9 E-04	7.4 E-04	26%	74% less
Terrestrial ecotoxicity	kg 1,4-DB eq - see above	1.2 E-04	2.0 E-04	59%	41% less
Freshwater ecotoxicity	kg 1,4-DB eq - see above	7.8 E-03	1.3 E-02	60%	40% less
Total water used	Liters	6.14	57.45	11%	89% less
Fossil Depletion	kg oil equivalents	0.59	1.57	38%	62% less
Total energy (based on CED)	MJ – Megajoule	29.25	73.53	40%	60% less

The environmental impact of using recycled PET in HP ink cartridges was found to be significantly less than that of virgin PET in the areas of climate change, water use and fossil fuel depletion.

Climate change: To make virgin PET plastic, materials must be refined and reacted together—processes that require large quantities of energy. This energy comes from burning fossil fuels, and carbon dioxide is released whenever fossil fuels are combusted. The HP recycled PET program uses fossil fuel energy to collect cartridges and process them. However, the carbon dioxide released across all rPET production processes, including transportation, is up to 33% less than the carbon dioxide released producing virgin PET.

Water use: In addition to the water used directly in the process of producing virgin PET, production of virgin plastic requires a significant amount of electricity. Electricity generation consumes water. Coal fired power plants heat water to create steam to turn turbine generators. Manufacturing recycled PET also uses water and electricity to clean and process the cartridges into plastic pellets for reuse and water is used in the manufacturing of paper for cartridge return envelopes. However, the total water required to produce rPET ink cartridges is up to 89% less than that required to produce ink cartridges with virgin PET plastic.

Fossil fuel depletion: Virgin PET production requires extraction of crude oil and natural gas as raw materials. Since recycled PET reclaims used PET, extraction of additional crude oil and natural gas is avoided. In addition, the manufacturing process for virgin PET requires more fossil-fuel energy than rPET production (see "Climate change" above). The fossil fuel depletion of recycled PET is up to 62% less than that of virgin PET.

The following table summarizes the improvements of the 2010 program compared to the average for the program across 2005-2010.

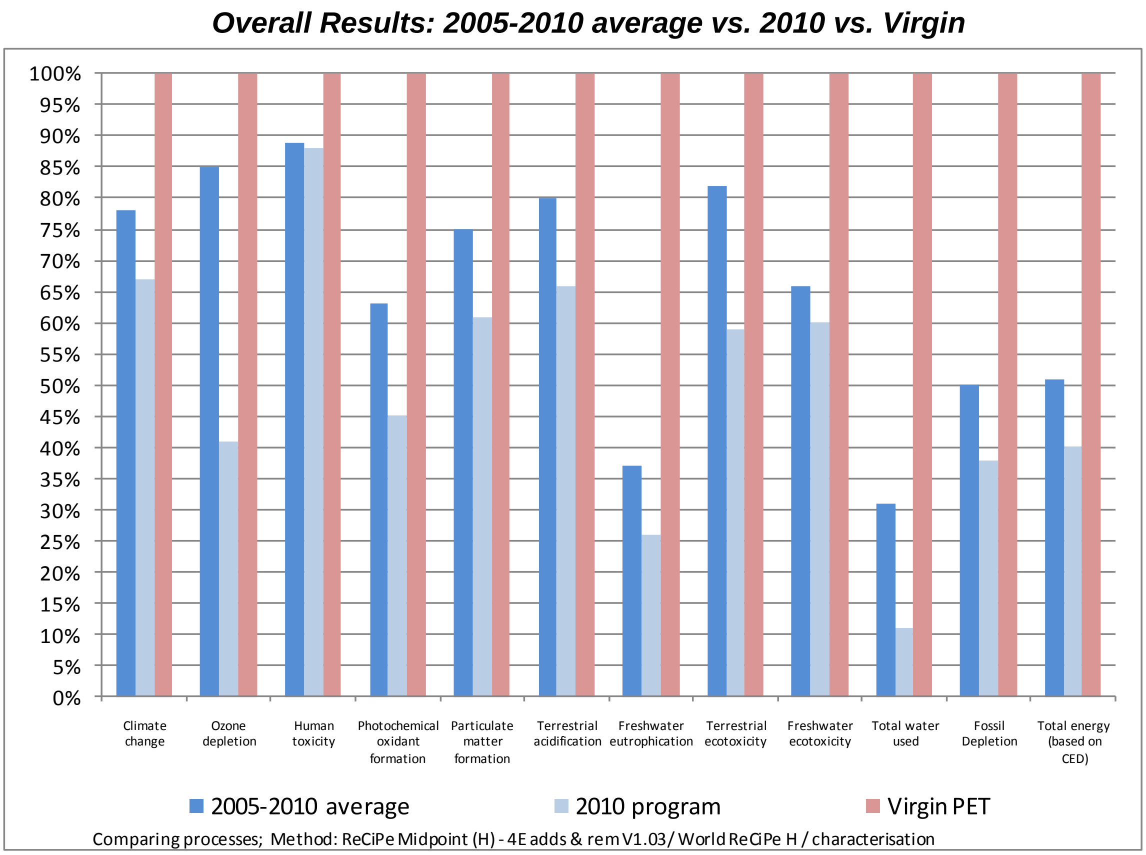
Comparison: 2005-2010 average vs. 2010 program, 1kg produced

Impact category	2005-2010 average rPET	2010 program rPET	Improvement
Climate change	2.12	1.82	14%
Ozone depletion	1.1 E-07	5.6 E-08	49%
Human toxicity	0.78	0.77	1%
Photochemical oxidant formation	4.8 E-03	3.5 E-03	27%
Particulate matter formation	2.5 E-03	2.0 E-03	20%
Terrestrial acidification	8.1 E-03	6.7 E-03	17%
Freshwater eutrophication	2.7 E-04	1.9 E-04	30%
Terrestrial ecotoxicity	1.7 E-04	1.2 E-04	29%
Freshwater ecotoxicity	8.6 E-03	7.8 E-03	9%
Total water used	17.92	6.14	66%
Fossil Depletion	0.78	0.59	24%
Total energy (based on CED)	37.60	29.25	22%

The improvement in current results can be attributed to three key factors:

1. No virgin PET in HP's recycled PET in 2010. Across 2005 through 2010, a portion of the recycled PET was produced by a European recycled PET producer, which used a small percentage of virgin PET in its production of recycled PET. Lavergne uses no virgin PET in the production of rPET. The recycled PET produced in 2010 contains no virgin PET.
2. Development of efficient cartridge collection systems. The introduction of collection at retail recycling partners generated an improvement in efficiency due to the advantages of bulk shipping.
3. Introduction of HP's Disassembly Tool. HP developed an all-in-one technology which disassembles, shreds, and separates cartridges, and cleans the scrap to create a contaminant-free PET ready for blending and compounding into recycled PET. This disassembly tool began operation in 2010. The tool streamlines the process, reducing overall energy and water use. The new process recovers a higher percentage of cartridge PET than the previous multi-facility process. Less water is required for rinsing and cleaning and transport of PET material between processing facilities is eliminated.

As the tool is employed more fully, the environmental performance of HP recycled PET is expected to be even more favorable than shown for the 2010 program above.


Overall Results: 2005-2010 average vs. 2010 vs. Virgin
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Climate change
Ozone depletion
Human toxicity
Photochemical oxidant formation
Particulate matter formation
Terrestrial acidification
Freshwater eutrophication
Terrestrial ecotoxicity
Freshwater ecotoxicity
Total water used
Fossil Depletion
Total energy (based on CED)
2005-2010 average
2010 program
Virgin PET
Comparing processes; Method: ReCiPe Midpoint (H) - 4E adds & rem V1.03 / World ReCiPe H / characterisation

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 PET and recycled PET. 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.

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 effects 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).

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.

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

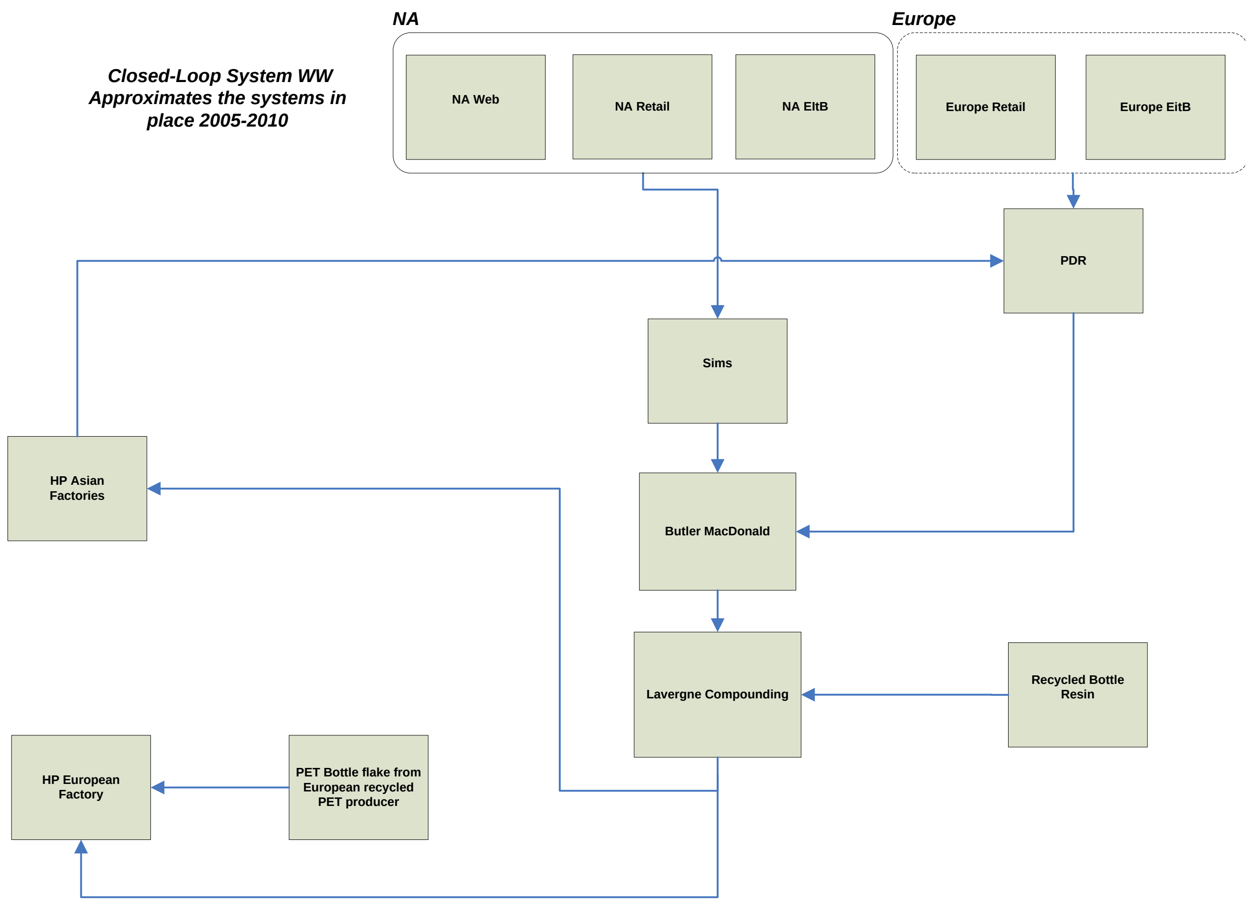
Fossil fuel depletion is the measure of the use—or depletion—of fossil fuels and is measured in oil-equivalents. Fossil fuel depletion tracks use of fossil fuels for energy as well as fossil fuels embedded in products made up of hydrocarbons, such as plastics.

Total energy is reported in Megajoules and includes not only energy to process PET 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.

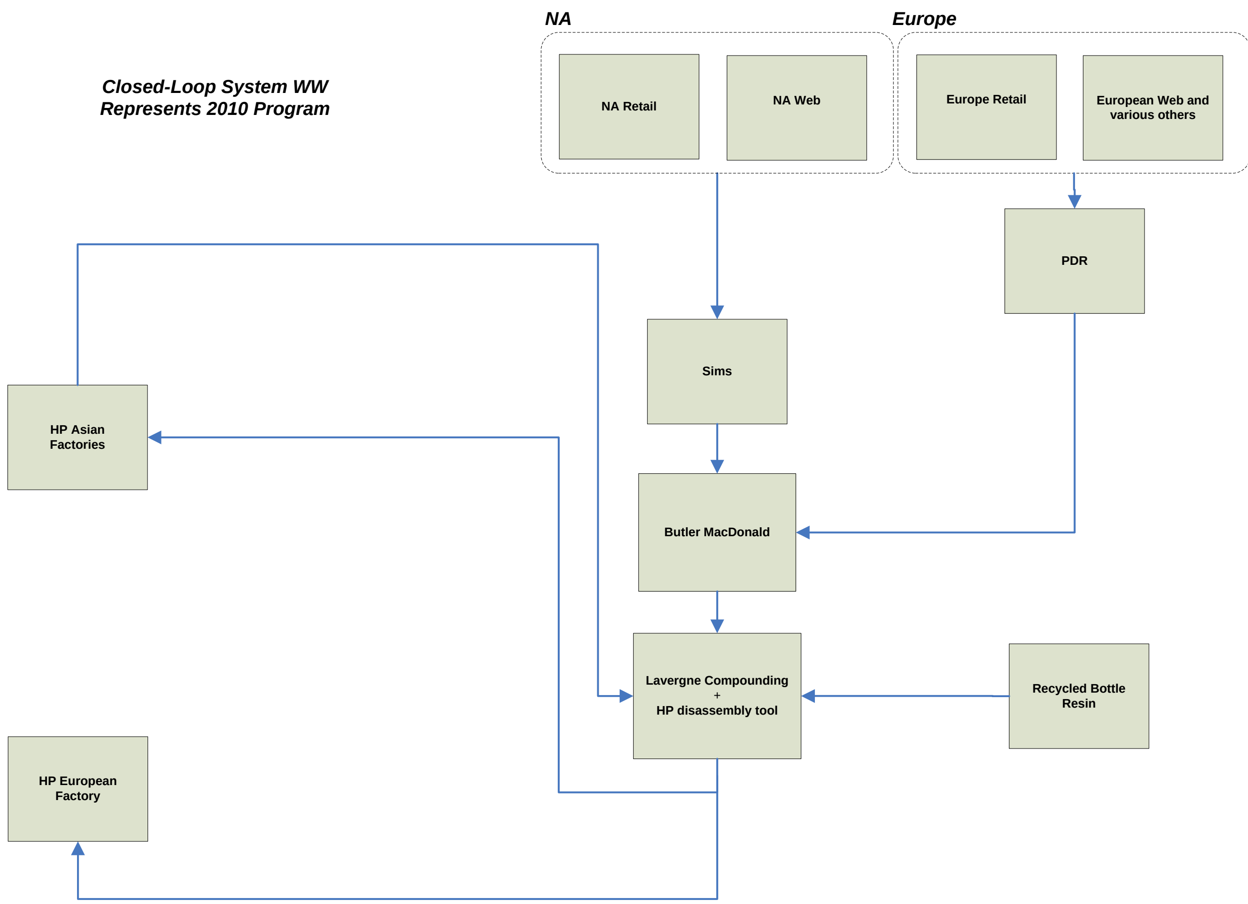
APPENDIX 3— PROCESS FLOWS AND ASSUMPTIONS

The two diagrams below present a global view of the average production of HP recycled PET across 2005-2010 and the 2010 program as modeled. Various consumer return routes include collection at retail drop-off centers, return via the "Envelope in the Box" (EitB) program, and web-based returns. The cartridges collected are sent to Sims in NA and PDR Recycling GmbH + Co KG in Europe for cartridge disassembly, shredding, and cleaning. The shredded PET is sent to Butler-MacDonald for further processing and then to Lavergne for compounding into recycled PET resin. Across 2005-2010, scrap from HP's Asian manufacturing facilities, was sent to PDR for material separation/reclamation. Beginning in 2010, HP manufacturing scrap has been sent directly to Lavergne for processing using HP's Disassembly Tool. Lavergne ships the finished recycled PET resin material to HP injection molding facilities in Asia and Europe.

Overall System Boundaries: 2005-2010 rPET Program Average



Overall System Boundaries: 2010 rPET Program



Cartridge Return Routes—Collection from Consumers

When "closed loop" ink cartridge recycling was first incorporated into the Planet Partners program, only EitB was used—postage-paid return envelopes were provided with Original HP ink cartridge packaging. EitB has been replaced by a web-based envelope request program and recycling at retail partners in order to reduce shipping material required for recycling returns and to streamline the return process.

Retail Recycling Centers

The analysis of retail recycling includes consumer drop-off of used cartridges at HP authorized retail recycling locations in North America and Europe, including Staples, and transport of the cartridges from the retail recycling partners to Sims in North America and to PDR in Europe.

The consumer's trip in a passenger vehicle to drop off empty cartridges at a retail recycling location was included in the model. An externally peer-reviewed Franklin Associates LCA study which evaluated a similar scenario was used to model consumer trips. See Appendix 5 for more detail.

Shipping from retail recycling locations to Sims in NA and PDR in Europe was also included in the analysis.

Envelope in the Box (EitB)

Production of envelopes used to return cartridges and mailing by the consumer through the postal system was included in the model. (Transportation of the envelope to the consumer was not included. The envelopes were shipped with the new HP cartridges and accounted for less than 0.1% of the total weight of the packaged cartridge.)

Postal transport of the returned cartridges to Sims in NA and PDR in Europe was also included in the model. A combination of truck and air freight was assumed, depending on the distance.

Web Return Program

The Planet Partners program offers postage-paid return packaging for cartridge returns through hp.com. A consumer may order any number of multiple cartridge envelopes or bulk collection boxes. Because the number of boxes ordered was small, envelopes were assumed in the analysis. HP provided the average number of envelopes ordered and the average number of cartridges returned per envelope.

Manufacturing information for the envelopes was provided by HP. Postal transport of the delivery envelope carrying an empty return envelope to the consumer was included in the model. Returned cartridges are sent to Sims via U.S. Postal Service First Class postage-paid. See postage transportation assumptions described for the NA EitB program. The analysis assumed the consumer recycles the delivery envelope with paper recycling.

The European web return program and various other European return programs were modeled using NA web return program assumptions.

Planet Partners Cartridge Recycling Processes

HP has several partners/suppliers who prepare cartridges and other recovered plastic for reuse:

- Sims (NA) shreds cartridges, separates the recoverable components, and washes the recovered PET.
- PDR (Europe) performs the same functions as Sims. PDR's processes and technologies are identical to Sims's.
- Butler-MacDonald separates the remainder of the precious metals and further prepares the cartridge PET for compounding; and
- Lavergne blends recycled cartridge PET, recycled PET bottle flake, and other additives such as glass fiber, and compounds these into recycled PET.
- Beginning in 2010, Lavergne also processes HP cartridge manufacturing scrap with the new HP-designed tool which disassembles cartridges and shreds, separates, and cleans the scrap in preparation for compounding into rPET.

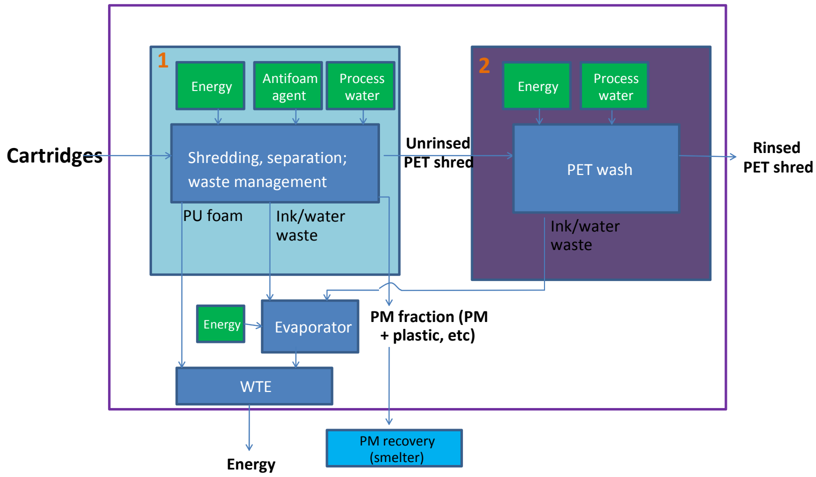
Sims (NA) and PDR (Europe)

Cartridges collected from consumers are first sent to Sims or PDR to be de-packaged, separated, shredded, and cleaned. Cartridges undergo manual and automated sorting to ensure shred is not contaminated with dissimilar plastics. After sorting, cartridges are processed on the shred line, which separates individual components and cuts up the plastic. The PET shred is then rinsed.

Sims provided data for their 2009 fiscal year (Oct 2008-Sept 2009) for this LCA. Since PDR's equipment and operations are nearly identical to Sims, the Sims data was used for PDR, with customization for energy and transportation differences.

Before 2010, PDR also received manufacturing scrap from HP's Asian factories for processing. Transportation from HP's Asian factories to PDR by truck and ocean freight was included in the analysis.

Sims System Boundary



Inputs	
Cartridge	All ink cartridges returned by consumers throughout the life of the Planet Partners program, were used in the production of recycled PET. No cartridges were disposed of in landfills.
Water (municipal)	
30% anti-foam emulsion	Represents less than 0.1% of inputs.
Electricity	Tennessee Valley Authority (TVA) grid.
Outputs	
PET shred	Sent to Butler-MacDonald for further processing
Precious Metal-rich stream (flex/labels/Plastic fines/Foam Fines/Contaminated Plastic)	Shipped to smelter for Precious Metal recovery. To give the recycled material the benefit of the full recovery of metal, an equivalent quantity of mining and beneficiation/milling upstream was subtracted out of the analysis. See appendix 6 for more detail.
Ink	Disposal: incineration with energy recovery.
Water waste	Evaporated with the incinerated ink.
Polyurethane foam, other waste materials.	Disposal: incineration with energy recovery.

Packaging from EitB and web return programs is managed with other waste materials at the plant. Cartridges returned via retail recycling, are shipped in bulk without packaging. Data on material inputs and the incineration processes came from EcoInvent and elements of the SimaPro database. Data on energy came from the U.S. LCI database.

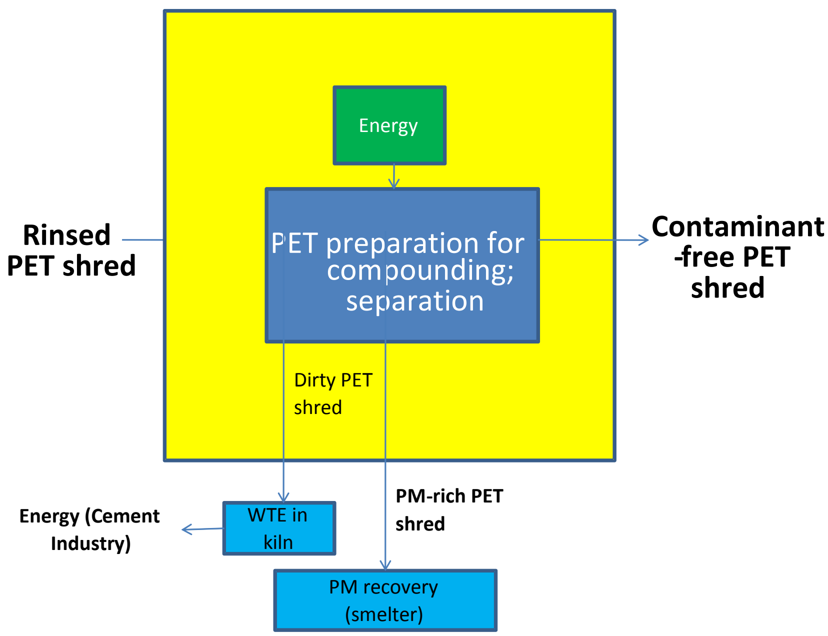
Butler-Macdonald

PET shred is shipped from Sims and PDR to Butler-MacDonald where contaminants are removed and incoming material is separated into several outputs:

- PET shred,
- Material sent to a cement kiln for energy recovery,
- Precious metals stream sent to a refiner for recovery, and
- Unusable/un-recyclable material.

Butler-MacDonald then cleans the PET shred and prepares it for Lavergne. Butler-MacDonald provided data for 2009 fiscal year (Oct 2008-Sept 2009).

Butler-Macdonald System Boundary



Inputs	
PET shred	From Sims or PDR
Water (municipal)	90% of the input is disposed because it is rinse water, 10% retained and reused
Electricity	Indianapolis Power & Light (IPL) electricity grid, primarily coal-based
Outputs	
PET (cleaned)	Sent to Lavergne for further processing
Precious Metal-rich stream (flex/labels/Plastic fines/Foam Fines/Contaminated Plastic)	Shipped to smelter for Precious Metal recovery. To give the recycled material the benefit of the full recovery of metal, an equivalent quantity of mining and beneficiation/milling upstream was subtracted out of the analysis. See appendix 6 for more detail.
Unrecoverable material	Disposal: incinerated with energy recovery
PET scrap to the cement kiln	

Elements of the electricity grid come from the U.S. LCI database. Data on waste disposal come from EcoInvent. Shipping of the PET shred from Sims and PDR to Butler-MacDonald by truck and ocean freight, as applicable, is included in the analysis.

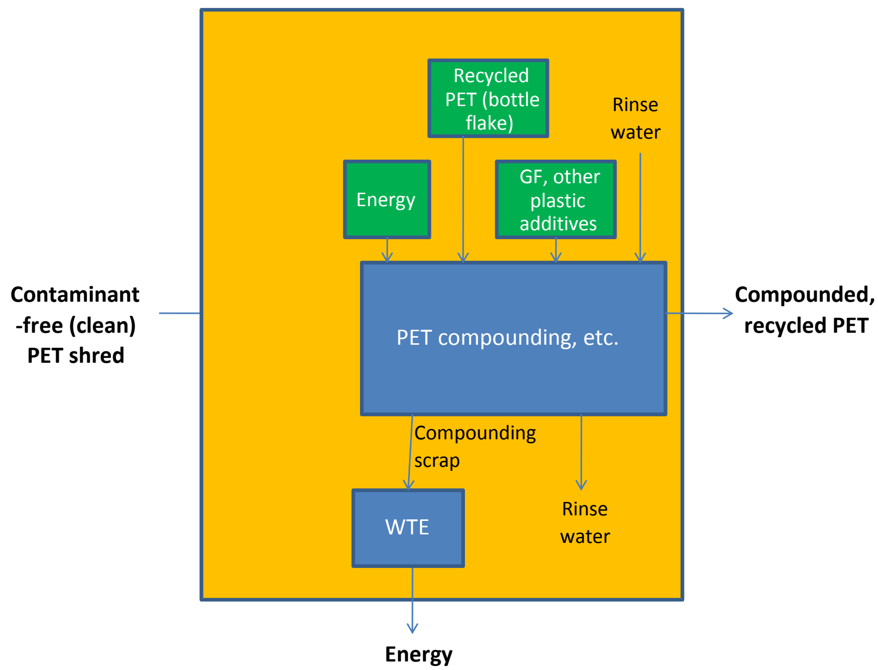
Lavergne

Processes at Lavergne include:

- blending the "closed loop" PET shred, produced from HP ink cartridges and HP manufacturing scrap, with recycled PET from plastic bottles and other additives,
- metal separation, and
- extrusion to create a plastic resin suitable for use in new HP ink cartridges.

Beginning in 2010, Lavergne also uses the all-in-one Disassembly Tool designed by HP to prepare HP manufacturing scrap for blending with other cleaned PET shred.

Lavergne System Boundary



Inputs	
PET flake from plastic bottles	
"Closed loop" PET from HP cartridges and HP manufacturing scrap	From Butler-Macdonald and HP-designed Disassembly Tool
Glass Fiber	
Additives	
Electricity	Hydroelectric power
Outputs	
Recycled PET	Final product ready for injection molding
Air emission: acetic acid	
Air emission: particulates	
Waste: production rejects	Landfill

Lavergne uses hydroelectric power for blending recycled PET, drying, metals separation, blending the additives, extrusion, and pneumatic transport. The data on glass fiber came from EcoInvent. Lavergne reported that the additives are 'virgin', petroleum-based chemicals that bring the properties of the recycled PET to virgin PET performance level.[14] The additives were modeled using EcoInvent data on generic organic chemical production.

Transportation of PET shred from Butler-MacDonald as well as recycled bottle resin, glass fiber and additives to Lavergne was included in the model.

Disassembly Tool

HP developed a technology which disassembles, shreds, and separates cartridges, and cleans the scrap to create a contaminant-free PET ready for blending and compounding into rPET with Recycled Bottle Resin and additives. This Disassembly Tool is located at Lavergne and started operation during 2010. The all-in-one tool performs the PET preparation functions previously performed at Sims and Butler-MacDonald, thereby reducing shipping. It recovers more PET and reduces overall energy and water use as compared to the previous multi-facility process. The analysis included the actual percentage of recycled PET for which this tool was used in 2010. Currently, the inputs are scrap from HP's Asian manufacturing facilities.

Inputs	
Cartridge scrap	From HP manufacturing facilities
Water (municipal)	
Electricity	Hydroelectric power
Outputs	
PET scrap	
Precious Metal-rich stream	Shipped to smelter for Precious Metal recovery. To give the recycled material the benefit of the full recovery of metal, an equivalent quantity of mining and beneficiation/milling upstream was subtracted out of the analysis. See appendix 6 for more detail.
Labels (paper)	Disposal: incinerated with energy recovery
Foam with ink	Disposal: incinerated with energy recovery
Solid waste	Disposal: landfill
Ink/water	Disposal: incinerated with energy recovery

After material separation, the cartridge PET is rinsed and shredded. The PET shred is then compounded with additives and glass fiber as described in the Lavergne process. Transportation of the scrap from HP's Asian factories to Lavergne by truck, ocean freight and train was included in the analysis.

[14] According to Lavergne, recovered plastic can undergo infinite cycles without loss of performance as demonstrated in a Lavergne test processing material through seven cycles with no loss of performance.

Other Processes

Recycled PET Production--2005-2010 European recycled PET producer

During part of the 2005-2010 period, some recycled PET used to produce new cartridges was purchased from a European recycled PET producer. This recycled content resin contained no HP “closed loop” recycled PET but, the supplier’s process produced a material similar to Lavergne. The rPET provided by this producer contained both recycled bottle resin and virgin PET.

Data for recycled bottle resin and virgin PET are described elsewhere.
Shipping of inputs to this producer and of recycled PET from the producer to HP European injection molding facilities were included in the analysis.

Recycled Bottle Resin Production

Data for recycled bottle resin production were from a 2010 Franklin Associates Life Cycle Inventory on 100% PET Recycled Resin from post-consumer containers and packaging.[15] This study provided North American data for PET reclamation/recycling operations, as well as collection of post-consumer plastic and sorting and separation from other co-collected recovered materials, such as paper, steel, and aluminum, and further separation of mixed plastics into individual resins.

Virgin PET Production

HP ink cartridge manufacturing with virgin material uses a compound of 85% virgin PET and 15% glass fiber. Virgin PET production data came from EcoInvent. It represents conventional production. The data, originating from Eco-profiles of the European plastics industry data, included material and energy inputs, waste, and air and water emissions. Data were from several European production sites. The glass fiber production data was also from EcoInvent and was the same as that used in modeling recycled content cartridges.

Transportation to Injection Molding Manufacturing Facilities

Transportation of the recycled PET from Lavergne, or virgin PET from various suppliers, to HP’s injection molding facilities was the last stage included in the system studied. Lavergne transports recycled PET to HP’s Asian and European facilities. Shipping by train, ocean freight, and truck was included in the analysis.

Virgin PET resin is produced in several locations. Virgin PET for HP’s Asian factories is shipped from a variety of Asian producers and virgin PET for HP’s European factories is produced by a European supplier. Actual distances and transport modes were used in the model.

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[15] Franklin Associates, April 2010. **Life Cycle Inventory of 100% Post-Consumer HDPE and PET Recycled Resin from Post-Consumer Containers and Packaging**, performed for American Chemistry Council, Inc., et al.

APPENDIX 4— DATA SOURCE AND QUALITY DETAIL

The study adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results. In accordance with ISO 14044, data were selected to ensure:

- Representativeness of the data in the study, including assessment of the temporal, geographical, and technological coverage;
- Consistency – the qualitative assessment of how uniformly the study methodology was applied to the various components;
- 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;
- Precision – the measure of the variability of the data values for each data category;
- Completeness – the percentage of the process that was measured or estimated;
- Uncertainty of information was addressed where possible.

In any LCA, there is an inherent margin of error due to various limitations such as data quality differences or the lack of availability of potentially relevant data. Wherever possible, this LCA used the best data available at the time of the study, including the operation of collection and processing facilities and database modules on energy, fuels, transportation, and basic materials from data available in the latest versions in the LCA software database.

Temporal, Technological, and Geographical coverage

	Temporal Information	Technological coverage	Type of data	Geographical coverage	Source of Data
Retail Planet Partners information	Representative for the 2005-2010 and 2010 models	n/a	Primary data. Some estimates used	NA and Europe	HP
EitB and Web return Planet Partners information	Representative for the 2005-2010 and 2010 models	n/a	Primary data for BOM, EitB program logistics. Some estimates used.	NA and Europe	HP
Recycled bottle resin	2009	All current; largely typical technology with a small % of non-typical technology	Study based on primary data	NA	Franklin Associates (2010)
Sims	2009	Typical technology	Primary	NA	Sims
PDR	2009 (assumed to be same as Sims)	Typical technology (assumed to be same as Sims)	Primary (assumed to be same as Sims)	NA plant data, but German electricity grid used to customize for Europe	Sims
Butler-MacDonald	2009	Typical technology	Primary	NA	Butler-MacDonald
Lavergne	2009	Typical technology	Primary	NA	Lavergne
Transportation routes (return routes, transport to HP manufacturing)	Representative for the 2005-2010 and 2010 models	n/a	Primary	NA and Europe	HP
Disassembly Tool	2009-2010	State of the art technology	Primary	NA and Europe	HP
Virgin PET production	2000-2005	Typical/average technology	Based on primary LCA data	European production	EcoInvent / Plastics Europe
Other materials production (additives, etc.)	Data mostly from 2000-2010	Average production technologies.	Secondary	European data, or NA data if no European data were available.	EcoInvent and other database in SimaPro
Energy and fuel data	Data from 2000-2010	The most representative technologies	Secondary	U.S. data for the NA market, European data for the European market.	EcoInvent and other database in SimaPro
Transportation data	Data from 2000-2010	Average technologies	Secondary	U.S. data for the NA market, European data for the European market.	EcoInvent and other database in SimaPro

APPENDIX 5— CONSUMER TRIP MODELING

Franklin Associates performed an externally peer-reviewed LCA study which measured the environmental impact of bottled water purchased at grocery stores.[16] The modeling approach in this study was used as a baseline to model the impact of consumer trips to drop off used cartridges at retail recycling centers.

Franklin Associates' study assumed:

- Water bottles were being purchased with other groceries, and an allocation was made based on a total number of items bought at the store. Franklin did not have statistics on consumer purchasing patterns on an individual shopping trip basis. The allocation to water was 4% of the trip as baseline, assuming that a total of 25 items were purchased. 50% allocation was tested for sensitivity.
- Consumers did one other errand along with the outing to the grocery store. Franklin added an incremental distance to the outing's round trip, and the overall distance traveled was then divided by two to allocate half to each stop made.

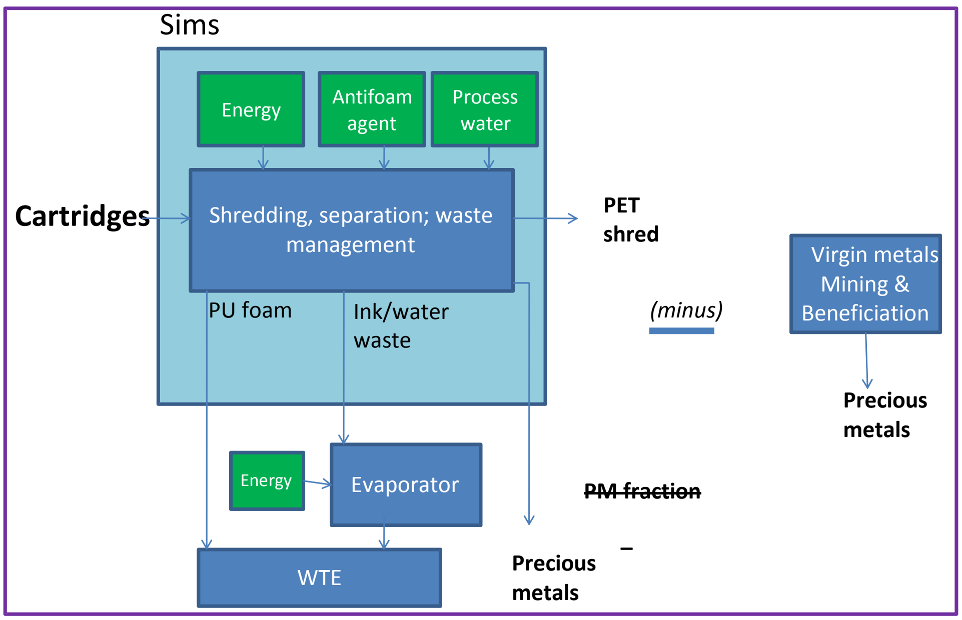
Based on the Franklin model, the consumer trip to the retail recycling location has been modeled as follows:

- The trip distance is 10 miles round trip.
- Two errands were assumed in the consumer trip, consistent with the Franklin study. A conservative estimate of an additional two miles of incremental distance was applied.
- The cartridge return allocation for the trip to the retail recycling location was set at 25%, based on the assumption that the consumer drops off the empty cartridge (25%), replaces the cartridge (25%), and buys two additional items (50%).
- For sensitivity, a worst-case scenario where no additional errands were included in the trip was analyzed.

[16] Franklin Associates, a Division of ERG, 2009. LCA of Drinking Water Systems: Bottle Water, Tap Water, and Home/Office Delivery Water, prepared for Oregon DEQ, found at http://www.deq.state.or.us/lq/sw/wasteprevention/drinkingwater.htm.

APPENDIX 6— PRECIOUS METAL RECOVERY MODELING

Cartridge disassembly processes produce both PET shred and precious metal-rich material. The metal-rich material is sent to a smelter for precious metal recovery. Since there are multiple outputs from the process (or "coproducts"), according to the ISO standards on LCA some modeling is necessary to assign environmental impacts to each of the outputs impartially. In this LCA, system expansion modeling was used: virgin production of precious metals was subtracted out of the total unallocated system. Sensitivity analyses using other available methods of allocation, i.e. mass and economic value, were performed. The sensitivity analyses did not change the overall result. The modeling of the subtraction of precious metals production is shown below.



APPENDIX 7—PEER REVIEW LETTER

Life Cycle Assessment Comparison of HP Virgin PET vs. HP recycled PET – Peer Review Statement

October 2010

Statement of Peer Review

Hewlett-Packard (HP) commissioned Four Elements LLC (4E) to conduct a Life Cycle Assessment (LCA) comparing the environmental impacts of using Polyethylene Terephthalate (PET) versus recycled Polyethylene Terephthalate (RPET) in their inkjet cartridges. Since their intent is to share the findings of the study with a diverse audience, in conformance with the ISO 14040 series of standards, HP also requested a comprehensive peer review of the study's goal and scope, assumptions, model and results. This statement is the culmination of that peer review process, and it summarizes the reviewer's overall approach, the initial comments provided to HP and 4E, and the conclusions on the overall report.

The Review Team

The peer review was conducted by Brian Glazebrook, an LCA expert with extensive expertise relevant to the subject of the study. He is currently Senior Manager at Cisco Systems, working on supply chain sustainability issues within the electronics industry. Mr. Glazebrook is not currently affiliated with HP or any companies in the plastics industry.

Disclaimer

The opinions and input provided by Mr. Glazebrook in this statement are his own and do not reflect the opinion of his employer. In addition, as a peer reviewer, his sole intent was to determine whether the study was consistent with ISO standards and to provide an assessment of the reasonableness of the model and interpretation of results; his participation in this review does not suggest an endorsement of the LCA's goals and conclusions.

The Peer Review Process

The ISO 14040 series of standards provides guidance on how to complete a full LCA and they provided the basis of comparison for the peer review. Broadly, the review focused on answering the following questions:

- Does the goal unambiguously state the intended application, including the reasons for carrying out the study and the intended audience?
- Does the scope clearly describe the function, system boundaries, assumptions, etc.?
- Are the methodological decisions scientifically and technically valid and do any product alternatives reflect reality, rather than being designed to support the study's argument?
- Is the model comprehensive and do the data sources seem sufficiently representative of the systems described?
- Do the final results seems to be reasonable and of the right scale?
- Are the conclusions supported by the results of the model?

The review process consisted of two steps – a review of the initial draft report and a review of 4E's response to the peer review comments in addition to the final report. This peer review statement was only provided after it was determined that all significant issues from the first review were addressed satisfactorily and that the final conclusions accurately reflect the data in the report.

Review of the Initial Draft

The draft version of the report provided by 4E was comprehensive and provided a good summary of what the study was looking to address. It answered most of the peer review questions outlined above, though there were some questions and comments. The feedback from the review can be summarized as:

- Requests for clarification of terms and consistency in terminology.
- Suggestions of extraneous information that could be taken out of the report.
- A request that the description of the functional unit be revised to more accurately reflect the product
- A question about modeling the cartridge return process and some suggested alternative approaches

The consultant 4E responded in writing to all of the peer review comments.

Review of the Final Report

The final report provided by 4E included changes to address most of the comments from the first review. For a few of the comments, 4E indicated that changes to the report were not warranted, but they provided sufficient justification for their reasoning that the reviewer felt was acceptable. The report was comprehensive and provided a lot of detail about the system boundaries and the data sources used to develop the model. The results and interpretation section was very detailed and provided sufficient information to the reason to support the overall conclusions.

Unresolved Issues

There were no issues left unresolved in the final version of the report.

Summary

The reviewer's final assessment of the LCA is that it is consistent with the requirements of the ISO 14040 series of standards. Specifically:

- The study's goal and scope were clearly explained.
- The functional unit is reasonable.
- Assumptions made throughout the report were well documented and acceptable.
- A clear effort was made to collect data that was as representative as possible of the specific technologies.
- The model as defined was very comprehensive and included some elements that normally would have been excluded in other studies.
- The impact categories selected were comprehensive and clearly explained.
- The data interpretation was clearly presented.
- Sensitivity analysis was used correctly to evaluate some of the key assumptions.

Around the issue of comparative assertion, the review team agrees that:

- The model was structured to ensure the comparison between the technologies is fair and equivalent.
- The methodological decisions and assumptions are scientifically and technically valid.

It should be noted that while a peer review can provide valuable input to the authors of an LCA, they are not obliged to accept and implement all of the input the peer reviewers provide. With this in mind, it is appreciated that HP and 4E were willing to address the issues presented in the peer review comments. Almost all of the comments and suggestions were either adopted in the final report or 4E made an effort to provide a detailed response to address the issue.

APPENDIX 8— LIFE CYCLE ASSESSMENT ANALYST

ANNE LANDFIELD GREIG, Four Elements Consulting, LLC

Anne Landfield Greig, Certified Life Cycle Assessment (LCA) Practitioner, is the principal and owner of Four Elements Consulting, LLC. Four Elements specializes in Life Cycle Management (LCM) and Life Cycle Assessment (LCA) services to help corporations, government and non-governmental organizations find valuable environmental and cost management solutions for their products and operations. Four Elements also carries out product- and corporate-wide greenhouse gas (GHG) assessments and carbon footprints, and assists companies with the preparation of GHG and carbon offset verifications. Anne Greig is an advisor on life cycle issues for CarbonFund's Carbon*free*™ 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.