Life Cycle Environmental Impact Study
For Latin America

HP LaserJet Toner Cartridges
vs.
Remanufactured Cartridges

SUMMARY REPORT

Four Elements Consulting, LLC

April 2016

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Executive Summary

HP Inc. commissioned Four Elements Consulting, LLC, to perform an environmental Life Cycle Assessment (LCA) comparing Original HP LaserJet toner cartridges with remanufactured (reman) cartridges sold as substitutes. The 2016 study on the Latin America (LA) region, mirroring an externally peer-reviewed 2015 LCA covering the Asia region, adheres to the International Standards Organization (ISO) 14040 series and evaluates all phases of the life of the cartridges, from material sourcing, manufacturing, use, and end-of-life disposition. This Summary Report presents the results of the LCA.

The goal of this study was to provide a comparative environmental assessment utilizing the most current research and data on production practices, disposition trends, product quality, and usage trends of Original HP toner cartridges and reman alternatives in LA. The study found that, as in previous HP LCA studies, paper consumption during printing is the largest contributor to the environmental impact across all phases of the life cycle for both the Original HP toner cartridge and the reman alternative.

In addition, the study shows that in all assessed categories, the Original HP cartridge showed the same or lower environmental impact than the reman alternative. Optimized print quality performance reduced the environmental impact for the Original HP cartridge because fewer pages were reprinted. Therefore, for customers who print documents for both internal and external purposes, and who are concerned about the environmental impact of their cartridge choice, Original HP cartridges are a wise choice compared to reman alternatives. For users whose print quality requirements are not as high, the environmental impact of HP and remanufactured cartridges is comparable.

Summary Report

Introduction

For over a decade, HP has been evaluating life cycle environmental impacts of its LaserJet toner cartridges; the most recent was in 2015, where HP commissioned Four Elements Consulting, LLC, to perform the LCA study for Asia. The Asia study underwent an external peer review process to ensure a sound methodology, high credibility and objectivity of the data and results as well as conformance with the ISO standards for an LCA. This LCA carries over the same methodology and goals as previous studies, including continually striving to gather and utilize the most current research and data for production practices, disposition, and product quality for Original HP toner cartridges and reman cartridges sold in the LA markets. The results are summarized below.

Methodology

Products Studied

HP selected the CF280A (80A) and CF283A (83A) toner cartridges for this study. The 80A model was chosen because it is a top-selling mono print cartridge model in LA and it has a wide selection of aftermarket cartridges available. The 83A has replaced the CE278A, which has been a top-selling mono print cartridge model. Thus, the 83A was chosen because it is also expected to be a top seller, and there are aftermarket cartridges available. For the LCA, the two cartridges were averaged into one hypothetical cartridge model. The life cycle data weighting for these two cartridges is based on the number of cartridges shipped in fiscal year 2015, multiplied by their ISO page yield.[i] A separate analysis was run that evaluated each cartridge model separately; since the results did not vary significantly from one model to the next and did not change any outcomes of the study, the hypothetical model was used.

Table 1 Summary of Cartridges Studied

Cartridge SKU	HP Original Printer	Page Yield	Wt.Avg Split	Relevance to this study
CF280A (80A)	LaserJet Pro 400 M401	2,700	66%	Significant contributor to its target markets: SMB and Enterprise
CF283A (83A)	LaserJet Pro MFP M127fn	1,500	34%	Significant contributor to its target markets: home office and small business

The HP 80A and 83A cartridges were compared to reman cartridges. This study defines a reman cartridge as a used HP shell that has been disassembled, inspected, cleaned, repaired, and has some parts replaced (a used OEM shell that has never undergone remanufacturing may also be referred to as a “virgin” OEM shell). The cartridge is then refilled with non-HP toner and reassembled. This analysis does not intend to mirror one specific brand of reman cartridge; it is acknowledged that there is broad variability in the reman industry.

Printing industry analyst, InfoTrends Research (InfoTrends), found that 80% of Original HP toner cartridges in the LA market are remanufactured only a single time, or are single "cycle".[ii] Therefore, this study compares an Original HP cartridge to a "single-cycle" reman cartridge in which a used HP cartridge is remanufactured only one time.

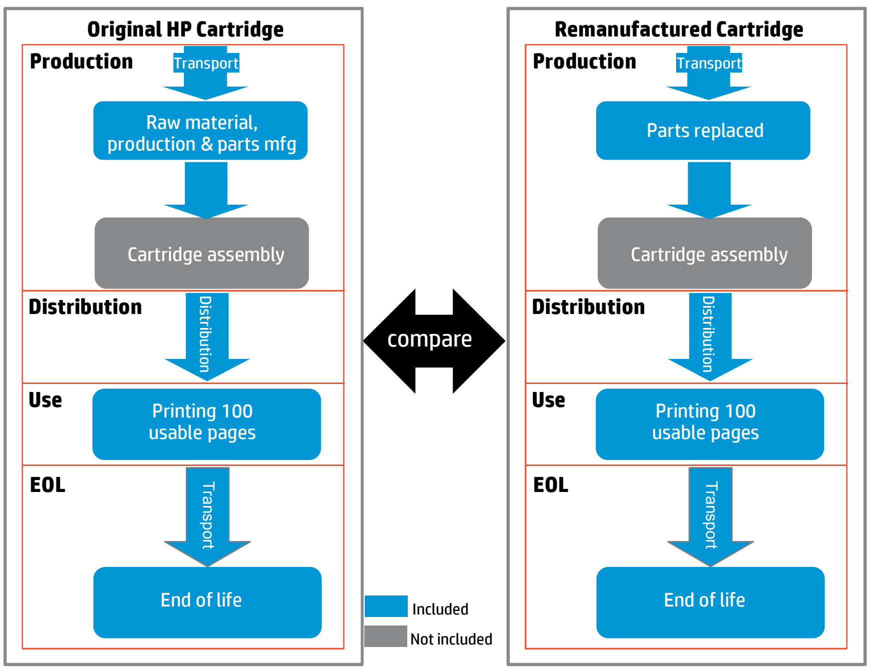
Adherence to the ISO Standards

This LCA adheres to the principles, framework and guidelines in ISO 14040 and 14044.[iii] LCA is a tool for the systematic evaluation of the environmental impacts of a product through all stages of its life cycle, which include production, distribution to the customer, use of the cartridge, and end of life.

System Boundaries

Figure 1 presents the study's system boundaries. Life cycle phases include production, distribution to the customer, use of the cartridge, and end of life (EOL).

Figure 1 System boundaries



Data Sources

HP provided data on the HP cartridges including the bill of materials, place of manufacture, packaging specifications, printing specifications, and cartridge recycling practices. InfoTrends provided data on current remanufacturing recycling practices,[ii] and these data were used for some of the key assumptions made for the reman cartridge. HP commissioned *SpencerLab*, an internationally recognized leader in independent research and comparative analysis of print system performance, to test the print quality and reliability performance of the Original HP 80A and 83A cartridges and compare them to leading reman brands.[iv] In 2013 and 2015, HP commissioned Market Strategies International (MSI) and Photizo Group, respectively, to conduct Customer Experience studies which provide intended page use data for customers who use HP LaserJet printers.[v] The *SpencerLab* Cartridge Reliability Comparison study and the MSI and Photizo Group studies were used to establish the number of printed pages required to attain 100 usable printed pages, the basis upon which the comparison is made (next section). Key assumptions were checked for sensitivity.

Secondary data sources were evaluated for temporal, geographical, and technological coverage. Data available from LCA software databases were evaluated, and the most current and/or best quality data available at the time of the study were used. SimaPro, a commercial LCA software product, was used to model and calculate the LCA.[vi] The study included data from the latest available version of the EcoInvent database.[vii] Utilizing the most current available data, especially from a well-known and accepted database, enhances the quality of the study and increases its transparency, reliability, and confidence level.

Function and Functional Unit

In order to conduct an ISO-compliant LCA, all flows within the system boundaries must be normalized to a unit summarizing the *function* of the system, enabling the comparison of products or systems on an equivalent basis. The function of a cartridge is to print pages. Because cartridge print quality performance has been evaluated, the function incorporates the print quality differences. Thus, the function of the system has been defined as printing to obtain usable pages for their intended use. With the function defined, a "functional unit", or reference flow, is chosen in order to calculate the systems on that quantitative basis. For this study, the functional unit is defined as "the printing of 100 usable monochrome one-sided pages," which includes printing 100 pages plus any reprinting needed to satisfy the intended use.

The *SpencerLab* study defined print quality in terms of the acceptability of the printed pages. Including the MSI and Photizo Group page use distribution as part of the definition of the functional unit is an important study assumption. The relationship between how one uses a printed page and the required print quality determines the amount of reprints one might experience.

Modeling and Assumptions

The sections below summarize each life cycle stage's modeling and assumptions. Appendix 2 provides the data and assumptions.

Production

The HP cartridge Production Phase includes the production of over 99.5% by mass of the materials in 80A and 83A cartridges, including parts forming (e.g., injection molding of plastic into cartridge parts, parts forming of aluminum and steel parts, etc.). The reman cartridge model includes transport of used cartridges to the remanufacturer, replacement of select cartridge parts, replacement of toner, and preparation for the market. The reman Production Phase must also account for impacts associated with collected cartridges not suitable for remanufacturing, determined during the "sort and discard" step prior to remanufacturing. The reman model, therefore, includes managing these unusable cartridges along with original cartridge parts that have been replaced. The packaging materials for shipment are included for both cartridge alternatives.

Production also includes intermediate and final assembly. However, no data were available for this aspect of production. The assembly process is automated, and while it consumes energy, the quantity is likely small relative to parts manufacturing. Remanufacturing includes disassembly of the empty core, removal of remaining toner by way of vacuum systems, parts cleaning, reassembly and/or reprocessing into like-new condition, and testing parts and cartridges for re-usability. Similar to the HP cartridge, replaced parts material production and parts forming has been included, but energy usage and other process aids used in the activities at the reman facility is also a data gap. The implications and limitations of the energy and processing data gaps are addressed in the Limitations section.

Distribution

The Distribution Phase refers to the delivery of the packaged Original HP and the reman cartridges from final assembly to the end user.

Use

Use Phase modeling accounts for the amount of paper and printer energy needed to print 100 usable pages. Information on pages printed and printer energy are found in Table 10. The paper production model, based on a comprehensive paper and printing LCA completed in 2010[viii] is described in the Data Quality section (p. 9). Page quality performance was assessed in the *SpencerLab* study where a sample of Original HP and reman cartridges were evaluated and 64 pages were taken at periodic intervals over the life of each cartridge tested. The sampled pages were graded on overall print quality using a scale created from a psychometric research study of business laser printing users. The psychometric research provided a scale in which print quality could be sorted into four acceptability levels or categories, described as follows and summarized with the *SpencerLab* test results in Table 2.[iv]

1. <u>All uses, including External Use</u>: Acceptable for all uses, including distribution outside a company to customers, vendors, suppliers, etc. Examples: marketing materials to promote the company or products, official company correspondence, invoices.
2. <u>Internal Use</u>: Acceptable for distribution inside a company, but not acceptable for distribution outside a company. Examples: documents to distribute to colleagues, immediate superiors or subordinates as business communication.
3. <u>Individual Use:</u> Individual use only; usable as a copy to read, file or mark-up but not acceptable for distribution, either within or outside a company.
4. <u>Unusable</u>: Not acceptable for any business purpose.

Table 2 Print Quality Distribution

	External Use	Internal Use	Individual Use	Unusable
HP Cartridges Tested	95.1%	4.3%	0.6%	0.0%
Average Reman Cartridges Tested	39.4%	58.9%	2.0%	0.0%

From the *SpencerLab* study, HP learned that print quality acceptability depends on the intended use for the pages being printed. The psychometric study demonstrated that in business settings, some minimum level of print quality is necessary for External, Internal or Individual use. If the minimum required print quality level for the intended use is not met, the page may be reprinted. From the acceptability categories, it could be deduced when a customer might reprint a page that is not suitable for the use it was intended. For example,

1. External use pages would not need to be reprinted for any purpose as they are of the highest quality.
2. Internal use pages would need to be reprinted if the intended use was for external distribution.
3. Individual use pages would need to be reprinted if the intended use was for internal or external distribution.
4. Unusable pages would need to be reprinted for any intended use.

The MSI and Photizo Group studies surveyed HP LaserJet users in 16 countries on their printing behavior in the work environment, and the resulting page use was distributed across three categories: "External Use", "Internal Use", and "Individual Use".[v] These categories corresponded to the page use categories from the *SpencerLab* study shown in Table 2. The page use distribution from MSI and Photizo was used for the baseline analysis. Sensitivity analyses were performed to examine the case in which a user requires all output to be used for external communication, with reprinting required for all pages not of the highest quality, and another case in which a user prints for individual use only, where lower quality prints are acceptable. Table 3 summarizes the distributions for each scenario.

Table 3 Page Use Distribution

		External Use Acceptable for all uses	**Internal Use** Limited use: Not for external distribution	**Individual Use** Limited use: Not for distribution
Baseline	MSI and Photizo Group	32.3%	42.8%	24.9%
Sensitivity	100% External Use	100%	0%	0%
	100% Individual Use	0%	0%	100%

Page use was combined with print quality performance to calculate the number of pages where reprinting is required to meet the intended use and, hence, total number of pages printed in order to obtain the functional unit of 100 usable pages.

Table 4 Pages printed to obtain 100 Usable Pages

		Total pages printed to obtain a functional unit		% more reman pages printed
		HP	Reman	
Baseline	MSI and Photizo Group	102	150	47.5%
Sensitivity	100% External Use	105	254	141%
	100% Individual Use	100	100	0%

End of life

End of life Phase refers to the fate of the cartridge after toner depletion. The used HP cartridge is assumed to be returned for recycling through HP Planet Partners Return and Recycling Program. The reman cartridge is assumed to be returned for remanufacturing. Sensitivity analyses looked at results where the HP cartridge and reman were thrown away into the municipal solid waste (MSW) stream, which includes landfilling (97.5%) and materials recovered to be recycled (2.5%).[ix]

RESULTS

Baseline results

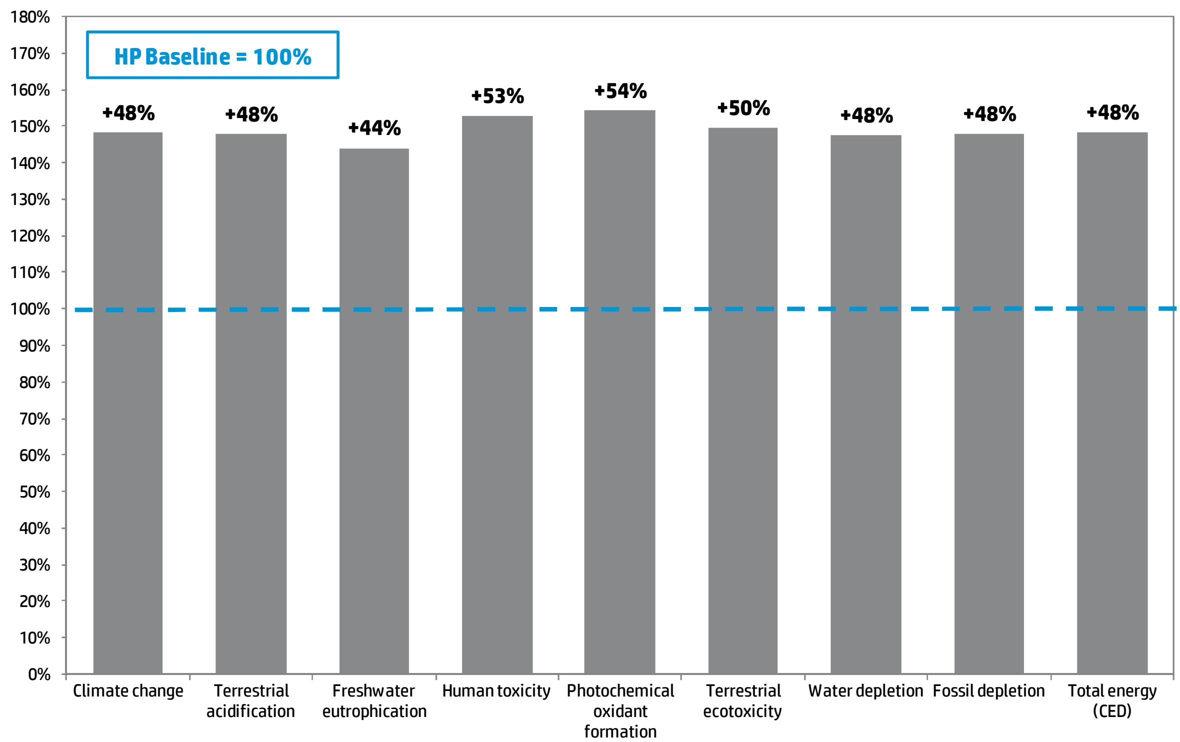
Table 5 and Figure 2 present results for the baseline comparison. The last column in the table shows that the environmental impacts for the reman cartridge are higher than 44% in all categories. As mathematical models of complex systems, all LCAs have inherent limitations that result in some level of uncertainty (see the limitations section for more details). As a result, one cannot definitively conclude that one alternative is better than another without accounting for some margin of error, and a +/- 10% margin of error has been applied to these results. For these baseline findings, it can be said that the reman cartridge impacts are higher than HP in the impact categories measured.

Table 5 Baseline Results

Impact category	Unit	HP Cartridge	Reman Cartridge	Reman compared to HP*
Climate Change	kg CO2 eq	8.5 E-01	1.3 E+00	48.2%
Terrestrial Acidification	kg SO2 eq	6.9 E-03	1.0 E-02	47.8%
Freshwater Eutrophication	kg P eq	1.6 E-04	2.3 E-04	44.1%
Human Toxicity	kg 1,4-DB eq	1.8 E-01	2.8 E-01	52.9%
Photochemical Oxidant Formation	kg NMVOC	4.4 E-03	6.8 E-03	54.2%
Terrestrial Ecotoxicity	kg 1,4-DB eq	1.1 E-04	1.6 E-04	49.6%
Water Depletion	m^3	4.6 E-02	6.7 E-02	47.6%
Fossil Depletion	kg oil eq	2.6 E-01	3.8 E-01	48.0%
Total Energy (CED)	MJ	2.8 E+01	4.2 E+01	48.4%

* % that reman is higher (positive number) or lower (negative number) than HP

Figure 2 Reman Results Compared to HP Results



Life Cycle Stage Contribution Analysis

Table 6 and Table 7 present a breakdown of impact category results across the four defined life cycle stages of the cartridges. These results are consistent with previous studies, that the "Use Phase," and specifically paper use, is the largest contributor to the environmental impact of a toner cartridge. This is the case for both Original HP and reman cartridges.

Table 6 Contribution Analysis - Life Cycle of HP Cartridge

Impact category	Unit	HP TOTAL	HP Production	HP Distribution to User	HP Use Phase	HP EOL - Recycling program
Climate Change	kg CO2 eq	8.5 E-01	25%	2.3%	80%	-6.8%
Terrestrial Acidification	kg SO2 eq	6.9 E-03	17%	2.6%	84%	-3.7%
Freshwater Eutrophication	kg P eq	1.6 E-04	31%	1.0%	75%	-7.9%
Human Toxicity	kg 1,4-DB eq	1.8 E-01	31%	1.7%	74%	-7.2%
Photochemical Oxidant Formation	kg NMVOC	4.4 E-03	16%	4.4%	83%	-3.8%
Terrestrial Ecotoxicity	kg 1,4-DB eq	1.1 E-04	13%	2.2%	85%	0.2%
Water depletion	m^3	4.6 E-02	6.4%	0.1%	96%	-2.5%
Fossil Depletion	kg oil eq	2.6 E-01	27%	2.7%	78%	-8.6%
Total Energy (CED)	MJ	2.8 E+01	13%	1.1%	90%	-4.1%

Note: 0% implies value less than 0.1%

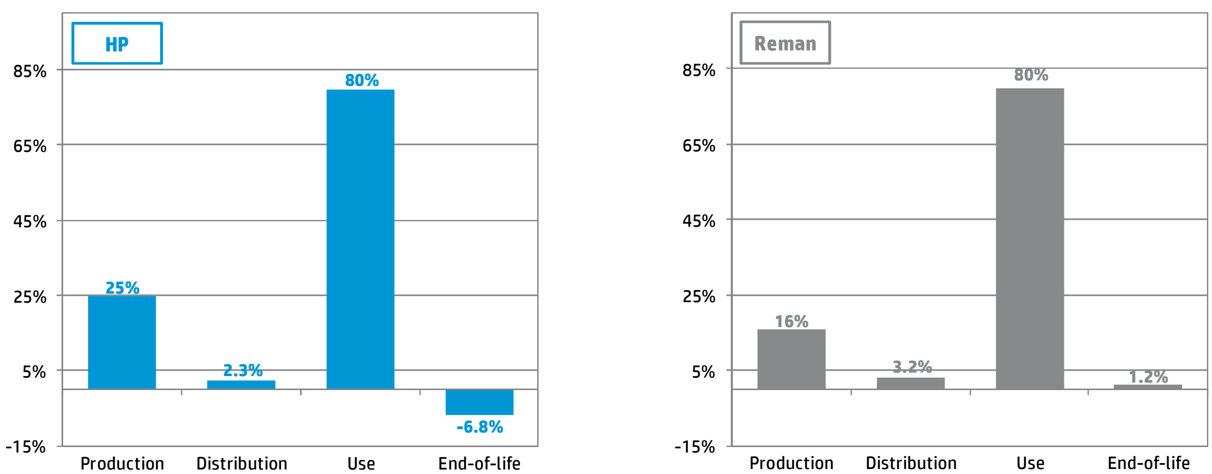
Table 7 Contribution Analysis - Life Cycle of Reman Cartridge

Impact category	Unit	Reman TOTAL	Reman Production	Reman Distribution to User	Reman Use Phase	Reman EOL - Sent to Reman
Climate Change	kg CO2 eq	1.3 E+00	16%	3.2%	80%	1.2%
Terrestrial Acidification	kg SO2 eq	1.0 E-02	12.0%	2.3%	85%	0.9%
Freshwater Eutrophication	kg P eq	2.3 E-04	21%	1.2%	78%	0%
Human Toxicity	kg 1,4-DB eq	2.8 E-01	22%	2.4%	72%	3.2%
Photochemical Oxidant Formation	kg NMVOC	6.8 E-03	13%	4.8%	80%	2.2%
Terrestrial Ecotoxicity	kg 1,4-DB eq	1.6 E-04	12%	3.7%	84%	0.5%
Water depletion	m^3	6.7 E-02	3.2%	0.2%	97%	0%
Fossil Depletion	kg oil eq	3.8 E-01	16%	3.7%	79%	1.1%
Total Energy (CED)	MJ	4.2 E+01	7.7%	1.6%	90%	0.4%

Note: 0% implies value less than 0.1%

The importance of the Use Phase, shown above and in Figure 3 using the Climate Change metric, supports the critical nature of cartridge performance. Because the Use Phase impacts are so large in relation to other phases, poor print quality can have a controlling influence over the life cycle results. In this case, the benefit of raw material savings for the reman cartridge is offset by a greater impact during the Use Phase, due to its lower quality output and the need to reprint (see Table 4). Note that the negative values for end-of-life of the Original HP represent the offset of materials at recycling and the energy offset from waste-to-energy (WTE) of the remaining materials at the HP recycling facility (see EOL assumptions in Table 10).

Figure 3 Contribution Analysis by Life Cycle Stage – Climate Change for HP and Reman



Sensitivity Analyses

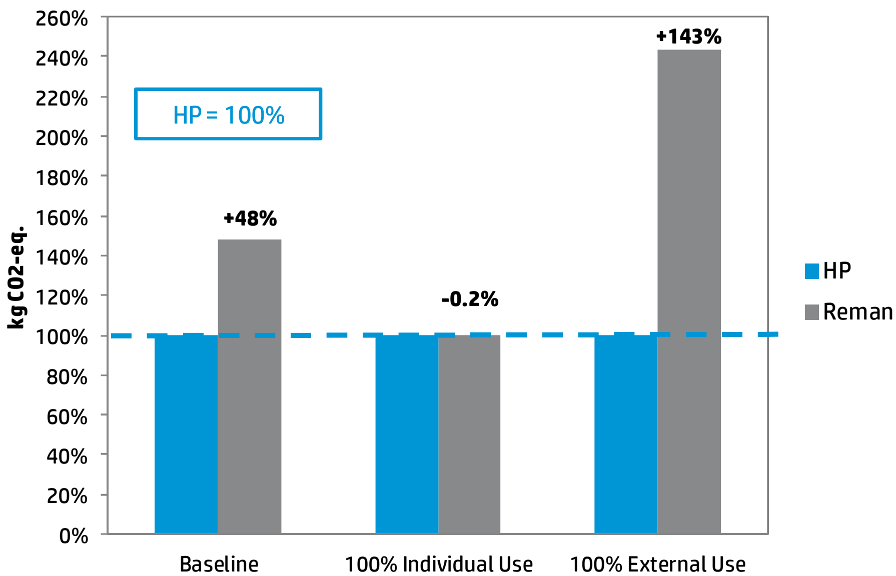
Sensitivity of Page Use Distribution

As has been demonstrated, cartridge performance and page use have a critical influence on the cartridge's environmental life cycle metrics. In order to examine the degree of influence that page use has on the results, two sensitivity analyses were performed: one in which all prints were used for external purposes (distribution outside of the company or marketing material) and one in which all prints were for individual use (usable as a copy to read, file or mark-up).

The Climate Change category is used to present the sensitivity results in Figure 4. When the page use is for external purposes only, the need for higher quality (customer ready prints) pages require the user to reprint more pages if using a reman cartridge – 2.4 times more – than when using an Original HP cartridge (see Table 4). As a result, the reman cartridge Climate Change impact jumps to 143% higher than HP. When prints are for individual use only, which can be of much lower quality, both cartridge types print essentially the same number of pages. In this case, the reman cartridge's environmental impact is nearly equivalent to the Original HP. While intuitively one might think the reman would have lower environmental impacts, this is not the case for two reasons. First, the Original HP cartridge system benefits from materials and energy recovery during recycling at EOL, offsetting its production impacts. Second, at EOL, the reman cartridge is returned to a remanufacturer. Since 80% of remans are made from virgin OEM cartridges,[ii] a returned reman is rejected 80% of the time and must be managed as waste. In LA, waste management is 98% landfilling and 2% recycling;[ii] with such a small recycling rate, the reman gets very little benefit (i.e., material offset).

While these two page use extremes are not common scenarios, the results illustrate that as user print quality requirements increase, the environmental advantage offered by the Original HP cartridge also increases. When low quality prints are acceptable, the benefit of recycling the Original HP cartridge at end of life, through HP Planet Partners program, helps to offset some of the production impacts.

Figure 4 Sensitivity - Change in Page Use – Climate Change



Sensitivity of Select Model Assumptions

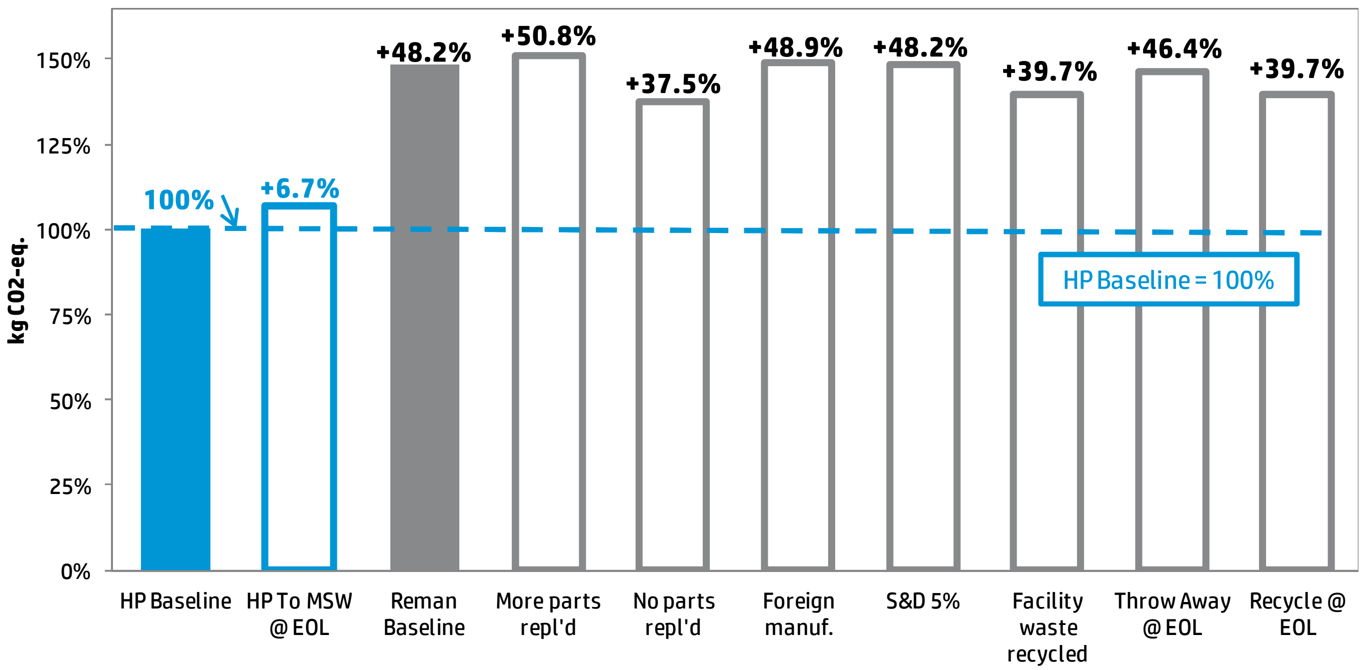
Select model assumptions were assessed for sensitivity, and these are summarized in Table 8. The Climate Change category was used to present the results in Figure 5.

Table 8 Summary of Sensitivity Analyses

Model Affected	Baseline assumption	Sensitivity assumptions
HP	Cartridge is recycled through HP's recycling process at end of life	Cartridge is disposed of in the MSW stream at end of life.
Reman	Parts replaced: OPC drum, cleaning blade, developer blade, chip, toner and toner dam seal	1) Additional part replaced: primary charge roller and developer roller sleeve 2) only toner replaced[x]
Reman	The end user is in LA and the remanufacturing facilities are in LA.	The end user is in LA and the remanufacturing facility is in China. The cartridge depleted of toner is transported from LA to China (see Table 10).

Reman	Sort & discard rate is 45%[ii]	Sort & discard rate is 5%. (Accounts for less transportation impacts to the remanufacturing facility and less waste is managed.)
Reman	Management of unusable cartridges (sort & discard) and replaced parts is based on market research (mix of recycling, landfilling, WTE, if applicable)[ii]	Unusable cartridges (sort & discard) and replaced parts are recycled
Reman	The cartridge is sent back to remanufacturer with intent to recycle.	1) Cartridge is disposed of in the MSW stream at end of life. 2) Cartridge is recycled at end of life.

Figure 5 Sensitivity Analyses – Climate Change



The HP baseline (solid blue) is on the far left, with its corresponding sensitivity analysis to its right. The reman baseline has a dark grey fill with its corresponding scenarios to its right. All results are normalized to the HP baseline (100%), and the percentages shown are the net difference.

When the HP cartridge is thrown away instead of recycled at the end of life, the overall Climate Change impact increases by 6.4%. When the reman cartridge is thrown away at the end of life, its Climate Change impact decreases almost 2%, primarily because the transport to local disposal has less impacts than the cartridge transported back to a remanufacturer. When the reman cartridge is recycled at end of life, its impact decreases 8.5% due to material recovery and energy offsets from WTE.

The sensitivity analysis results for the reman do not change significantly from the baseline results, with the exception of three of the tested parameters. When the remanufacturing facility recycles waste cartridges and materials, and when the reman is recycled at EOL, both sets of results decrease by 8.5%. Also, when only the toner is replaced, the results decrease more than 10%. However, it should be noted that no adjustment in the Use Phase has been made for an expected lower print quality when only toner is replaced and no key parts are replaced. On the other hand, as more parts are replaced, the environmental impact increases 2.6%. Foreign remanufacturing causes a small increase (0.6%). When the sort & discard rate decreases from 45% to 5%, the results do not change. The latter two parameters change little if any because these aspects of the life cycle are already insignificant (see, for example, the distribution bar in Figure 3). As is evident from Figure 5, even though results increase and decrease to some degree, modifications to the baseline model assumptions does not significantly affect the outcome of the study, giving testament to the main driver of the study: paper production drives the results, and many other aspects of the life of the cartridges are secondary.

Sensitivity of Duplex

The effect of duplex was evaluated using the baseline results and leveraging InfoTrends data pertaining to the use of duplex. Monthly print volume and duplex use rates for office printers were used to calculate the percent of pages saved using duplex. An overall weighted average of 19% of pages saved was used.[xi]

Table 9 Sensitivity Analysis – Duplex

		Duplex Results			Baseline
Impact category	Unit	HP Cartridge	Reman Cartridge	% Difference (Reman vs. HP)	% Difference (Reman vs. HP)
Climate Change	kg CO2 eq	7.2 E-01	1.1 E+00	**48%**	48%
Terrestrial Acidification	kg SO2 eq	5.8 E-03	8.6 E-03	**48%**	48%
Freshwater Eutrophication	kg P eq	1.3 E-04	1.9 E-04	**43%**	44%
Human Toxicity	kg 1,4-DB eq	1.6 E-01	2.4 E-01	**54%**	53%
Photochemical Oxidant Formation	kg NMVOC	3.7 E-03	5.8 E-03	**55%**	54%
Terrestrial Ecotoxicity	kg 1,4-DB eq	8.8 E-05	1.3 E-04	**50%**	50%
Water depletion	m^3	3.7 E-02	5.5 E-02	**47%**	48%
Fossil Depletion	kg oil eq	2.2 E-01	3.3 E-01	**48%**	48%
Total Energy (CED)	MJ	2.3 E+01	3.5 E+01	**48%**	48%

With duplex, the relative differences between the cartridges were found to be largely the same as the baseline results (presented again in the far right column in Table 9).

Data Quality Requirements and Evaluation

This LCA adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results.

Temporal, Geographical, and Technological Representativeness

Temporal representativeness describes the age of data and the minimum length of time (e.g., one year) over which data are collected. The data applied to this study represent current products and practices. The HP 80A and 83A and their reman counterparts are cartridges used in popular printer models. The parts and materials lists (PMLs) provided by HP are current and representative. Waste management practices for the cartridges are based on the best available current data, as is the MSW management disposition percentages to landfill, WTE, and recovery of materials. The cartridge performance data came from a recently published study. Other cartridge specifications (electricity usage, etc.) are current. Energy and transportation data are mid-2000's, and production data for materials are largely based on data sets ranging from the mid- to late-2000's and beyond. The paper production data are based on primary data collected for production during 2006 and 2007.

Geographical representativeness describes the geographical area from which data for unit processes are collected to satisfy the goal of the study. Data for energy, materials, processes, and transportation are based on European sources. Paper production comes from U.S. and Canadian paper producers and represents average North American production, and this data source is considered to be high quality, representing current technologies and primary data.

Technological coverage, corresponding to the time period of the data sets, is current. Technological data for most materials and processes are generally industry average, and in some instances, typical.

Consistency

Consistency is a qualitative understanding of how uniformly the methodology is applied to the various components of the study. Consistency was maintained in the handling of the products as well as the approach to previous toner cartridge LCA studies.

Reproducibility

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

Precision and Completeness

Precision represents the degree of variability of the data values for each data category. Precision cannot be quantified for this study since only one set of data for each HP cartridge was provided. For the remanufacturing industry, there is so much variability amongst practices that precision could not be explicitly quantified; however, sensitivity analyses were performed to address variation. Completeness is the percentage of flows that have been measured or estimated. The PMLs contain well-measured, accurate data. However, no other primary data was collected so an evaluation on completeness is not possible.

Limitations and Uncertainty

General Limitations and Uncertainty

It should be borne in mind that the LCA, like any other scientific or quantitative study, has limitations. While it provides an indication of the environmental impacts and attributes associated with product systems, it is a not a perfect tool for assessing actual impacts and attributes. This is true for all LCA studies. As is normal for an LCA, much of the data used for modeling the materials is secondary. Because the quality of secondary data is not as good as primary data, the use of secondary data creates some level of uncertainty since it may cover a broad range of technologies, time periods, and geographical locations. As well, since hundreds of data sets are linked together and it is often unknown how much the secondary data used will deviate from the specific system being studied, quantifying data uncertainty for the complete system becomes very challenging. As a result, it is not possible to provide a reliable quantified assessment of overall data uncertainty for the study, but it is understood that each product compared possesses this similar type of uncertainty. Because of the uncertainty in the study, results within +/- 10% are characterized as on par.

Missing Manufacturing Data

Similar to previous studies, a data gap is encountered for cartridge processing and assembly for both alternatives, due to lack of available data.[xii] While the 80A and 83A's production stage included over 99.5% of the materials from the PML plus generic parts forming, no specific assembly data for the OEM, or dis-assembly/reassembly, cleaning, testing, or other process data for the reman were available. However, since inclusion of materials production and forming is robust and since often the bill of materials collectively embody higher environmental impacts than manufacturing, then excluding the assembly data (which represents only one portion of the production stage) probably has little effect on the overall model.

Furthermore, in light of broadly varying remanufacturing practices over the multitude of remanufacturing organizations, this lack of manufacturing/assembly data may result in greater uncertainty. However, updated information from InfoTrends provided information on parts replacement, and the model captured production of new parts and waste management of replaced parts, two important aspects of remanufacturing processes.

For both cartridges, process impacts are missing. Yet, this in itself, gives way to slightly less uncertainty for the following reasons:

1. The LCA normalizes products to a functional unit, so the relative, not absolute, differences in impacts for products being compared are measured. Therefore, when both products lack similar information, the data gap may be mitigated.
2. The results and sensitivity analyses have shown that the overwhelming contributor to the life cycle of the cartridges is paper consumption at the Use Phase, so the exclusion of assembly and other process impacts may not make a difference although quantifying the magnitude of this uncertainty is not possible.

Conclusion

Environmentally based decision-making for cartridges should undoubtedly consider the cartridge's entire life cycle, especially the Use and End-Of-Life Phases. The most current research and data on production practices, product quality, and disposition trends were used to model the life cycles of the Original HP and leading reman cartridges. Reliability testing of these cartridges showed that Original HP exhibited more reliable output quality than reman alternatives. Based on these data, pages where quality was unacceptable for their intended use were assumed to require reprinting, leading to greater consumption of paper and printer energy. In the Use Phase, paper consumption during printing was found to be the largest contributor for both the Original HP and reman cartridges. Factors that influence the consumption of paper – in this case, quality of the printed pages – were found to have a controlling effect on life cycle environmental impacts.

The baseline results showed that the reman's poor print quality performance results in a higher environmental impact relative to the Original HP cartridge in all of the categories measured. For users who require high quality, customer ready prints, the Original HP cartridge offers a clear environmental advantage. For users whose print quality requirements are much lower, where the quality is only good enough for individual use, the environmental impact of HP and remanufactured cartridges is comparable, especially when HP cartridge users take advantage of HP's Planet Partners cartridge recycling program.

Other findings of the study conclude that:

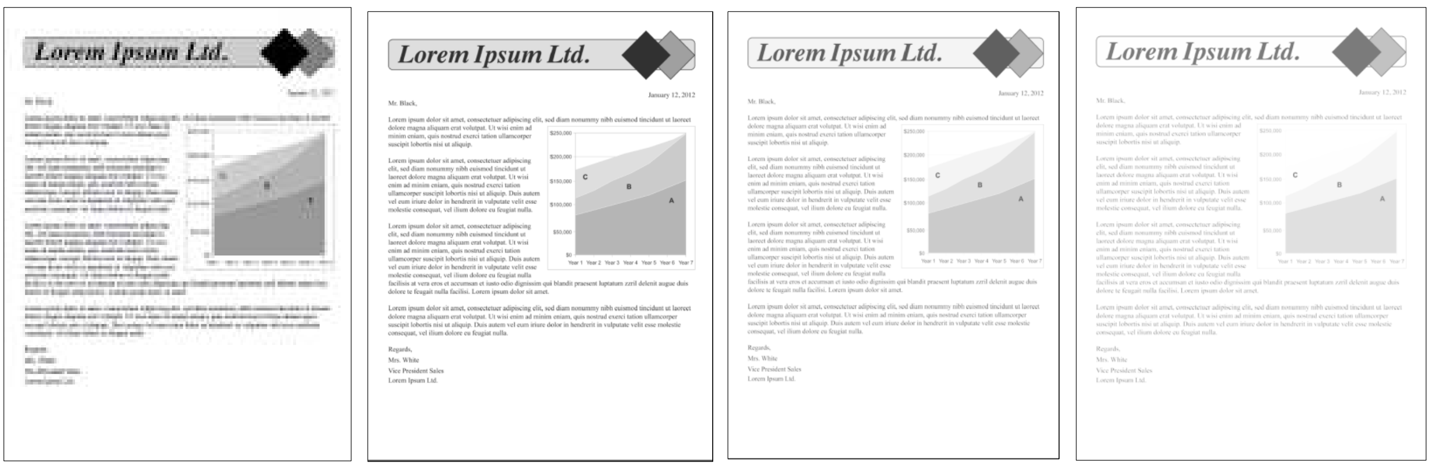
- In the sensitivity analyses of other model parameters, some of the assumptions tested caused an increase or decrease in the cartridge systems' results, but the Use Phase still largely influenced the overall outcome of the study.
- In the End-of-Life Phase, recycling and recovery of materials can be especially important in reducing the environmental impact of a toner cartridge.
- The reman cartridge can improve its environmental profile with improved quality performance and more recycling at the remanufacturing facility.

To conclude, a comprehensive look at the life cycle reveals a more complex picture and challenges the conventional wisdom that remanufactured cartridges are better for the environment. Rather, the evidence shows that reman cartridges' poor print quality performance position them to be higher than the Original HP cartridge in all impact categories.

Paper continues to be the main source of printing's environmental impact, and cartridge print quality plays a significant role in paper consumption. The bottom line is that the use of higher quality Original HP cartridges can lead to fewer reprints and less paper consumed, which lowers environmental impact and makes them a wise overall choice.

APPENDIX 1 *SPENCERLAB* PAGE CATEGORY EXAMPLES

Figure 6 Print Quality Categories [iv]



External Use	External/Internal Boundary	Internal/Individual Boundary	Individual/Unusable Boundary
	Lower PQ - Internal	Lower PQ - Individual	

*Note: Page scans may not be accurately reproduced when printed from this report.

**Scanned pages are for demonstration purposes only, and not specific to any single printer platform or brand in the study.

Appendix 2 Summary of Data

Table 10 Summary of the Cartridge Data used in the Study

	Baseline		Sensitivity Analyses	
			Lower Limit	Upper Limit
	HP Cartridge	Reman Cartridge	Reman Cartridge	Reman Cartridge
PRODUCTION				
Upstream Materials Production	The bill of materials was provided by HP in current Parts Materials List (PMLs). Over 99.5% of materials in the cartridge were included in the modeling.	• The Organic Photoconductor (OPC) drum, wiper (cleaning) blade, toner and the toner dam are replaced.[ii] • Fate of replaced parts at facilities in LA:[ii] - Landfill: 98% - Incineration with energy recovery (waste-to-energy (WTE)): 0% - Recycle: 2%	• Sensitivity: No materials are replaced except for the toner.[x] • Sensitivity of fate of replaced parts at facilities in LA: - 100% recycled	• Selected additional components are replaced: primary charge roller (PCR) and developer roller sleeve.[ii] • Fate of replaced parts at facilities in LA:[ii] - Landfill: 98% - WTE: 0% - Recycle: 2%
Transportation to Manufacturing	• HP80A and 83A are manufactured in Japan and Virginia, USA. • Transportation of materials and components to final manufacturing is represented by global averages for materials by truck and other modes of transport.	• Remanufacturing locations are in Latin America. A weighted average of these is taken. • Spent cartridge is transported a weighted average of 2,137 mi by truck and 1,398 mi by boat to the remanufacturing plant from the end-user locations in Mexico City and Sao Paolo.		• Remanufacturing is in Shanghai, China; empty OEM 80A and 83As are sourced from Mexico City and Sao Paolo. • Cartridge is transported 9,912 mi by ship and 1,378 mi by truck from end-user in LA.
Manufacturing & Assembly	There were no data available on final steps of manufacturing including assembly, yet injection molding and other plastic parts forming data and steel and aluminum parts forming processes were included as data proxies to cartridge parts manufacturing. See Limitations section.	• Very limited manufacturing data on remanufacturing processes. No assembly modeled. • Replaced parts were given the same modeling (injection molding, parts forming, etc.). See Limitations section		
Discarded Empty Cartridges	**Unusable empties (sort & discard) rate**: N/A	**Unusable empties (sort & discard) rate**: • 45% of collected cartridges are unsuitable for remanufacturing.[ii] • Management of unusable empties at facilities in LA:[ii] - Landfill: 98% - WTE: 0% - Recycle: 2%	**Unusable empties (sort & discard) rate**: • Sensitivity: 5% discard rate is assessed. • Sensitivity: Management of unusable empties: - Recycled	
Packaging	Packaging is included:[xiii] – Box / carton: corrugated paper (from recycled sources) – Composite plastic bag, composite air-filled bag – Pulp end caps: molded pulp / paper, assumed to be from recycled sources - Polyethylene bag	Packaging is included, and is modeled the same as the HP cartridges.		
DISTRIBUTION				
Distribution to End-User	• HP80A and 83A are manufactured in Japan and Virginia. • Weighted averages are taken for the cartridges to be distributed: 1,128 mi by truck and 6,943 mi by ship to Mexico City and Sao Paolo.	• Some of the largest remanufacturers supplying LA are in LA. • Reman is distributed a weighted average of 2,137 mi by truck and 1,398 mi by boat to the end-user locations in Mexico City and Sao Paolo.		• Remanufacturing is in Shanghai, China. • Cartridge is transported 9,912 mi by ship and 1,378 mi by truck to end-user in Mexico City and Sao Paolo.
USE PHASE				

Printing	• **Paper Type**: Standard 8.5 x11, 20lb (75gsm), copy paper. • **The electricity** use by cartridge for printing was modeled using HP's specifications on power consumption:[xiv] - LaserJet Pro 400 M401 (80A): 570 Watts in print mode, 35 ppm output. - LaserJet Pro MFP M127fn (83A): 480 Watts in print mode, 21 ppm output	• **Paper Type**: Standard 8.5 x11, 20lb (75gsm), copy paper. • **The electricity** used by the cartridge for printing was modeled using the HP printer specifications		
Print Quality Data	2016 *SpencerLab* Reliability Comparison study. **Print quality distribution**[iv] - 95.1% External use - 4.3% Internal use - 0.6% Individual use - 0.0% Unusable	2016 *SpencerLab* Reliability Comparison study. **Print quality distribution**[iv] - 39.4% External use - 58.9% Internal use - 2.0% Individual use - 0.0% Unusable		
Pages printed per 100 usable pages	2013 MSI and 2015 Photizo Group Customer Experience studies[v] **Page use data** – 32.3% External use – 42.8% Internal use – 24.9% Individual use Total pages printed to obtain the functional unit: 102	2013 MSI and 2015 Photizo Group Customer Experience studies[v] **Page use data** – 32.3% External use – 42.8% Internal use – 24.9% Individual use Total pages printed to obtain the functional unit: 150	Sensitivity: • Page use: 100% for individual use. • Total pages printed to obtain the functional unit: – HP cartridge: 100 – Reman cartridge: 100 Sensitivity: Duplex is included. A weighted average of 19% of pages was saved using duplex on the LJ Pro 400 M401 and LaserJet Pro MFP M127fn printers.[xi]	• Page use: 100% for external use. • Total pages printed to obtain the functional unit: – HP cartridge: 105 – Reman cartridge: 254
Re-use Scenario	Used 1 time, i.e., An Original HP cartridge is used one time in the printer.	Used 1 time, i.e., a depleted Original HP cartridge is remanufactured and then used one time in the printer. (According to InfoTrends, 80% of toner cartridges are remanufactured 1 time).[ii]		
END-OF-LIFE				
	Baseline: • The HP cartridge is sent to the HP regional recycling center in Gloucester, VA, which includes crushing, disassembly/sorting, and recycling. • An average of 88% of the cartridge materials is recycled, and the balance goes to WTE.[xv] No material goes to landfill.[xvi] • Includes transport of the used cartridge to Gloucester, VA. **Sensitivity:** HP cartridge is disposed of per Mexico and Brazil's average MSW disposition (see "Sensitivity" to right).	**Baseline**: The cartridge is sent back to remanufacturer (with intent to remanufacture). • 20% of the time it is made into reman (according to InfoTrends, 80% of toner cartridges are remanufactured 1 time).[ii] • Remaining portion:[ii] - Landfill: 98% - WTE: 0% - Recycle: 2%		**Sensitivity**: Cartridge is discarded by the end-user, and an average of Mexico and Brazil MSW dispositions are used: - 97.5% landfill and 2.5% recovery/recycling.[ix]

Appendix 3 Indicator Descriptions

The life cycle impact assessment (LCIA) categories evaluated in this study are from the ReCiPe methodology[xvii] (except where noted below), and reflect a comprehensive set of environmental issues that cover different environmental media (i.e., air emissions, water effluents, waste, etc.) and endpoints (affects to vegetation, human health, etc.). By presenting results for a comprehensive set of issues, the reader will be able to understand trade-offs in the systems. This reduces the subjectivity of choices made during category selection.

- **Climate Change** measures the greenhouse gas emissions which have been generated by the systems and includes production of materials, production of paper, electricity during use, transportation and distribution, etc. 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". Climate change is reported in kilograms (kg) of carbon dioxide-equivalents.
- **Human Toxicity and Terrestrial Ecotoxicity:** Human toxicity provides an indication of the risk to human health, while terrestrial ecotoxicity provides an indication of the risks of damage to ecosystems on land. These are reported in terms of 1,4 dichlorobenzene equivalents.
- **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).
- **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.
- **Freshwater Eutrophication** 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.
- **Fossil Depletion** is the measure of the use – or depletion – of fossil fuels used in a system 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,** reported in Megajoules and based on the Cumulative Energy Demand methodology,[xviii] includes not only energy for the cartridge to print but also the energy required to produce paper during use, all cartridge parts and materials, and transportation throughout the supply chain. Total energy encompasses fuel energy, including fossil- and non-fossil fuels such as nuclear power, hydropower, and biomass, and embodied energy, such as hydrocarbons embodied in plastics.
- **Water Depletion**, reported in cubic meters, measures the use of water in the systems and encompasses cooling water, process water, and any water use associated with the systems.

Endnotes

i Page yield is based on 5% coverage, per the ISO standard method for the determination of toner cartridge yield for monochrome laser printers. See ISO/IEC 19752:2004 -- Method for the determination of toner cartridge yield for monochromatic electrophotographic printers and multi-function devices that contain printer components. Actual use varies considerably. HP Page yield data found in product specifications published on www.hp.com.

ii InfoTrends, 2016 Latin America Region Supplies Collection and Recycling Study commissioned by HP. Results based on interviews with 12 remanufacturers, 15 distributors, 1 component manufacturer and 1 component distributor. For details, see www.hp.com/go/LA-2016InfoTrends.

iii 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.

iv A *SpencerLab* 2016 study commissioned by HP compared Original HP Mono LaserJet toner cartridges with five non-HP brands of cartridges sold in five countries within the Latin America region for the 80A and 83Acartridge models used in the HP LaserJet Pro 400 M401and HP LaserJet Pro M127fn, respectively. SpencerLab Digital Color Laboratory (2015), Monochrome Cartridge Reliability Comparison Study – 2016: HP LaserJet Toner Cartridges vs. Non-HP Brands in Latin America. For details, see www.spencerlab.com/reports/HPReliability-LA-RM2016NB.pdf

v A 2013 tracking survey for LA users was averaged with 2015 tracking surveys for NA and EMEA regions, which showed newer trends towards more internal use and less external use. Conducted by MSI and Photizo Group and commissioned by HP, the survey responders were micro, small, medium and enterprise business customers. Results of the LA 2013 study were based on 820 HP monochrome LaserJet users who had used both Original HP and non-HP toner cartridges. Studies were conducted in Argentina, Brazil, Chile, Colombia, Mexico, Peru and Venezuela. For details see www.marketstrategies.com/hp/LA_cartridge_study.pdf. Results of the 2015 studies were based on 2009 HP monochrome LaserJet users who had used both Original HP and non-HP toner cartridges. Studies were conducted in USA, Canada, France, Germany, Italy, UK, Russia, Poland, and Turkey. For details see www.photizogroup.com/na-customer-study and www.photizogroup.com/emea-customer-study.pdf.

vi PRe Consultants, SimaPro version 8 LCA Software (Analyst). More information can be found at www.pre.nl.

vii Ecoinvent Centre, *Ecoinvent data v3* (Dübendorf: Swiss Centre for Life Cycle Inventories, 2013), retrieved from: www.ecoinvent.org.

viii June 2010, National Council for Air and Stream Improvement, Inc., Life Cycle Assessment of North American Printing and Writing Paper Products – Final Report, prepared for American Forest and Paper Association (AF&PA) and Forest Products Association of Canada (FPAC), found at www.afandpa.org/docs/default-source/default-document-library/life-cycle-assessment-(lca)-final-report.pdf.

ix MSW management data for Mexico (97% LF, 3% recycling) from: March 2012, Hoornweg, D and P. Bhada-Tata (World Bank), WHAT A WASTE: A Global Review of Solid Waste Management, Publication 68135, Annex L. For Brazil (98% LF, 2% recycling) from: Novais, Andréa, 13 May 2015. "Recycling of waste in Brazil". Found at: http://thebrazilbusiness.com/article/recycling-of-waste-in-brazil.

x When only toner is replaced, the cartridge is considered a refilled cartridge, not a reman cartridge. While refilled cartridges were not evaluated in this study, looking at the overall impact of a used HP shell with only the toner replaced was still worthwhile to understand the sensitivity of parts replaced.

xi "Infotrend Global Supplies Summary Forecast for 2011-2017 for page printers, copiers, inkjet printers and fax machines" commissioned by HP

xii Note: One data point, 7.9 kWh electricity per remanufactured cartridge, was found in an EcoInvent report (Hischier, R. et al., Life cycle inventories of Electric and Electronic Equipment: Production, Use & Disposal. ecoinvent report No.18. Empa / Technology & Society Lab, Swiss Centre for Life Cycle Inventories, Dubendorf, 2007). This was not used since the data were over 10 yrs old, and using this data point for the reman and not the HP cartridge would have created an unfair comparison for the reman system.

xiii 2015 HP internal data on packaging.

xiv Specifications found at www.hp.com.

xv 2015 HP internal data on the HP Planet Partners recycling facility.

xvi 2014 HP Global Citizenship Report: www8.hp.com/us/en/hp-information/global-citizenship/reporting.html.

xvii ReCiPe was developed in 2008 by RIVM, CML, PRé Consultants, and Radboud Universiteit Nijmegen. Please see www.lcia-recipe.net or www.pre.nl for more information.

xviii CED is based on EcoInvent version 2.0 and has been expanded to include elements from the SimaPro database. Frischknecht R., Jungbluth N., et.al. (2003). Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000, Swiss Centre for LCI. Duebendorf, CH, www.ecoinvent.ch. See also www.pre.nl for more information.