Life Cycle Environmental Impact Study For North America

HP LaserJet Toner Cartridges Vs. Remanufactured Cartridges

SUMMARY REPORT

Four Elements Consulting, LLC

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EXECUTIVE SUMMARY

Hewlett-Packard (HP) commissioned Four Elements Consulting, LLC, to perform an environmental Life Cycle Assessment (LCA). This 2014 LCA report shows the results of the environmental impacts comparing Original HP LaserJet toner cartridges with remanufactured (reman) cartridges sold as substitutes. The LCA 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.

The goal of this study was to provide a comparative environmental assessment utilizing the most current research and data on production practices, disposition trends, and product quality of Original HP toner cartridge and reman alternatives in North America. 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 a decade, HP has been evaluating life cycle environmental impacts of its LaserJet toner cartridges; the most recent was in 2011, where HP commissioned Four Elements Consulting, LLC, to perform the LCA study for North America. The 2011 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 the 2011 study, and it utilizes the most current research and data for production practices, disposition, and product quality for Original HP toner cartridges and reman cartridges sold in the North American markets. Results are summarized below.

METHODOLOGY

Products Studied

HP selected the CE285A (85A) and CE505A (05A) toner cartridges which are used in the HP LaserJet Pro P1102 and the LaserJet P2035 printers. These models were chosen because they are popular in the North America market and have a wide selection of 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 are based on the number of cartridges shipped over the last 12 months ending September 2013 times its ISO page yield.[i]

Table 1 Summary of Cartridges Studied

Cartridge SKU	Printer	Page Yield	Wt.Avg Split	Relevance to this study
CE285A (85A)	LaserJet P1102	1,600	33%	Significant contributor to its target markets: home office and small business
CE505A (05A)	LaserJet P2035	2,300	67%	Significant contributor to its target markets: SMB & enterprise

The HP 85A and 05A 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. The cartridge is then refilled with non-HP toner and reassembled. This analysis does not intend to mirror one specific brand of reman cartridge.

Printing industry analyst, InfoTrends Research (InfoTrends), found that 78% of Original HP toner cartridges in the North American market are remanufactured only a single time, or a 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.

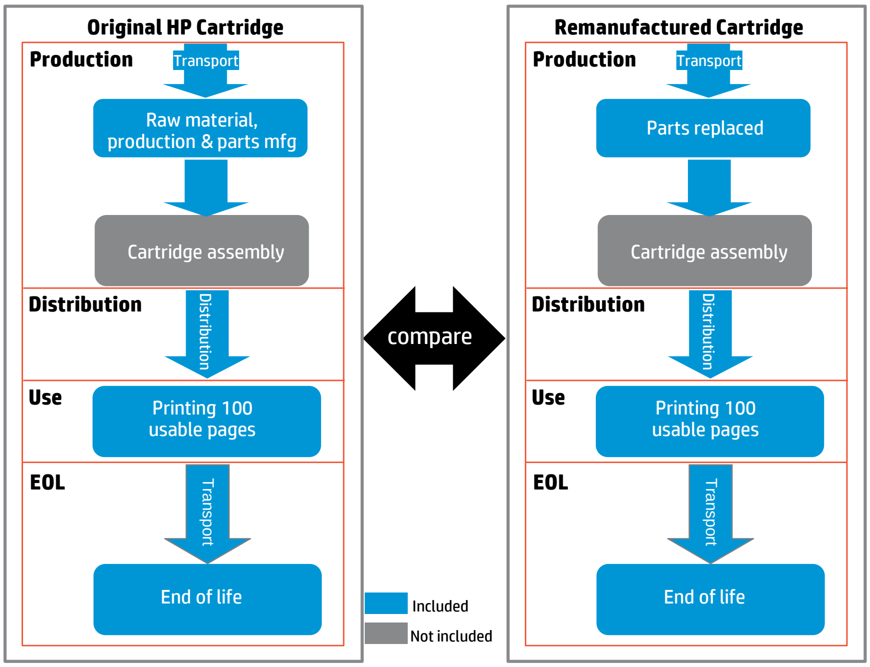
Adherence to the ISO Standards

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 system boundaries. Life cycle phases include production, distribution to the customer, use of the cartridge (Use Phase), 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, 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 85A and 05A cartridges and compare them to leading reman brands.[iv] In 2012, HP commissioned Photizo Group to conduct a Customer Experience study[v] which provided page use data for customers who use HP LaserJet printers. Additionally, an online tracking study was commissioned by HP and conducted in 2012 by HANSA-GCR[vi] which also provided page use data of HP LaserJet printer users. A weighted average of the two studies' page use results was used for the LCA. The *SpencerLab* Cartridge Reliability Comparison study and the Photizo Group/HANSA-GCR 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.[vii] The study included data from the latest available version of the EcoInvent database[viii] and the U.S. LCI Database.[ix] 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 these differences. Thus, the function of the system has been defined as printing to obtain usable pages for the 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".

The *SpencerLab* study defined print quality in terms of the acceptability of the printed pages. Including the Photizo Group/HANSA-GCR 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 detail on the data and the assumptions.

Production

The HP cartridge Production Phase includes the production of over 99.5% (by mass) of the materials in 85A and 05A 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 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 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.

Manufacturing

HP cartridge Manufacturing Phase includes metal and plastic cartridge parts forming and intermediate and final assembly. Over 99.5% of the cartridge parts manufacturing has been included in the LCA, which includes extraction of raw materials, material production, and parts forming. No data were available for assembly of the parts into the final cartridge. 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 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 model, based on a comprehensive paper and printing LCA completed in 2010,[x] is described in the Data Quality section (p. 10). 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 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, to customers or others. 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	94.7%	4.4%	0.9%	0%
Average Reman Cartridges Tested	65.3%	32.8%	1.9%	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 Photizo Group study surveyed HP LaserJet users on their printing behavior in the work environment, and the HANSA-GCR study tracked users' printing behavior in the work environment.[v,vi] The weighted average of the two studies determined how page use was distributed across three categories. These categories included page use for "External Use", "Internal Use", and "Individual Use".[iv] These categories corresponded to the page use categories from the *SpencerLab* study shown in Table 2. The weighted average page use distribution 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	Photizo Group / HANSA-GCR	30.2%	36.0%	33.8%
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	Photizo Group / HANSA-GCR studies	102	117	15%
Sensitivity	100% External Use	106	153	45%
	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 and incineration with energy recovery (waste-to-energy or WTE).

RESULTS

Baseline results

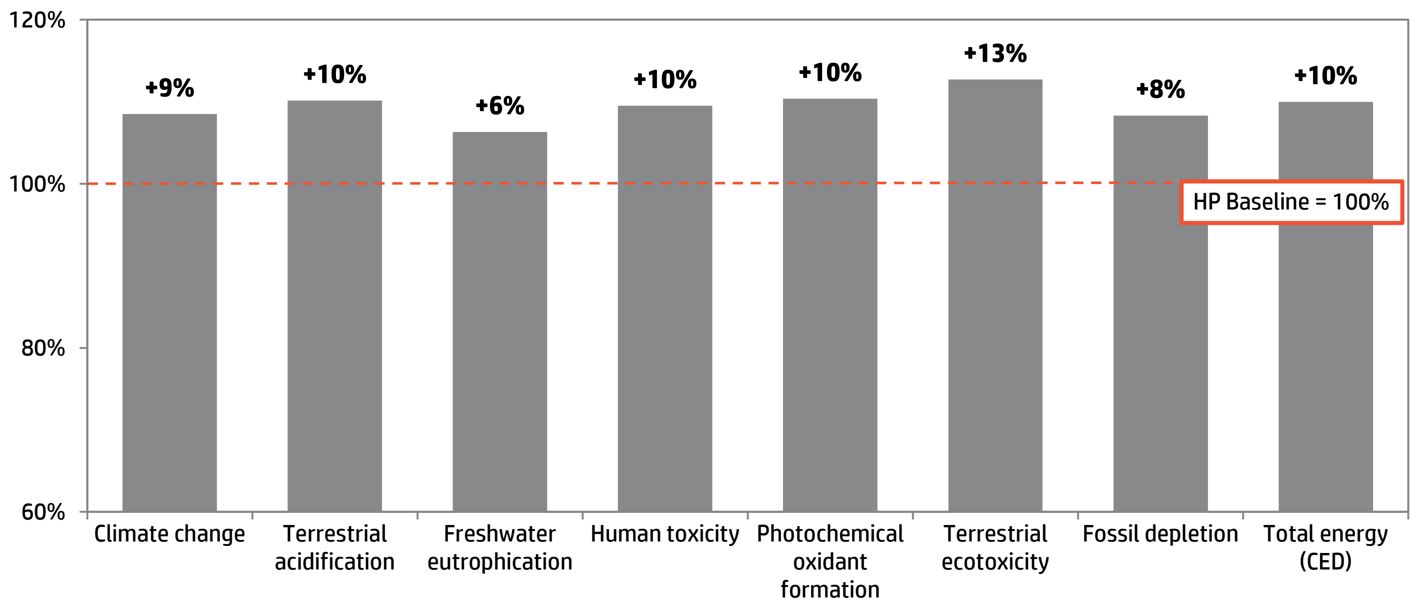
Table 5 and Figure 2 present results for the baseline comparison. The last column in the table shows that the environmental impacts for the reman cartridge are 6% or higher in all categories, with half of the categories 10% or higher. As mathematical models of complex systems, all LCAs have inherent 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. Thus, in these baseline findings, it is more appropriate to say that the reman cartridge is higher or on-par with 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	1.0 E+00	1.1 E+00	8.5%
Terrestrial Acidification	kg SO2 eq	8.4 E-03	9.2 E-03	10.1%
Freshwater Eutrophication	kg P eq	2.0 E-04	2.2 E-04	6.3%
Human Toxicity	kg 1,4-DB eq	9.0 E-02	9.8 E-02	9.5%
Photochemical Oxidant Formation	kg NMVOC	7.4 E-03	8.1 E-03	10.4%
Terrestrial Ecotoxicity	kg 1,4-DB eq	1.6 E-04	1.8 E-04	12.7%
Fossil Depletion	kg oil eq	3.0 E-01	3.2 E-01	8.3%
Total Energy (CED)	MJ	2.1 E+01	2.3 E+01	10.0%

* % 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 the past study, that paper use, i.e., “Use Phase”, 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	1.0 E+00	20%	2%	89%	-11%
Terrestrial Acidification	kg SO2 eq	8.4 E-03	12%	2%	93%	-7%
Freshwater Eutrophication	kg P eq	2.0 E-04	31%	0%	86%	-18%
Human Toxicity	kg 1,4-DB eq	9.0 E-02	19%	0%	92%	-11%
Photochemical Oxidant Formation	kg NMVOC	7.4 E-03	9%	3%	93%	-5%
Terrestrial Ecotoxicity	kg 1,4-DB eq	1.6 E-04	6%	0%	95%	-2%
Fossil Depletion	kg oil eq	3.0 E-01	22%	2%	90%	-13%
Total energy (CED)	MJ	2.1 E+01	15%	1%	92%	-9%

Note: 0% implies value less than 0.1%

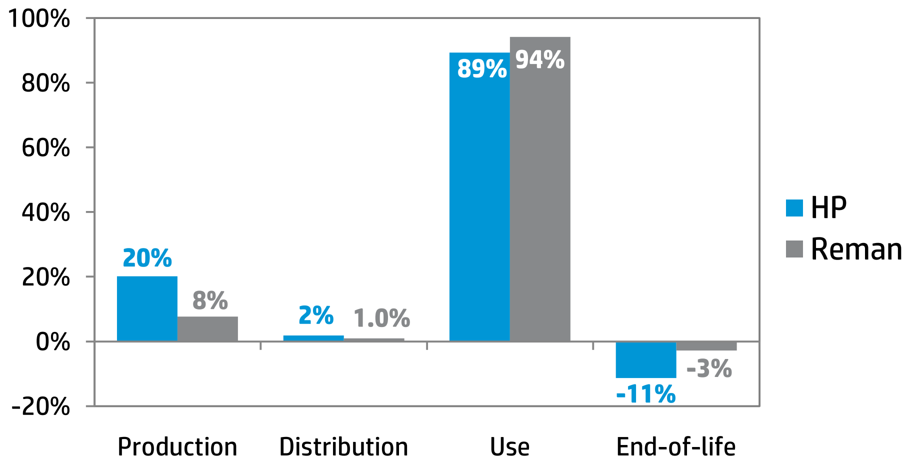
Table 7 Contribution Analysis - Life Cycle of Reman Cartridge

Impact category	Unit	Reman TOTAL	Reman Production	Reman Distribution to User	Reman Use Phase	Reman EOL - Throw Away to MSW
Climate Change	kg CO2 eq	1.1 E+00	8%	1%	94%	-3%
Terrestrial Acidification	kg SO2 eq	9.2 E-03	5%	0.6%	96%	-2%
Freshwater Eutrophication	kg P eq	2.2 E-04	14%	0%	93%	-6%
Human Toxicity	kg 1,4-DB eq	9.8 E-02	8%	0%	96%	-4%
Photochemical Oxidant Formation	kg NMVOC	8.1 E-03	4%	1%	96%	-1%
Terrestrial Ecotoxicity	kg 1,4-DB eq	1.8 E-04	4%	0%	97%	-0.1%
Fossil Depletion	kg oil eq	3.2 E-01	8%	1%	95%	-3%
Total Energy (CED)	MJ	2.3 E+01	5%	0.6%	96%	-2%

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 (89% for HP and 94% for remans for Climate Change in the Contribution Analysis tables and Figure 3), 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 represent the offset of materials due to cartridge recycling and grid electricity due to cartridges going to waste-to-energy (WTE) (see EOL assumptions in Table 10).

Figure 3 Contribution Analysis by Life Cycle Stage – Climate Change



Sensitivity Analyses

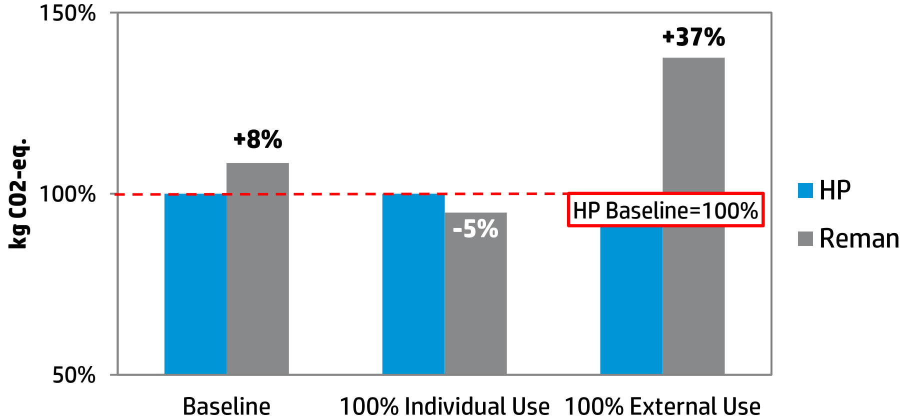
Sensitivity of Page Use Distribution

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).

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 – 45% more pages than if using an Original HP cartridge. As a result, the reman cartridge impact jumps to 37% higher than HP. When prints are used for individual use only, which are of much lower quality, both cartridge types print essentially the same number of pages. As a result, the reman cartridge's environmental impact is 5% less than HP, which is considered to be comparable to, or on par with, HP, accounting for the +/- 10% margin of error.

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



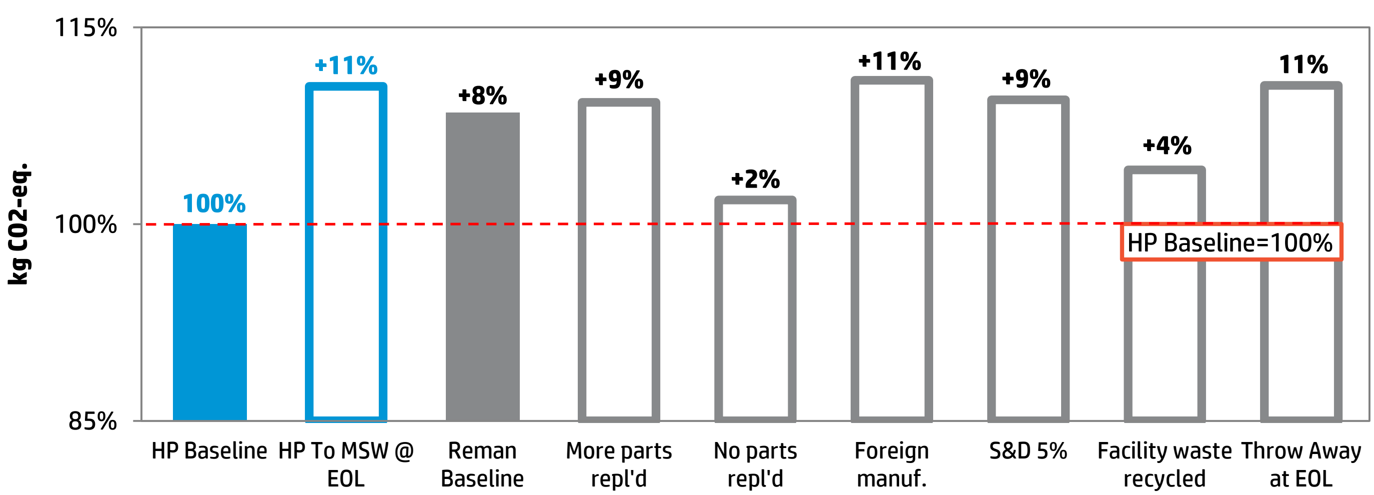
Sensitivity of Select Model Assumptions

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[xi]
Reman	The "facility" is an aggregated average of the largest remanufacturers supplying NA, located in Mexico, West Virginia, Arizona, and Canada.[xii]	Remanufacturing facility is in China. A cartridge depleted of toner is transported from St. Louis to China, and the reman cartridge is then sent to St. Louis.
Reman	Sort & discard rate is 23%	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)	Unusable cartridges (sort & discard) and replaced parts are recycled
Reman	The cartridge is sent back to remanufacturer with intent to recycle.	Cartridge is disposed of in the MSW stream 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. As well, 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 11%. When the reman cartridge is thrown away at the end of life, its Climate Change impact equals that of the HP cartridge when it is thrown away (both 11% higher than the HP baseline), demonstrating that a reman's savings in raw materials at production is offset by greater impacts during the Use Phase, due to its lower quality output (and the need to reprint).

The remaining reman results in the chart intuitively increase or decrease, depending on the assumption. Compared to the reman baseline, as more parts are replaced, the environmental impact increases by 1%. When only toner is replaced, the impact decreases by 6%, though 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. Foreign manufacturing causes an increase of 3%, and when a reman facility's unusable cartridges and cartridge parts are recycled, the result decreases by 4%. Interestingly, when the sort & discard rate decreases from 23% to 5%, the results counter intuitively increase a percentage point. This is because less unusable parts are recycled and incinerated with energy recovery (both creating credits for the system), so the offsets are not as great. What is evident from this chart is that even though results go up and down to some degree, modifications in these model assumptions largely do not make any difference to 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 become less significant.

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 the duplex rate on the HP LaserJet Pro P1102 and P2035 printers were used to calculate the percent of pages saved using duplex. An overall weighted average of 10% of pages saved was used.[xiii]

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**	9.20 E-01	9.93 E-01	8%	9%
Terrestrial Acidification	**kg SO2 eq**	7.58 E-03	8.31 E-03	10%	10%
Freshwater Eutrophication	**kg P eq**	1.85 E-04	1.95 E-04	6%	6%
Human Toxicity	**kg 1,4-DB eq**	8.15 E-02	8.88 E-02	9%	10%
Photochemical Oxidant Formation	**kg NMVOC**	6.68 E-03	7.34 E-03	10%	10%
Terrestrial Ecotoxicity	**kg 1,4-DB eq**	1.42 E-04	1.60 E-04	13%	13%
Fossil Depletion	**kg oil eq**	2.71 E-01	2.91 E-01	8%	8%
Total Energy (CED)	**MJ**	1.87 E+01	2.05 E+01	10%	10%

With duplex, the relative differences between the two cartridges were found to be the same as the baseline results (presented again in the far right column in Table 9). The exception to this is the shift to one percent lower for Climate Change and Human Toxicity.

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 HP05A and 85A 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 current, as is the MSW management disposition percentages to landfill and WTE. 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 mid- to late-2000's data sets. 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 largely on North American sources and some 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 the 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 to be 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.[xiv] While the 85A and 05A'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 production data.

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 is 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 in half of the categories measured while the other half are on par relative to the Original HP cartridge. 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:

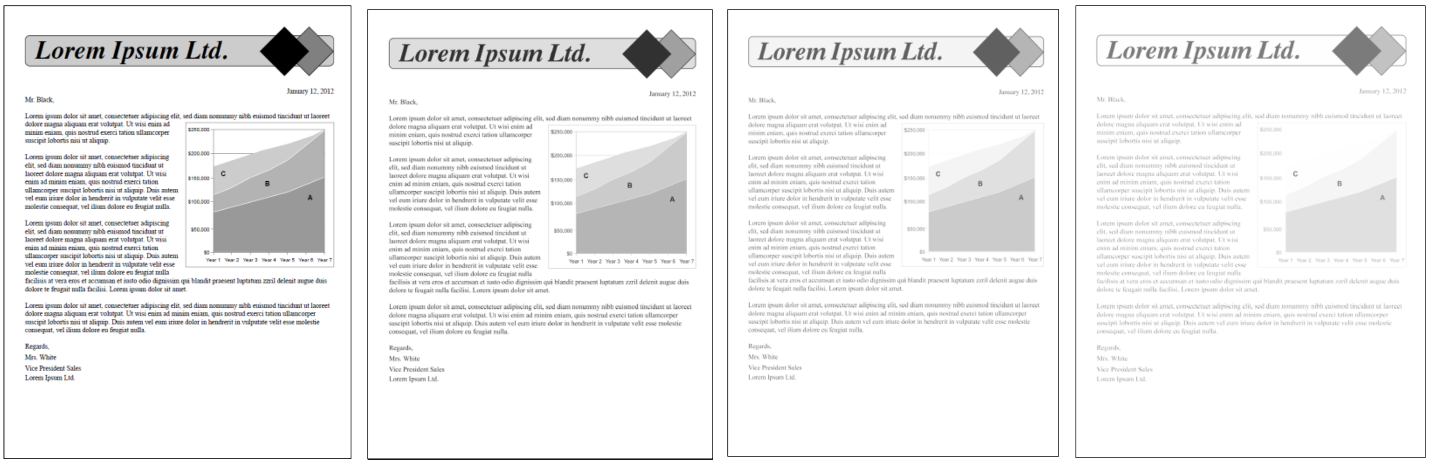
- In the sensitivity analyses of other model parameters, none of the assumptions tested significantly affected the overall outcome of the study, further substantiating the importance of the Use Phase.
- In the End-Of-Life Phase, recycling and recovery of materials can be especially important in reducing the environmental impact of a toner cartridge.
- The reman cartridge can improve its environmental profile in 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 or on par with 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** Lower PQ - Internal	**Internal/Individual Boundary** Lower PQ - Individual	**Individual/Unusable Boundary**

*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 the U.S:[ii] - Landfill: 50% - Incineration with energy recovery (waste-to-energy(WTE)): 15% - Recycle: 35%	• Sensitivity: No materials are replaced except for the toner. • Sensitivity of fate of replaced parts at facilities in the U.S: - 100% recycled	• Selected additional components are replaced: primary charge roller (PCR) and developer roller sleeve.[ii] • Fate of replaced parts at facilities in U.S:[ii] - Landfill: 50% - WTE: 15% - Recycle: 35%
Transportation to Manufacturing	• HP05A and 85A are manufactured in Japan. • Transportation of materials and components to final manufacturing is 300 miles by truck.	• The largest remanufacturers supplying NA are in Mexico, WV, AZ, and CA. [xii] • Spent cartridge is transported a weighted average of 1,382 miles by truck to the remanufacturing plants from the end-user in St. Louis. Distance calculated using weighted average of facilities based on contributions to the NA market.		• Remanufacturing in China. • Cartridge is transported 1,850 miles by truck to a west coast port (San Diego), plus 6,675 miles by ship to China.
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**: • 23% of collected cartridges are unsuitable for remanufacturing.[ii] • Management of unusable empties at facilities in the U.S:[ii] - Landfill: 50% - WTE: 15% - Recycle: 35%	**Unusable empties (sort & discard) rate**: • Sensitivity: 5% discard rate is assessed. • Sensitivity: Management of unusable empties: - Recycled	
Packaging	Packaging is included:[xv] – Box / carton: corrugated paper (from recycled sources) – Composite plastic bag – Pulp end caps: molded pulp / paper, assumed to be from recycled sources - Pull tab and other misc. plastic parts: polypropylene	Packaging is included, and is modeled the same as the HP cartridge.		
DISTRIBUTION				
Distribution to End-User	• HP 05A and 85A are manufactured in Japan. • Japan: Distributed 4,943 miles by ship and 1,850 miles by truck to the end-user in St. Louis	• The largest remanufacturers supplying NA are in Mexico, WV, AZ, and CA. [xii] • Reman is transported a weighted average of 1,382 miles by truck to the end-user in St. Louis.		Remanufacturing operations in China; distributed 6,700 miles by ship and 1,850 miles by truck to the end-user in St. Louis

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:[xvi] - LaserJet P2035 (05A): 550 Watts in print mode, 30 ppm output. - LaserJet Pro P1102 (85A): 360 Watts in print mode, 19 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	2013 *SpencerLab* Toner Reliability Comparison study. **Print quality distribution**[iv] - 94.7% External use - 4.4% Internal use - 0.9% Individual use - 0% Unusable	2013 *SpencerLab* Toner Reliability Comparison study. **Print quality distribution**[iv] - 65.3% External use - 32.8% Internal use - 1.9% Individual use - 0.0% Unusable		
Pages printed per 100 usable pages	2012 Photizo Group Customer Experience study and 2012 HANSA-GCR study [V,VI] **Page use data** – 30.2% External use – 36.0% Internal use – 33.8% Individual use Total pages printed to obtain the functional unit: 102	2012 Photizo Group Customer Experience study and 2012 HANSA-GCR study [V,VI] **Page use data** – 30.2% External use – 36.0% Internal use – 33.8% Individual use Total pages printed to obtain the functional unit: 117	• Page use: 100% for individual use. • Total pages printed to obtain the functional unit: – HP cartridge: 100 – Reman cartridge: 100 Duplex is included. A weighted average of 10% of pages was saved using duplex on the LJ P2035 and LJ Pro P1102 printers.[xiii]	• Page use: 100% for external use. • Total pages printed to obtain the functional unit: – HP cartridge: 106 – Reman cartridge: 153
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, 78% of toner cartridges are remanufactured 1 time).[ii]		
END-OF-LIFE				
	Baseline: • The HP cartridge is sent to the recycling facility, which includes crushing, disassembly/sorting, and recycling. • 88% of the cartridge is recycled, balance goes to WTE.[xvii] No material goes to landfill.[xviii] • Includes transport of the used cartridge to the regional recycling center in Gloucester, VA **Sensitivity:** HP cartridge is disposed of per U.S. average MSW disposition (see "Sensitivity" to right).	**Baseline**: The cartridge is sent back to remanufacturer (with intent to remanufacture). • 22% of the time it is made into reman (according to Infotrends, 78% of toner cartridges are remanufactured 1 time).[ii] • Remaining portion:[ii] - Landfill: 50% - WTE: 15% - Recycle: 35% **Sensitivity**: Cartridge is discarded by the end-user and the U.S. average MSW disposition is used. – U.S. average = 82% landfill and 18% waste-to-energy.[xix]	.	

APPENDIX 3 INDICATOR DESCRIPTIONS

The life cycle impact assessment (LCIA) categories evaluated in this study are from the ReCiPe methodology[xx] (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,[xxi] 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.

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, 2014 U.S. Supplies Recycling Study commissioned by HP. Results based on interviews with 13 remanufacturers and brokers. For details, see www.hp.com/go/NA-2014InfoTrends.

[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* 2013 study commissioned by HP compared Original HP Mono LaserJet toner cartridges with 9 remanufactured brands sold in North America for the HP LaserJet P2035 and P1102 printers, HP 05A and 85A cartridges. For details, see www.spencerlab.com/reports/HP-Reliability-NA-RM-2013.pdf.

[v] 2012 NA Photizo Group, commissioned by HP. Results based on 1009 HP monochrome LaserJet users who have used both Original HP and non-HP toner cartridges, of whom 424 experienced problems with non-HP cartridges. For details go to www.photizogroup.com/information-hub/

[vi] 2012 HANSA-GCR tracking survey, commissioned by HP, is based on 377 samples from the U.S. for Single Function and Multifunction printer users. Total monochrome page count was collected using printed configuration page.

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

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

[ix] North American-based process and material life cycle inventory data, retrieved from www.nrel.gov/lci/.

[x] 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

[xi] 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.

[xii] HP estimates based on a 2013 HP and InfoTrends assessment of the industry.

[xiii] August 2013 InfoTrends printer and copier/MFP paper and supplies forecast.

[xiv] 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.

[xv] 2013 HP internal data.

[xvi] Specification found at www.hp.com.

[xvii] 2013 HP internal data.

[xviii] 2012 HP Global Citizenship Report: www8.hp.com/us/en/hp-information/global-citizenship/reporting.html

[xix] Source: U.S. EPA. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2011, Table 4 (MSWcharacterization_508_053113_fs.pdf), found at www.epa.gov/epawaste/nonhaz/municipal/pubs/MSWcharacterization_508_053113_fs.pdf. Note that this average is adjusted without the recycled and composted percentage.

[xx] 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.

[xxi] 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.