LaserJet Cartridge Life Cycle Environmental Impact Comparison Refresh Study

HP LaserJet 10A Print Cartridge vs. Remanufactured Brands in North America

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Executive Summary

In 2008, Four Elements Consulting, LLC completed a refresh of a 2004 Life Cycle Assessment study comparing the environmental impacts of a popular HP LaserJet print cartridge with compatible remanufactured cartridges. This environmental Life Cycle Assessment (LCA) evaluates all phases of the life of the cartridges, from material sourcing and manufacturing through use and end-of-life disposition, and adheres to the International Organization for Standardization (ISO) 14040 series of standards on LCA.

The goal of this refresh was to provide a comparative environmental assessment utilizing the most current research and data on production practices, disposition trends, and product quality and reliability. The study finds that, as in previous LCA studies, paper consumption during printing is the largest contributor to the environmental impact of the print cartridge across all phases of the life cycle for both the HP Original Equipment Manufacturer (OEM) cartridge and the remanufactured alternative.

In addition, the study shows that the HP cartridge has a lower overall environmental impact than the remanufactured alternative. In all assessed categories the HP cartridge showed the same or lower environmental impact. The lower overall environmental impact of the HP cartridge is especially pronounced where higher user output quality requirements drive a relatively greater amount of reprints from the remanufactured cartridge.

Greater reliability and consistent print quality result in lower environmental impact for the HP cartridge. Consistently good print quality requires a much lower number of pages to be reprinted to meet the same quality page output. This leads to less paper consumed by the HP cartridge and therefore an overall lower environmental impact.

For users who print for both internal and external purposes and are concerned about the environmental impact of their cartridge choice, HP cartridges should be preferred over the remanufactured alternative since fewer reprints means less paper consumed to obtain usable pages, resulting in a more environmentally efficient cartridge.

Background and Introduction

In October 2004, First Environment completed and published for Hewlett-Packard Company (HP) a comparison of the life cycle environmental impacts of one of HP's popular LaserJet toner print cartridges with compatible remanufactured toner print cartridges. The environmental Life Cycle Assessment (LCA) evaluated all phases of the life of the cartridges, from sourcing and manufacturing through use and end-of-life disposition.

In 2008, Four Elements Consulting completed a refresh of the 2004 study, incorporating more recent and in some cases, new, data. Updated elements of this study include the following:

1. Use of the more recent HP LaserJet Q2610A Black Print Cartridge ("HP 10A");
2. Use of recent data from the 2007 Reliability Comparison Study: HP LaserJet Toner Cartridges vs. North American Remanufactured Brands, conducted by QualityLogic;
3. Application of a user-based psychometric print quality scale;
4. Updated assumptions on remanufacturing practices;
5. Updated assumptions on cartridge end-of-life;
6. Updated LCA data utilizing current, state-of-the-art quality and industry research; and
7. Simplified scenario analyses.

The following report summarizes this refresh study's methodology, model parameters and assumptions and detailed results.

Methodology

Products Studied

The 2008 LaserJet Cartridge Life Cycle Environmental Impact Comparison Refresh Study compared an Original HP LaserJet Q2610A black print cartridge ("HP 10A") with a theoretical compatible remanufactured alternative. The HP cartridge is designed to work with HP LaserJet 2300 series printers. The target markets are small businesses, small workgroups and personal businesses. HP describes the rated output as, "Approximate cartridge yield: 6,000 standard pages; declared yield value in accordance with ISO/IEC 19752."[1]

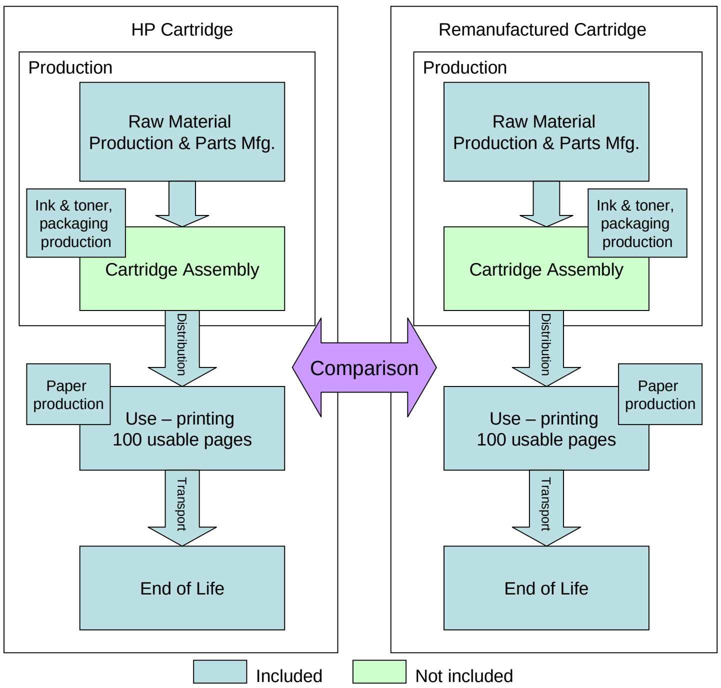
The remanufactured cartridge evaluated in this study is a hypothetical brand (designated in this study as “R10A”) with the following characteristics:

1. Meets industry standard definition of a remanufactured print cartridge - one in which the plastic body, as well as varying numbers of other components, have been taken from a previously used cartridge. The cartridge must always be refilled with toner and select used components are replaced.
2. Print quality and reliability performance based on the averages of remanufactured cartridges tested in the 2007 Reliability Comparison Study: HP LaserJet Toner Cartridges vs. North American Remanufactured Brands[2], conducted by QualityLogic.
3. Environmental performance based on data reported by printing industry analyst InfoTrends, published in printing trade publications and, where other authoritative data was not available, HP market intelligence.

System Boundaries

Figure 1 presents the system boundaries for each cartridge. The life cycle stages include production, distribution to the consumer, use of the cartridge, and end of life. This is consistent with the previous study.

Figure 1 Study system boundaries



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. Once the function is 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" (see Figure 1). This is consistent with the prior study.

The definition for "usable pages" was adopted from the 2007 Reliability Comparison Study: HP LaserJet Toner Cartridges vs. North American Remanufactured Brands, conducted by QualityLogic. In the QualityLogic study, "usability" was determined using a customer-calibrated print quality scale based on psychometric testing of a demographic cross-section of laser printing users (see discussion on "More recent print quality and reliability data" below).

Including the page usability as part of the definition of the functional unit is an important study parameter that highlights the strengths and weaknesses of both systems. Previous LCA studies have found that paper production and use make up the most significant contribution to a print cartridge's total environmental footprint. As a result, when the amount of re-printing due to page quality not meeting intended usability requirements is taken into consideration, it has a significant impact on the cartridge's environmental impact. In fact, results will show that other life cycle aspects become insignificant in comparison.

Data Categories

The life cycle impact assessment (LCIA) categories evaluated for the refresh 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.). This is consistent with the prior study.

By presenting results for a comprehensive set of issues, the reader will be better able to understand trade-offs in the systems. This minimizes the subjectivity of value choices made during category selection. The LCA model and LCIA calculations were performed in SimaPro 7.0, a commercial LCA software product.[3] Table 1 presents the LCIA list with units and methodology.

Table 1 - LCIA categories

Category	Unit	Methodology
Global warming potential	kilograms (kg) carbon dioxide (CO2) equivalents (eq)	IPCC[note 1]
Acidification potential	kg sulfur dioxide (SO2)-eq	IMPACT 2002[note 2]
Eutrophication Potential	kg phosphate (PO4)-eq	IMPACT 2002
Resource depletion potential	Megajoules (MJ) of energy surplus	EcoIndicator 99[note 3]
Photochemical smog potential	kg ethylene (C2H4)-eq	CML[note 4]
Human toxicity potential	kg vinyl chloride (C2H3Cl)-eq	IMPACT 2002
Total energy	MJ	Inventory result
Total waste	Kg	Inventory result

Modeling and Parameters

Changes in the Model

While the scope of work remained largely unchanged, revisions to the model were made to update the subject matter and data, improve the robustness of the study, and address feedback on the prior report. The major changes are described below:

- **More recent cartridge model**.

A newer cartridge model, the HP LaserJet Q2610A ("HP 10A") was evaluated.

- **More recent print quality and reliability data**

This refresh incorporates cartridge quality and reliability testing data for the HP10A and popular remanufactured brands of cartridges from the 2007 Reliability Comparison Study: HP LaserJet Toner Cartridges vs. North American Remanufacture Brands, conducted by QualityLogic.[4]

As described in their report, QualityLogic conducted a psychometric study, "To create a print quality scale calibrated to actual business laser printing user behavior …. An independent market research organization recruited a representative demographic cross-section of laser printing users. Study participants provided input on the print quality levels appropriate for certain uses. The study data was used to create a scale. QualityLogic page inspectors used the scale to sort sampled pages into the following categories:

- All uses, including external distribution
- Limited use: Not for external distribution
- Limited use: Not for distribution
- Unusable"[5]

"Psychometric study participants were from a range of industries and business sizes, from micro/small (1-49 employees) to large/enterprise (>500 employees). All respondents used laser printers to create documents for a variety of uses, including external distribution."

"The results for cartridges tested were combined to create the overall percentage of pages for each use category."[6] (See Table 2.)

Table 2 - QualityLogic print quality results

	Any use, including external distribution	Limited use: Not for external distribution	Limited use: Not for distribution	Unusable
Test Results for the HP Cartridges	95.0%	3.7%	<1%	<1%
Test Results for the Average of Tested Remanufactured Cartridges	70.0%	26.5%	3.5%	<1%

This reliability and performance data from the 2007 QualityLogic study was used to establish the basic parameter for the LCA study refresh, that is, the number of printed pages required to attain a functional unit of output (i.e. 100 usable printed pages) for both HP and remanufactured cartridges. (See Appendix A for printed samples of each usage category.)

- **Print Quality Requirement Assumptions**

The intended use for printed pages is an important study parameter because when combined with print quality it determines how many pages need to be reprinted to meet the intended user requirements and consequently total paper usage.

HP provided two sets of survey data which described business users' printed page distribution requirements. The two surveys targeted different populations—one targeted IT and purchasing managers ("survey number 1") and a second targeted select office printer users ("survey number 2"). Both surveys assessed expected, rather than actual, distribution requirements. The results differed, with wide variations about the means in both surveys. Due to the variability in the survey data, a baseline scenario for the study was considered, where page distribution requirements (i.e., intended use for printed pages) were equally weighted across the top three output quality levels in Table 2. The data from the two surveys, in addition to a scenario in which printed pages were intended for all uses including external distribution, were assessed for sensitivity (see Table 3 and Sensitivity of Desired Print Quality).

Table 3 - Desired Output Quality Requirements

Scenario	All uses, including external distribution	Limited use: Not for external distribution	Limited use: Not for distribution
Baseline	33%	33%	33%
Sensitivity: Survey 1 - IT & Purchasing Managers	28%	33%	39%
Sensitivity: Survey 2 - Office Printer Users	33%	43%	24%
Sensitivity: All Uses	100%	0%	0%

- **Reprint Quantities**

User print quality requirements were combined with print quality data from the QualityLogic study to identify the quantities of pages requiring reprinting to meet intended use requirements, and hence the total number of pages printed in order to obtain the functional unit of 100 usable pages.

Table 4 - Pages printed per functional unit: equally weighted user requirements

	Total Pages printed to obtain a Functional Unit		% more Reman 10A pages printed
	HP 10A	Reman 10A	
Baseline: Equally Weighted Distribution requirements (33% - 33% - 33%)	101	114	13%

- **Cartridges assessed based on the ISO standard page yield**.

For the QualityLogic test, a suite of three images, representing a range of page types, was printed. The purpose of the test was to evaluate cartridge page quality performance, rather than yield. The test suite used was not the ISO standard suite. As a result, page counts from the QualityLogic tests are not page yields according to the applicable ISO standard test method.[7]

To adjust to ISO yield, the page count for the HP10A was set at the rated ISO page yield value of 6000 pages and the R10A was "scaled" proportionately, using the following calculation, where *HP10A rated yield* = 6000 pages:

$$Adjusted\ R10A\ page\ count = Observed\ R10A\ page\ count \times \frac{HP10A\ rated\ \ yield}{HP10A\ page\ count}$$

This relative scaling ensures the comparison accounts for the differences observed by QualityLogic between HP10 and R10A page counts. It is important to note that the yield observed by individual users is highly variable, and is dependent upon such factors as the image density (or "page coverage") and typical print job size, among other factors. Given the information at hand and the existence of standardized test results for page yield, this approach was judged to be the fairest treatment of the data.

The resulting comparison accounts for the variable page counts of cartridges, as well as premature failures and "dead on arrival" cartridges. No additional impacts (e.g., due to maintenance calls) were assigned based on cartridge failures, a conservative approach as no HP cartridges failed during the quality testing.

- **Revised assumptions on remanufacturing**.

Several assumptions on remanufacturing practices have been revised from the previous study, based on an assessment of environmental practices conducted by printing industry analyst InfoTrends as well as direct observation of replaced parts in remanufactured cartridges.

1. <u>Percentage of collected cartridges that is usable for remanufacturing</u>. InfoTrends estimated that 16% of cartridge collections in the US and Western Europe are "bad" and will be recycled or landfilled.[8] Thus a 16% "sort and discard" rate has been assumed for the baseline remanufactured cartridge. A more conservative sort and discard rate of 5% has been evaluated for sensitivity.

2. <u>Fate of unusable empty cartridges and other remanufacturing waste</u>. "InfoTrends estimates that 25% of the European and U.S. laser cartridge remanufacturing waste … in the U.S. and Europe is recycled or managed in some way."[9] This refresh models the waste management practices at remanufacturing plants according to InfoTrends' assessment (see Appendix A).

3. <u>Cartridge parts replacement</u>. The parts replacement assumptions for the remanufactured cartridge in this refresh have been based on autopsies of cartridges utilized in quality testing. In summary, the remanufactured cartridges examined typically contained replaced organic photoconductor (OPC) Drums and toner seals. Other parts were also replaced with varying frequency.

- **Simplified scenario and sensitivity analyses**.

A number of scenarios which had no influence on prior results and/or are no longer relevant have been eliminated. For example, the "drill-and-fill" scenario reflects a practice that is no longer relevant in the US and Europe, and was eliminated. Additionally, the "international" scenario was removed from the refresh in favor of more specific sensitivity analyses. Instead, upper and lower limit scenarios were applied to test the sensitivity of the models, presented in Appendix A.

The analysis of the use of 100% recycled paper from the previous study was also eliminated. Assessment of different fiber sourcing strategies is an area of some debate, and beyond the scope of this study. We have modeled 20 lb, 30% recycled content copy paper as representative of what would be used in an office with environmental programs.

- **Improved LCA data**.

The most up-to-date data sets were applied to the LCA models, including the U.S. LCI Database which provides current data based on North American technologies and markets[10] and the EcoInvent database.[11] Utilizing the most currently available data, especially from well-known and accepted databases, enhances the quality of the study and increases its transparency, reliability, and confidence level.

The printing paper database used for the study is based on EcoInvent's data on virgin uncoated paper production and paper recycling (with de-inking). The issue of whether the carbon sequestered in paper should be counted, which would affect overall global warming potential results, was deliberated. It was decided to utilize the paper model as "carbon-neutral", with the presumption that at the final end of life of the printed pages, the biomass carbon in the paper would be released back into the atmosphere. Even as carbon-neutral, CO2 equivalency factor of 1.5 kg CO2-eq. per one kg paper is conservative, with some published equivalency factors several times higher.

- **Review**

An external peer review panel found the 2004 study to adhere to the International Organization for Standardization's (ISO's) 14040 series of standards for LCA. While this update did not undergo a similar external review, the same system boundaries, methodological choices, and data quality adherence were employed. This report provides an overview of the more recent QualityLogic data for North America, details the updated assumptions, and presents the new results of the comparative environmental assessment. Since the goal of this refresh was to update the prior study with updated and/or improved data and research, and since all other work on this refresh was performed consistently with the prior, peer reviewed study, further peer review was deemed to be unwarranted.

Results and Sensitivity

Overall Results

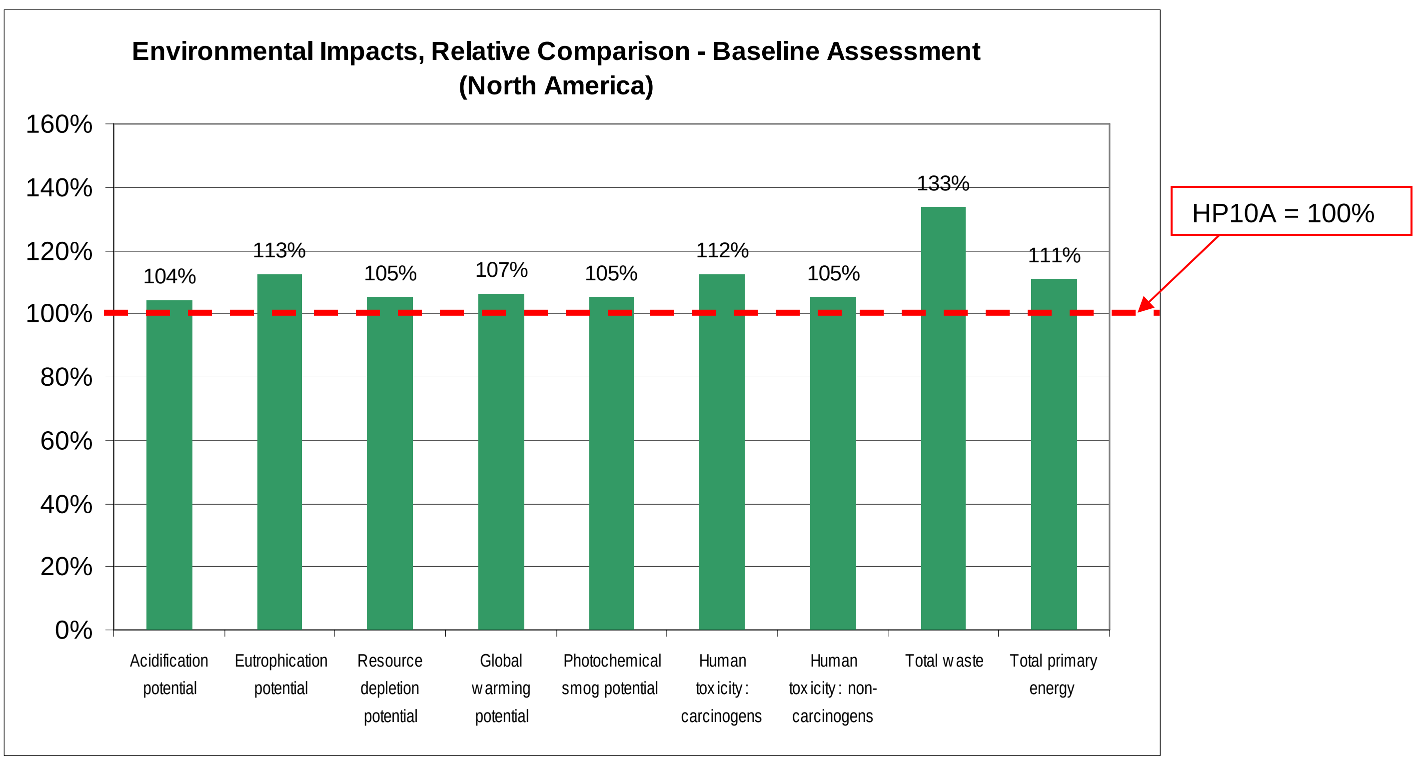
Table 5 and Figure 2 present results for the baseline comparison, which assumes equivalent use distribution requirements (e.g., one-third for each usable page category). The impacts for the R10A are higher than 4% in all categories, with about half of the categories higher than 10%.

As mathematical models of complex systems, LCAs have inherent uncertainties. A difference in results of 4% or 5%, as observed in several impact categories, can be considered to be essentially insignificant and therefore the results on-par with one another. It is noteworthy in the findings presented below, however, that the HP10A results are on-par or better in every impact category. These results indicate that, under these conditions, the HP cartridge is an environmentally preferable choice.

Table 5 - Overall Results for the Baseline Scenario

		Baseline Assessment Results		
		HP 10A	R 10A	Reman/HP
Acidification potential	kg SO2 eq	3.1 E-02	3.2 E-02	**104%**
Eutrophication potential	kg PO4	2.6 E-04	3.0 E-04	**113%**
Resource depletion potential	MJ surplus	9.6 E-01	1.0 E+00	**105%**
Global warming potential	kg CO2 eq	7.9 E-01	8.4 E-01	**107%**
Photochemical smog potential	kg C2H4	4.2 E-04	4.4 E-04	**105%**
Human toxicity: carcinogens	kg C2H3Cl eq	7.4 E-03	8.3 E-03	**112%**
Human toxicity: non-carcinogens	kg C2H3Cl eq	3.3 E-02	3.4 E-02	**105%**
Total waste	Kg	8.0 E-02	1.1 E-01	**133%**
Total primary energy	MJ	2.2 E+01	2.4 E+01	**111%**

Figure 2 Remanufactured (R10A) results presented as a percentage of HP (10A) results Baseline Scenario



Life Cycle Phase Contribution Analysis

Previous Life Cycle Analysis studies have shown that paper use is the biggest contributor to the environmental impact of a print cartridge. The results from this current study are consistent with previous findings.

Tables 6 and 7, representing the HP10A and R10A respectively, present a breakdown of impact category results across the four defined life cycle stages. When examined by life cycle stage, the results clearly show that the "Use" phase (and specifically paper usage) represents the majority of environmental impact for both systems.

Table 6 - Contribution analysis - life cycle of HP 10A

HP 10A Breakdown		Total	Production	Distribution	Use	EOL
Acidification potential	kg SO2 eq	3.1 E-02	11%	3%	88%	-3%
Eutrophication potential	kg PO4	2.6 E-04	1%	0%	99%	0%
Resource depletion potential	MJ surplus	9.6 E-01	22%	2%	83%	-8%
Global warming potential	kg CO2 eq	7.9 E-01	12%	2%	89%	-3%
Photochemical smog potential	kg C2H4	4.2 E-04	14%	2%	90%	-5%
Human toxicity: carcinogens	kg C2H3Cl eq	7.4 E-03	25%	0%	70%	5%
Human toxicity: non-carcinogens	kg C2H3Cl eq	3.3 E-02	13%	2%	86%	-1%
Total waste	kg	8.0 E-02	13%	0%	96%	-9%
Total primary energy	MJ	2.2 E+01	7%	1%	95%	-3%

Table 7 - Contribution analysis - life cycle of R10A

R 10A Breakdown		Total	Production	Distribution	Use	EOL
Acidification potential	kg SO2 eq	3.2 E-02	3%	1%	96%	0%
Eutrophication potential	kg PO4	3.0 E-04	0%	0%	99%	0%
Resource depletion potential	MJ surplus	1.0 E+00	10%	1%	89%	0%
Global warming potential	kg CO2 eq	8.4 E-01	5%	1%	94%	0%
Photochemical smog potential	kg C2H4	4.4 E-04	4%	1%	96%	-1%
Human toxicity: carcinogens	kg C2H3Cl eq	8.3 E-03	27%	0%	70%	3%
Human toxicity: non-carcinogens	kg C2H3Cl eq	3.4 E-02	3%	1%	92%	3%
Total waste	kg	1.1 E-01	6%	0%	81%	13%
Total primary energy	MJ	2.4 E+01	3%	0%	97%	0%

The importance of the use phase highlighted above supports the critical nature of cartridge performance. Because use phase impacts are so large in relation to those of other phases, quality deficiencies that affect efficiency during use can have a controlling influence over the life cycle comparison. In this case, the benefits of material recovery for the remanufactured cartridge are offset by greater impacts during the use phase, due to lower quality output and reprints.

Figure 3 and Figure 4 present contribution analyses for Global Warming Potential (GWP) and Total Waste in order to more easily evaluate the trade-offs in the system. For example, in both figures, HP10A's production stage is higher than its counterpart, but the offset of higher quality printing, which results in lower paper consumption per functional unit, more than offsets the production impacts. These figures also highlight the importance of the use phase.

Figure 3 Contribution Analysis, Global Warming Potential

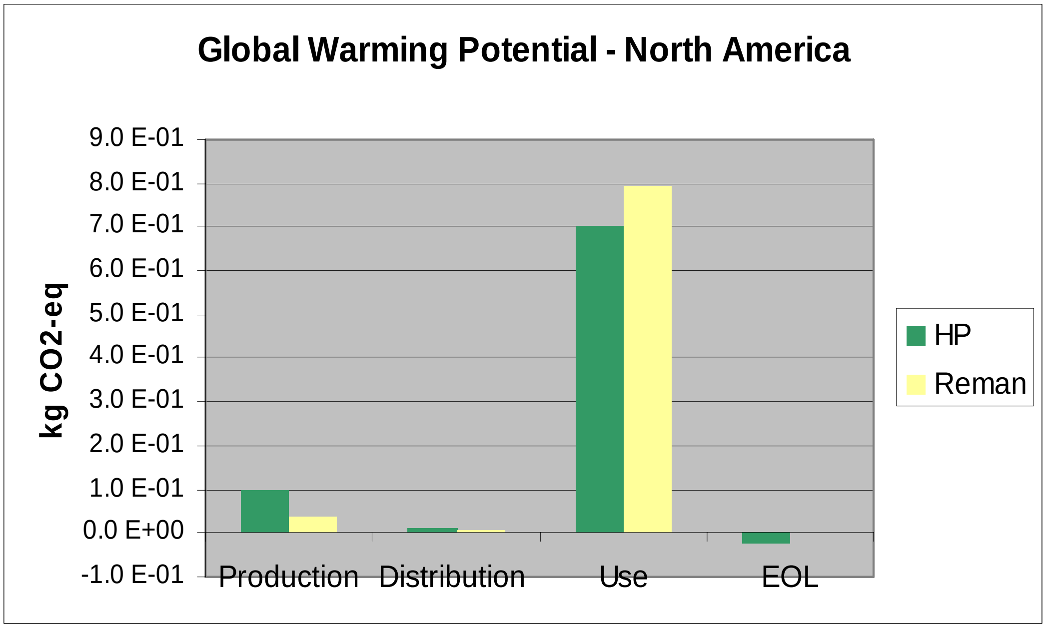
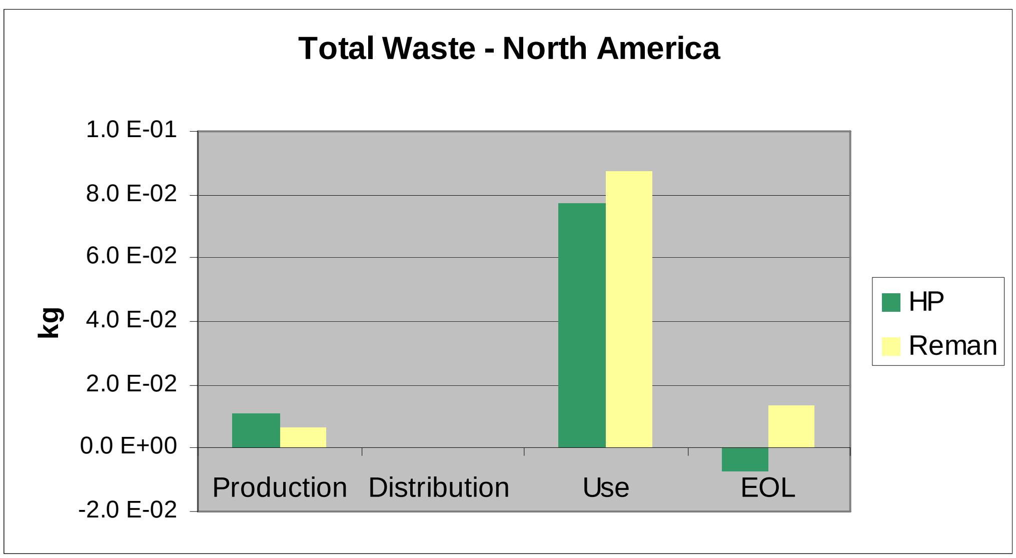


Figure 4 Contribution Analysis, Total Waste



Sensitivity of Desired Print Quality

As noted above, cartridge performance during use has a critical influence on overall life cycle environmental impacts. User print quality requirements define whether printed pages are acceptable or must be reprinted. Thus, user print quality requirements are an important variable affecting modeled use phase performance.

To examine the degree of influence on results, a sensitivity analysis was performed to address the variance in printed page distribution requirements resulting from two user surveys. An additional analysis was performed to examine the case where a user has strict quality requirements, requiring all output to be of suitable quality for external distribution. Table 8 presents the total number of pages needed to be printed to obtain the functional unit of 100 usable pages.

Table 8 - Sensitivity analysis parameters for each level of desired quality output

Desired Output Quality Requirements	Total Printed Pages		% more Reman 10A pages printed
	HP 10A	Reman 10A	
Baseline: Equally Weighted 33% - 33% - 33% - 0%	101	114	13%
Survey 1: IT & Purchasing Managers 28% - 33% - 39% - 0%	102	113	11%
Survey 2: Office Printer Users 33% - 43% - 24% - 0%	102	116	13%
All Uses (incl. external distribution) 100% - 0% - 0% - 0%	105	143	36%

As shown in the results presented for Global Warming Potential and Total Waste (Figures 5 and 6, respectively), the differences in the survey responses do not significantly change the outcome of the baseline analysis.

However, the last scenario is quite sensitive; the higher quality requirement, which translates to more reprints and hence greater paper consumption, increases the R10A overall results significantly – yet does not significantly affect the HP10A results. These results are further evidence of the high impact of paper in the overall model, as well as the importance of user print quality requirements. They illustrate that as user quality requirements increase, the environmental advantage offered by the superior quality of the HP 10A also increases.

Figure 5 Sensitivity analysis: varying levels of desired quality output – GWP

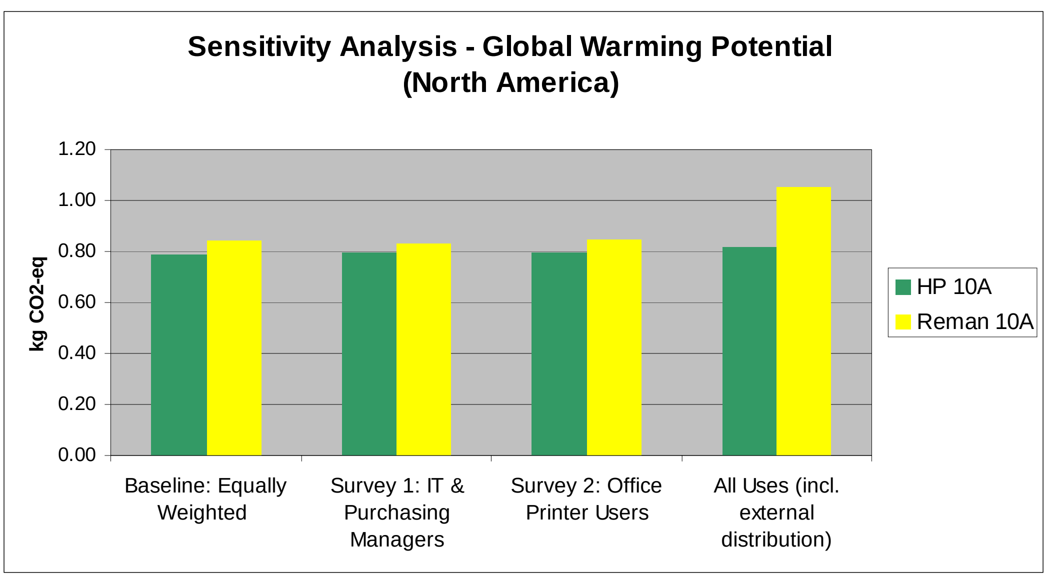
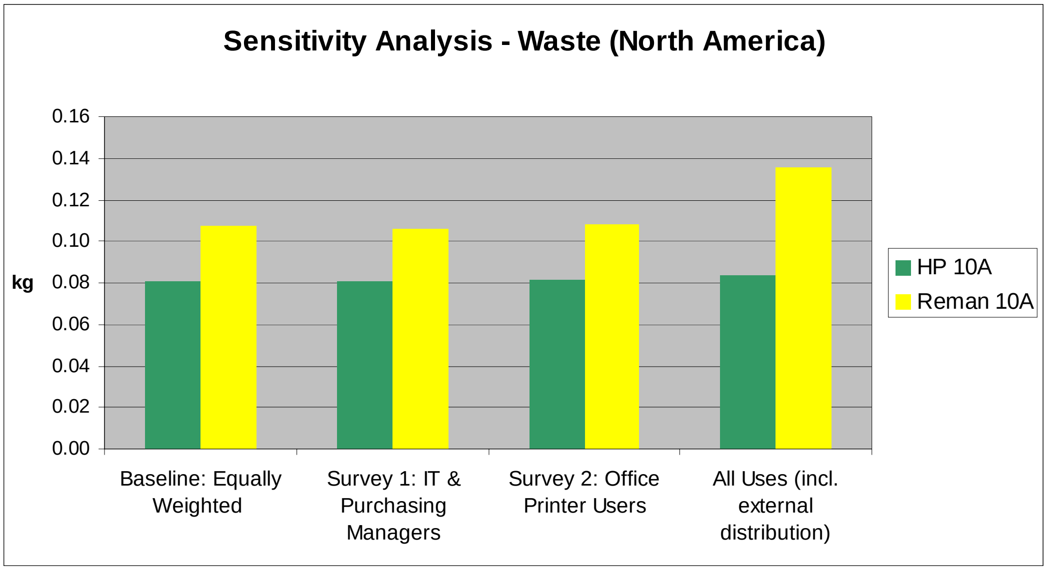


Figure 6 Sensitivity analysis: varying levels of desired quality output – Total Waste



Sensitivity of Some Model Parameters

Select model parameters were assessed for sensitivity, and these are summarized below (Table 9) with a description of their affect on the overall model in terms of GWP and waste. Figures 7 and 8 present the results for GWP and waste.

Table 9 - Select model parameters sensitivity checks

Baseline model	Check for sensitivity	Affect on the results
HP10A goes to an HP recycling center at EOL	HP10A disposed of in the MSW stream at EOL	Little effect (approximately 3%) on the model for GWP, more sensitive for waste (approximately 24% increase)
R10A: OPC drum replaced	No materials except toner replaced	Not much effect on the model for GWP (goes slightly down), slightly more sensitive for waste.
R10A: OPC drum replaced	More parts replaced. Also includes recycling and disposal of the replaced parts.	Not much effect on the model for GWP (goes slightly up), slightly more sensitive for waste.
R10A: Sort & discard rate: 16% (includes recycling and disposal of unusable cartridges)	Sort & discard rate: 5% (includes recycling and disposal of unusable cartridges)	Very little effect on the model.
R10A: remanufactured 1500 miles away, and includes transportation of used cartridge(s) to the plant and remanufactured cartridge from the plant to the user.	Remanufactured in China (include transportation of used cartridge(s) to the plant from the NA user and the distribution of the reman cartridge back to the user)	Very little effect on the model (see comment below).
R10A: disposed of per average MSW stream	All parts/materials are recycled	The results for the R10A are improved when the cartridge is recycled at EOL. Still, HP results are better.

Some of these sensitivity results are counterintuitive, such as the lack of sensitivity for foreign production (e.g., transportation/distribution impacts). This gives testament to the real driver of the study, which is the impacts associated with the production of paper; because of that, many other aspects of the life of the cartridges become insignificant.

Also noteworthy is the lack of sensitivity to the end-of-life fate of the HP cartridge. While much attention has been paid to this aspect of the cartridge life cycle, it proves to have little influence on overall environmental impacts such as global warming. Thus, while recycling efforts are commendable, performance during the use phase has a controlling influence on environmental impact of cartridges and warrants priority consideration when evaluating product alternatives.

Figure 7 Sensitivity analysis: model parameters – Global Warming Potential

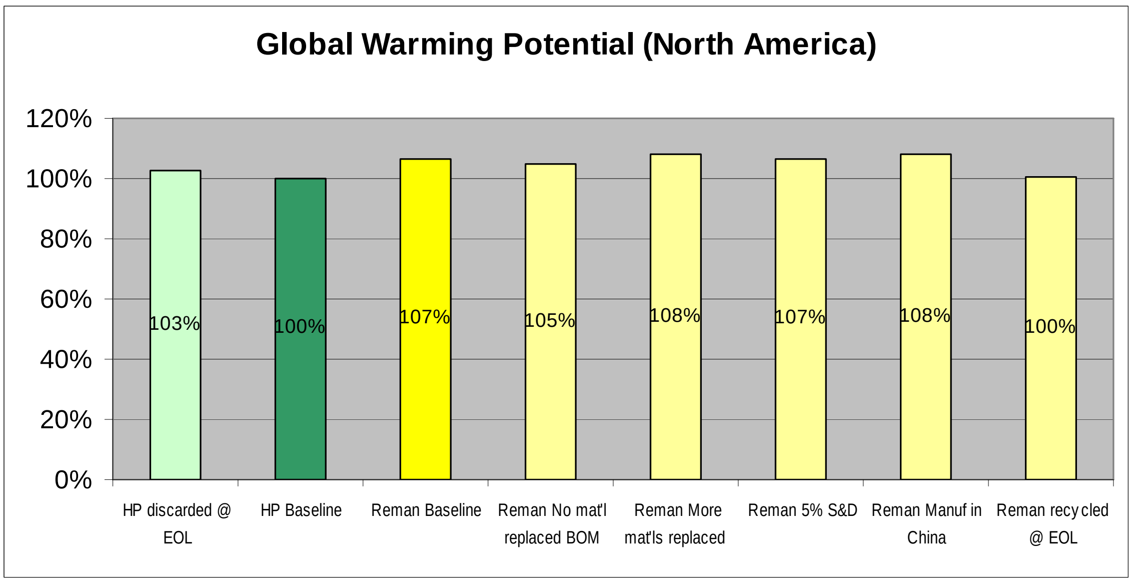
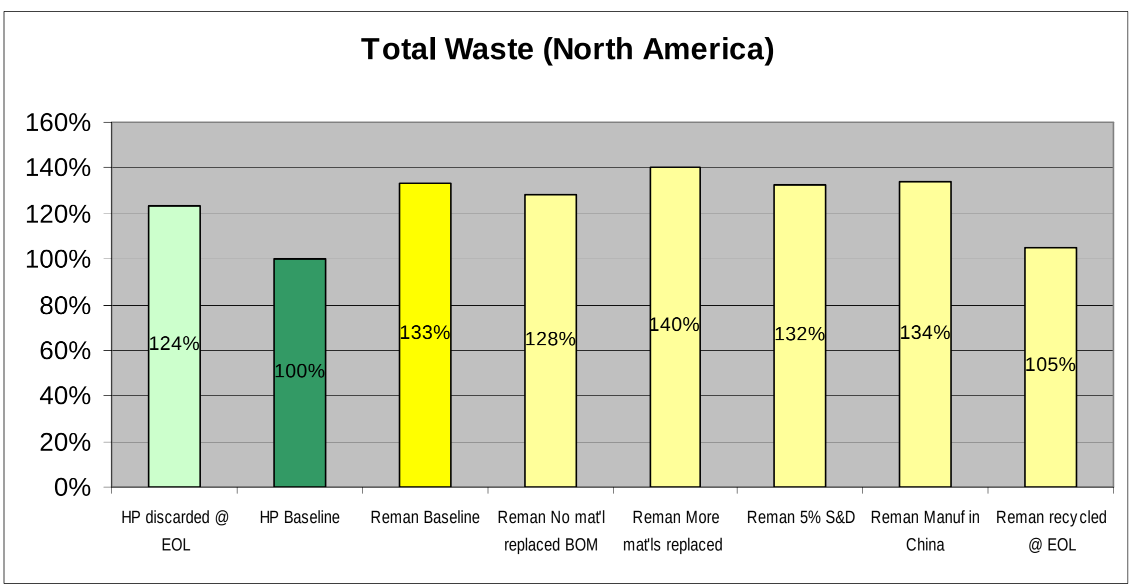


Figure 8 Sensitivity analysis: model parameters – Total Waste



Data Quality Requirements and Evaluation

This refresh adheres to the ISO standards on data quality to help ensure consistency, reliability, and clear-cut evaluation of the results. The following sections describe the major data quality requirements as established by the ISO 14040 series of standards.

Temporal, Geographical, and Technological Representativeness

Temporal
Temporal representativeness describes the age of data and the minimum length of time (e.g., one year) over which data are collected. Most of the data applied to this study represent current products and practices. The HP10A Parts and Materials List (PML) is current and representative. Waste management practices for the cartridges are current, as is the MSW management disposition percentages to landfill and incineration for energy. The cartridge reliability and quality data come from a very recently published study. Other cartridge specifications (electricity usage, etc.) are current. Energy and transportation data are based on low- to mid-2000's, and production data for materials are largely based on low- to mid-2000's data sets. The paper production data is based on early 2000's facility data.

Geographical
Geographical representativeness describes the geographical area from which data for unit processes are collected to satisfy the goal of the study. Data for energy and transportation are U.S.-based. Data for materials and processes are based on a combination of U.S. and European sources, however, wherever possible, customization to U.S. operations was performed. Paper production comes from several European paper producers and is considered to be average European production. The energy and materials elements within these data have been customized to U.S. data.[12]

Technological
Technological coverage, corresponding with 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 study methodology is applied to the various components of the study. Consistency was maintained in the handling of the competing product models, and with the exception of items identified in this refresh, this study is very consistent with its predecessor.

Reproducibility

The modeling has been performed and transparently described such that it could be reproduced by another practitioner.

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 cartridge was provided. Completeness is the percentage of flows that have been measured or estimated. The HP10A's PML contains well-measured, accurate data. However, no other primary data was collected so an evaluation on completeness is not possible.

Limitations

General Limitations and Uncertainty

It should be borne in mind that LCA, like any other scientific or quantitative study, has limitations and is a far from perfect tool for assessing the environmental impacts and attributes associated with product systems. Much of the data used for modeling the materials is secondary, i.e., publicly-available, data. Because the quality of secondary data is not as good as primary, i.e., company-specific, data, the use of secondary data becomes an inherent limitation to the study; secondary data may cover a broad range of technologies, time periods, and geographical locations. However, from a practical standpoint it is impossible to collect actual process data for each of the hundreds or thousands of unit processes included in a complete life cycle model so the use of secondary data in an LCI is normal and necessary.

Nonetheless, the use of secondary data does present some margin of error. But because hundreds of data sets are linked together and because it is often unknown how much the secondary data used deviate from the specific system being studied, quantifying data uncertainty for the complete system becomes very challenging. As a result, it is not possible to provide a reliable quantified assessment of overall data uncertainty for the study.

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

Study-Specific Limitations

Some of the limitations from the prior study have been addressed with more available data (see Section on Changes in the Model). Additionally, scenario analyses evaluated the sensitivity of some of the assumptions made.

However, there is still a data gap in cartridge manufacturing and assembly for both alternatives. While HP10A's production stage included over 99.5% of the materials from the PML plus generic parts forming, no specific cartridge manufacturing or assembly data was available. However, since the BOM inclusion is robust and parts production data was included, then excluding the assembly process data, which represents only one portion of the production stage, probably has little effect on the overall model.

Manufacturing and assembly of the R10A was also excluded due to lack of available data. And in light of broadly varying remanufacturing practices over the thousands of remanufacturing organizations, this lack of data may result in greater uncertainty. However, updated information provided better information on parts replacement, and the model captured production of new parts and waste management of replaced parts, two important components of remanufacturing production data.

So for both cartridges, process impacts are missing. This in itself, however, gives way to slightly less uncertainty for the following reasons:

1. Because LCA normalizes products to a functional unit, the relative, not absolute, differences in impacts for products being compared are measured. So when both products lack similar information, then the data gap is mitigated (see Figure 1 – Study System Boundaries).

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.

Conclusions

The goal of this refresh was to provide a comparative environmental assessment of a current HP OEM cartridge versus its comparable remanufactured counterpart, utilizing the most current research and data on production practices, disposition trends, and product quality and reliability.

The main conclusions of this study are, (1) that paper consumption during printing is the overwhelming contributor to the life cycle environmental impacts of both print cartridge alternatives, and (2) factors that influence the consumption of paper – in this case, output quality – can have a controlling effect on life cycle environmental impacts.

Based on psychometric testing of print quality, it is reasonable to expect that pages of unsuitable quality will require reprinting, leading to greater consumption of paper. Recent quality comparison studies show that Original HP Cartridges exhibited more reliable output quality than leading remanufactured alternatives. Use of higher quality HP cartridges in turn leads to fewer reprints, less paper consumed, and, for the cartridges assessed in this model, lower environmental impact.

In the sensitivity analysis of different user print quality requirements, the HP10A was found to be lower than or at par with the R10A for the assessed environmental impact categories. In the model parameter sensitivity analysis, few of the parameters tested for sensitivity significantly affected the overall results. The results may be surprising to some readers. For example, the additional transportation impacts from foreign production did not greatly affect the results – but this further attests to the fact that life cycle impacts are dominated by the use phase, and specifically paper consumption. One exception was recycling of the remanufactured cartridge, which was found to be more sensitive. Including a recycling program does improve the life cycle for Total Waste impact category.

To conclude:

- For users with low quality requirements—for example, those who print documents for personal use only — the environmental impact of HP and remanufactured cartridges is comparable.

- For users with higher quality requirements, who must reprint pages with quality defects, HP cartridges will have a lower overall environmental impact and should be preferred over their remanufactured alternative. Fewer reprints, and hence less paper consumption to obtain usable pages of desired quality, translate to a more environmentally efficient cartridge.

Appendix A - Summary of the Modeling and Assumptions

The following table summarizes the main modeling and assumptions used for this analysis.

Summary of the 10A Cartridges Evaluated for This Study

		HP10A Baseline	R10A Baseline	Lower Limit Remanufactured Cartridge Sensitivity/Scenario	Upper Limit Remanufactured Cartridge Sensitivity/Scenario
Production	**Upstream materials production**	The bill of materials (BOM) for HP10A was provided by HP in a current Parts Materials List (PML). Over 99.5% of materials in the cartridge were included in the modeling.	The OPC drum and toner seal are replaced in addition to the new toner. Fate of replaced parts: 25% is modeled as recycled, with the balance modeled as disposed of per U.S. average MSW disposition.-OPC drum (aluminum) is recycled -Balance of replaced materials are disposed of per U.S. average MSW disposition.	No materials are replaced except for the toner.	Selected additional components will are, including doctor blade, developer roller assy, & primary charge roller. Fate of replaced parts: 25% is modeled as recycled, with the balance modeled as disposed of per U.S. average MSW disposition.
	Transport-ation to manufac-turing & assembly	HP10A is manufactured in Japan. No data were available to model transportation of materials and components to the place of final manufacture and assembly.	Remanufacturing is within the same region as the user. Cartridge is transported 1500 miles by truck to the remanufacturing plant from the end-user in St. Louis.		International remanufacturing. Cartridge is transported 1,850 miles by truck to a west coast port (San Diego), plus 6,700 miles by ship to China
	Manufac-turing & assembly	**Manufacturing**: There were no data available on manufacturing processes associated with the supply chain.[13] Injection molding data was used for the housing component which is mostly made up of PS, and steel and aluminum parts forming processes were included as data proxies to cartridge parts manufacturing. No assembly modeled. See Limitations section.	**Manufacturing**: Very limited manufacturing data on remanufacturing processes. Replaced parts were given the same modeling (injection molding, parts forming, etc.). No assembly modeled. See Limitations section.		

		HP10A Baseline	R10A Baseline	Lower Limit Remanufactured Cartridge Sensitivity/Scenario	Upper Limit Remanufactured Cartridge Sensitivity/Scenario
	Discarded empty cartridges	**Unusable empties (sort & discard) rate**: N/A	**Unusable empties (sort & discard) rate**: 16% of collected cartridges are unsuitable for remanufacture.[14] 25% of unusable empty cartridges is modeled as recycled, with the balance modeled as disposed of per U.S. average MSW disposition.	**Unusable empties (sort & discard) rate**: For a conservative sensitivity, a 5% discard rate is assessed. 25% of unusable empty cartridges is modeled as recycled, with the balance modeled as disposed of per U.S. average MSW disposition.	
	Packaging	Packaging is included:[15] - Polyethylene bag: 28 g - Corrugated cardboard: 355 g - Pulp end caps: 142 g	Packaging is included, and is modeled the same as the HP10A.		
Distribution	**Distribution to end-user**	Made in Japan, and distributed 3300 miles by ship and 1850 miles by truck to the end-user in St. Louis	1500 miles to the end-user in St Louis		Remanufacturing operations in China; distributed 6,700 miles by ship and 1850 miles by truck to the end-user in St. Louis
Use Phase	**Printing** Printing includes the manufacturing of the paper used for printing, plus electricity used by the cartridge.	Paper Type: Standard 8.5 x11, 20 lb, copy paper, 30% recycled content Electricity use: The electricity used by the cartridge for printing was modeled using HP's specifications on power consumption for the HP 2300 printer • 426 Watts in Print mode • 24 page per minute (ppm) output	Paper Type: Standard 8.5 x11, 20 lb, copy paper, 30% recycled content Electricity use: The electricity used by the cartridge for printing was modeled using the same HP specifications for the HP 2300 printer: • 426 Watts in print mode • 24 ppm output		
	Page count	6,000 pages based on the standard ISO yield.	5,877 pages based on a proportionate scaling of observed page counts and standard ISO yield.		

		HP10A Baseline	R10A Baseline	Lower Limit Remanufactured Cartridge Sensitivity/Scenario	Upper Limit Remanufactured Cartridge Sensitivity/Scenario
	Pages printed per 100 defined usable pages	Equal distribution for external use, internal use with limited distribution, and personal use only Total pages to be printed to obtain the functional unit: 101	Equal distribution for external use, internal use with limited distribution, and personal use only Total pages to be printed to obtain the functional unit: 114	Intended use per HP survey No. 1: External: 28% Internal: 33% Personal: 39% Total pages to be printed to obtain the functional unit: HP 10A: 102 Reman 10A: 113 Intended use per HP survey No. 2: External: 33% Internal: 43% Personal: 24% Total pages to be printed to obtain the functional unit: HP 10A: 102 Reman 10A: 116	Intended use: 100% for any use Total pages to be printed to obtain the functional unit: HP 10A: 105 Reman 10A: 143
	Reuse Scenario	Used 1 time, i.e., HP cartridge is manufactured and then used one time in the printer.	Used 1 time, i.e., a used cartridge is sent for remanufacturing and is then used one time in the printer.		
End-of-Life	**End of Life**	**Baseline:** The HP cartridge is sent to HP recycling facility, which includes crushing, disassembly/sorting, and recycling or incineration with energy recovery. 59% of the cartridge is recycled, balance goes to WTE (Source: 2008 HP Global Citizenship Report) Includes transport of the used cartridge to the HP regional recycling center in Gloucester, VA **Scenario analysis:** HP cartridge is disposed of per U.S. average MSW disposition.	Cartridge is discarded by the end-user, or collected and disposed of per U.S. average MSW disposition.[16]	The cartridge is recycled.	

<u>Notes</u>

The US average MSW disposition (adjusted without the recycled percentage): 82% LF, 18% WTE.[17]

Appendix B - Page Samples: QualityLogic Study

The following page scans illustrate pages typical of each of the Print Quality Categories from the QualityLogic study.

Figure 9 All uses, including external distribution

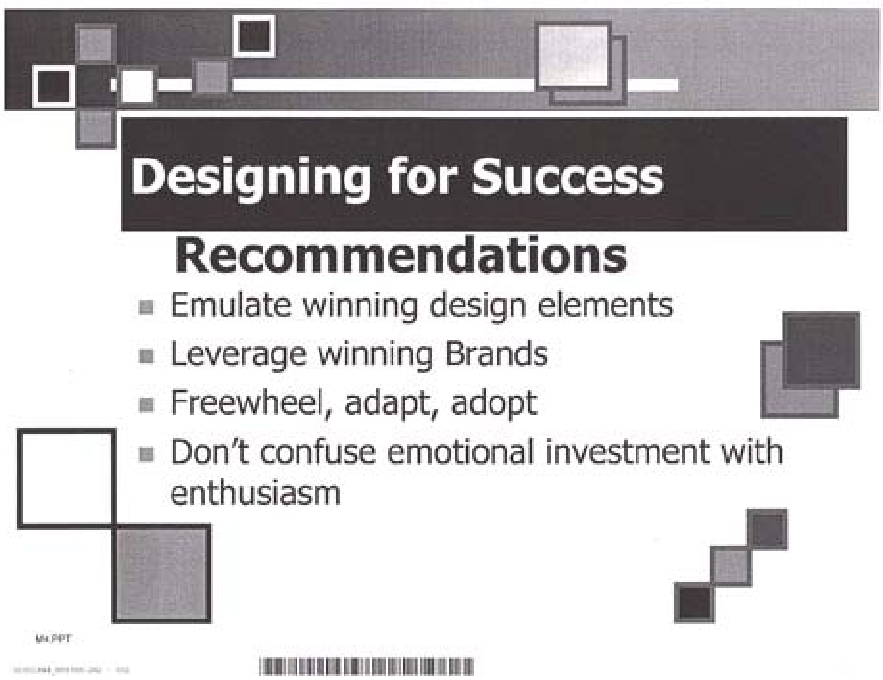


Figure 10 Limited use - not for external distribution

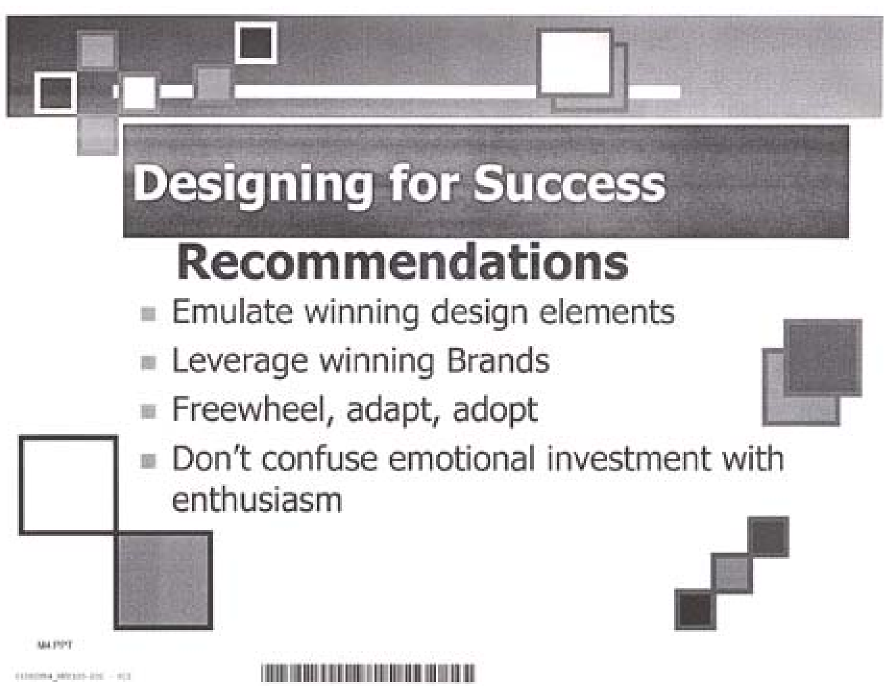


Figure 11 Limited use - no distribution

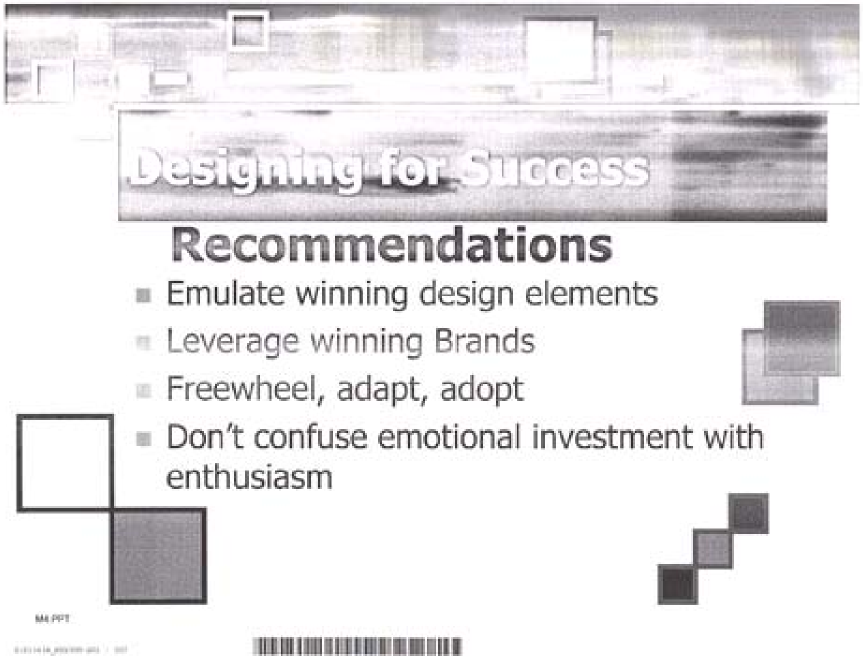
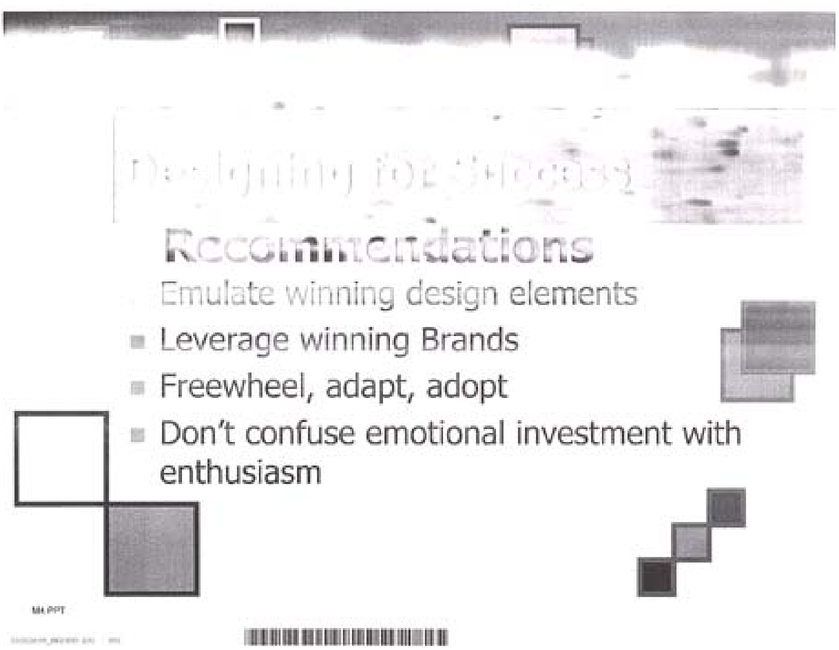


Figure 12 Unusable



Note: Page scans may not be accurately reproduced when printed from this report. See an electronic version of the QualityLogic study report for the most accurate representation of the scanned pages.

Endnotes

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[1] http://www.shopping.hp.com/store/product/product_detail/Q2610A, August 2008
[2] According to HP, the brands represent leading aftermarket brands available in North America, which supplied cartridges for the printer model at the time of the test. Given the market fragmentation, it is impractical to test all remanufactured brands.
[3] PRé Consultants: *SimaPro 7.0 LCA Software*. 2006. The Netherlands.
[4] 2007 Reliability Comparison Study: HP LaserJet 10A Toner Cartridges vs. North American Remanufactured Brands, an independent study, performed by QualityLogic Inc. and commissioned by HP. See http://www.qualitylogic.com/10ana/10ana.pdf.
[5] ibid
[6] ibid
[7] 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.
[8] Cathy Martin & John Shane, “U.S. and European Cartridge Collections and Recycling 2007: Laser and Inkjet Cartridges for Use in HP.” InfoTrends Primary Research Report, May 20, 2008, Commissioned by HP. Figure 4 (page 16) shows 84% of cartridges collected by remanufactures “become Good Remans” while 16% are “Bad” and are destined for “Recycle or Landfill”.
[9] ibid.
[10] Found at http://www.nrel.gov/lci/.
[11] Generally reputed to be current, representative data on processes and chemicals, the EcoInvent database is a for-purchase database developed by the Swiss Center for Life Cycle Inventories. EcoInvent is used in conjunction with other databases in the SimaPro software. More information can be found at www.ecoinvent.org.
[12] For example, the U.S. average electricity data set replaced the European average data set, etc.
[13] HP faced a similar limitation in conducting the prior LaserJet study.
[14] Martin & Shane, InfoTrends, 2007
[15] HP product specifications (www.hp.com)
[16] Martin & Shane, InfoTrends, 2007
[17] Source: U.S. EPA. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006. Available at http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/msw06.pdf

Table Notes

Table 1:
1) Climate Change 2007. IPCC Fourth Assessment Report. The Physical Science Basis. http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

2) Jolliet O, Margni M, Charles R, Humbert S, Payet J, Rebitzer G and Rosenbaum R (2003). “IMPACT 2002+: A New Life Cycle Impact Assessment Methodology.” Int J LCA 8 (6) 324-330.

3) EcoIndicator 99 – LCA methodology developed by Pre. Goedkoop and Spriensma, 2000, 2nd version.

4) CML - LCA methodology developed by the Center of Environmental Science of Leiden Universit (CML), December 2007.

Table 8:
The All Uses printed page output source is QualityLogic.[4]