LaserJet Cartridge Environmental Comparison:
A Life Cycle Study of the HP 96A Print Cartridge vs. its Remanufactured Counterpart in Germany

SUMMARY REPORT

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1) Introduction

The primary objective of this study, conducted by environmental research firm First Environment (www.firstenvironment.com), was to assess and compare the life cycle environmental impacts of Hewlett-Packard (HP) LaserJet toner print cartridges and leading remanufactured toner print cartridges available to customers.

The results here provide for HP and other interested parties a thorough and unique environmental comparison of these cartridges across the entire product life cycle: from production to distribution to use to end of life.

The study has been designed to transparently present the tradeoffs between two different product types so that it can be used to:

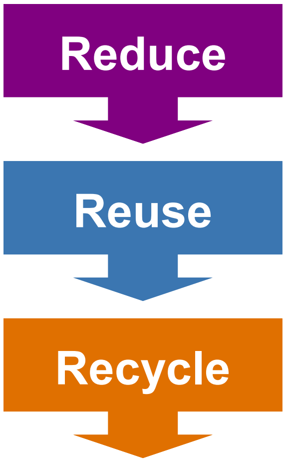
- Inform policy and purchasing decisions relating to the environmental impact of toner cartridges;
- Assess the applicability of the waste hierarchy to printer cartridges;
- Identify opportunities for product and/or process improvements;
- Provide a source of environmental information to interested parties; and
- Provide a benchmark assessment from which HP and other interested parties can measure future environmental progress relative to toner cartridge operations.

This document presents a summary of the full report, a copy of which can be obtained from First Environment (www.firstenvironment.com). Detailed information on the scope, methodology and results of the study are presented within the full report. Included with the report are the findings of the independent critical review conducted in accordance with ISO standards governing LCA.

2) Background

HP has examined the environmental impacts and performance of toner cartridges through previous, independent research. In 1998, it commissioned an evaluation of the life cycle environmental impacts of its LaserJet cartridges, which found that paper production and use had the most significant contribution to the product's total environmental footprint. In 2003, the testing firm Quality Logic Inc. analysed the reliability and print quality consistency of HP LaserJet cartridges in comparison to a number of key worldwide remanufacturers. QualityLogic found that HP cartridges produced usable printed pages more consistently and reliably than the tested remanufactured cartridges.

The study presented here was inspired by this previous research. It uses an internationally standardized method for evaluating products from production to end of life, called Life Cycle Assessment (LCA). The primary goal of this study was to compare the relative impacts of cartridge alternatives available to the consumer: an original HP LaserJet cartridge recycled through HP's Planet Partners program, and a remanufactured counterpart with various end of life management scenarios. A secondary goal was to examine whether the present, conventional application of the Reduce-Reuse-Recycle "waste hierarchy" to print cartridges adequately captures environmental impacts when the entire life cycle is examined.



The 'waste hierarchy' is a protocol for waste minimization and management that has been adopted by local, state and federal governments around the world. Broadly, the hierarchy emphasizes that a 'reduce-reuse-recycle' philosophy be used when any organization looks to manage the generation of solid waste.

The first step in the hierarchy, Reduce, emphasizes minimizing the generation of waste to begin with through more efficient management of materials. The second step, Reuse, involves the multiple uses of a product by repairing or reconditioning them, donating them, or selling them for either its original or an alternative purpose. The third step, Recycle, emphasizes the recovery and processing of waste material that would otherwise be landfilled or incinerated.

For printer consumables, this hierarchy could be represented as printing less often or more reliably (Reduce), recovery and refilling of the waste cartridge (Reuse), and then recovery of the waste cartridge at the end of its useful life (Recycle). Often, for printer consumables, reuse through the purchase of remanufactured cartridges is presented as the 'best' environmental option compared to purchasing original equipment manufactured (OEM) cartridges with an effective recycling program.

This study will focus on whether or not this dynamic is an accurate representation of the environmentally preferable situation.

3) Approach

The Life Cycle Assessment (LCA) employs a holistic 'systems assessment' approach that is useful in identifying the environmental trade-offs inherent in any product value chain. This study adheres to the International Organization for Standardization's (ISO's) 14040 series of standards for LCA. It was thoroughly reviewed by an external panel with representatives from academia (Harvard University), the non-profit sector (Institute for Environmental Research and Education) and industry (AT&T).

4) Scope

The focus of this study – Germany – was selected as the location of cartridge use, because of its central location in Europe and large market size. Four different country scenarios – North America, United Kingdom, Germany and Asia – were applied to the LCA model to account for variations and provide a more applicable result across differing geographies. Each scenario is analyzed in a different version of this report. While effects of materials treatment and transportation distances have some impact on resulting data and scores, the overall findings of the study do not change across the studied geographies.

The scope includes the full life cycle of four toner print cartridges: an HP LaserJet cartridge, which is manufactured, used once, and recycled in HP's current return and recycling program, and scenario representations of three types of compatible remanufactured cartridges. The life cycle stages for each scenario were based on well-known industry practices.

The HP cartridge (designated in this study as "HP 96A") was defined as the following:

- The HP C4096A is a LaserJet cartridge produced for use in the HP LaserJet 2100 and 2200 series printers, which, when originally sold, were targeted for the home and small office consumer. The LaserJet 2100/2200 series remains one of the most popular HP printing series, and the cartridge continues to sell in high volumes.

For the purposes of this study, a remanufactured cartridge (designated in this study as "R 96A") is 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. Select components are typically replaced. Because of the variety of remanufacturing processes, this study considers three different representative remanufactured cartridge scenarios:

- Baseline – A remanufactured cartridge representing common remanufacturing practices (see full LCA report, page 17).
- International Operation – Cartridges produced by a remanufacturing operation that is considered technically sophisticated and services multiple international markets. The cartridges in this scenario are modelled as having relatively high-end quality and reliability (see full LCA report, page 18).
- "Drill and Fill" Operation – Cartridges of highly variable quality and reliability produced by a remanufacturing operation that uses the least intensive form of processing (see full LCA report, page 18).

5) Functional Unit

To conduct an accurate LCA model under ISO guidelines, the function of the system should be defined so that the inventory results of the model can be understood on the basis of that function. Once this function is defined, a functional unit is chosen so that the systems can be compared on the same quantitative basis. For example, the comparison of the life cycles of aluminium can and a plastic bottle is made on the function that each product serves, i.e., packaging a quantity of a beverage, not on the basis of their materials, i.e., one pound of aluminium versus one pound of plastic.

Likewise, the cartridge comparison is being made in terms of the function of printing pages, so that it is fairly based on the service that the cartridge provides, not on a physical cartridge-to-cartridge comparison. Thus, the function of the system is defined here as printing to obtain usable pages, i.e., pages sufficiently devoid of imperfections such that they can be used for business communication. The functional unit is defined as the printing of 100 usable monochrome single-sided pages.

6) System Boundaries and Modeling

The cartridge life cycle stages included in the system boundaries are:

- Production: production of the materials in each cartridge and cartridge assembly (includes the sourcing of materials – be it transportation of used cartridge to remanufacturing facility and/or the extraction/refinement of needed metals and plastics to make new components in cartridge manufacture).

- Distribution: delivery of the finished product to the end user.
- Use: end user operation to produce the functional unit. This includes printing requirements, i.e., paper and cartridge-related resources needed to print 100 usable pages.
- End of Life: fate of the cartridge after it is depleted of toner.

Figure 1 represents the system boundaries for the HP and remanufactured cartridge systems, as well as how they relate to the functional unit.

Note that this study compared a single-use HP cartridge and a "single-cycle" remanufactured cartridge. Industry data strongly suggest that of the used cartridges (known in the industry as "cores") that are remanufactured, most are remanufactured only a single time, or a single "cycle." According to a prominent remanufacturer trade publication, "[In] 2000, at least 70 percent of first remanufacturing cycle cores were abandoned."[1] In a related article, the same author examines the prevalence of single cycle remanufacturing, finding that "virgin empties constitute almost 83 percent of the total aftermarket production of AIO [All-in-One device toner] cartridges."[2] Some remanufacturers claim a "virgin-only" strategy – or favouring cartridges that have been not been reused previously – as a quality feature.[3]

Multiple-cycle remanufacturing as a scenario was considered at the onset of the study. OEM cartridge environmental impacts can be easily demonstrated by the linear increase in production, use, etc., given the same quality OEM cartridge produced each time. However, modelling environmental impacts of successive cycles of cartridge remanufacturing presents some unique challenges. As a cartridge goes through additional cycles, more assumptions and modelling are necessary. For example, additional remanufacturing cycles can entail different transport, a higher percentage of cartridges that cannot be processed, and greater amounts of component replacement. Most importantly, data on the effect of multiple-cycle remanufacturing on cartridge reliability and print quality consistency were not available, although virgin-only remanufacturing strategies suggest reliability and quality will decline. Therefore, since it is well documented that the majority of remanufactured cartridges on the market are single-cycle, and because the environmental impacts of cartridge reliability and its print quality consistency are a critical study dimensions, it was determined that modelling single-cycle remanufacture would yield the most meaningful results.

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[1] Golden, Chad. "Worth Their Weight in Gold, Mining for Cartridge Core Profitability." *Imaging Spectrum*. August 2002. pp 25-30.

[2] Ibid. "Worth Their Weight in Gold-Part 2: Solutions for Cartridge Core Profitability." *Imaging Spectrum*. September 2002. pp 26-31. The author also notes that "only 17.2 percent of current production is based on the [multiple] reuse of a core, and second-cycle usage of a core is estimated at 80 percent of all multi-cycle core usage."

[3] See for example the Peach, Inc 2004 Product Catalogue, p. 9, "The Peach Rebuilt Toner modules utilize cartridges that have never been reconditioned before." (available at http://www.peach.info/)

Figure 1: Overall Study System Boundaries

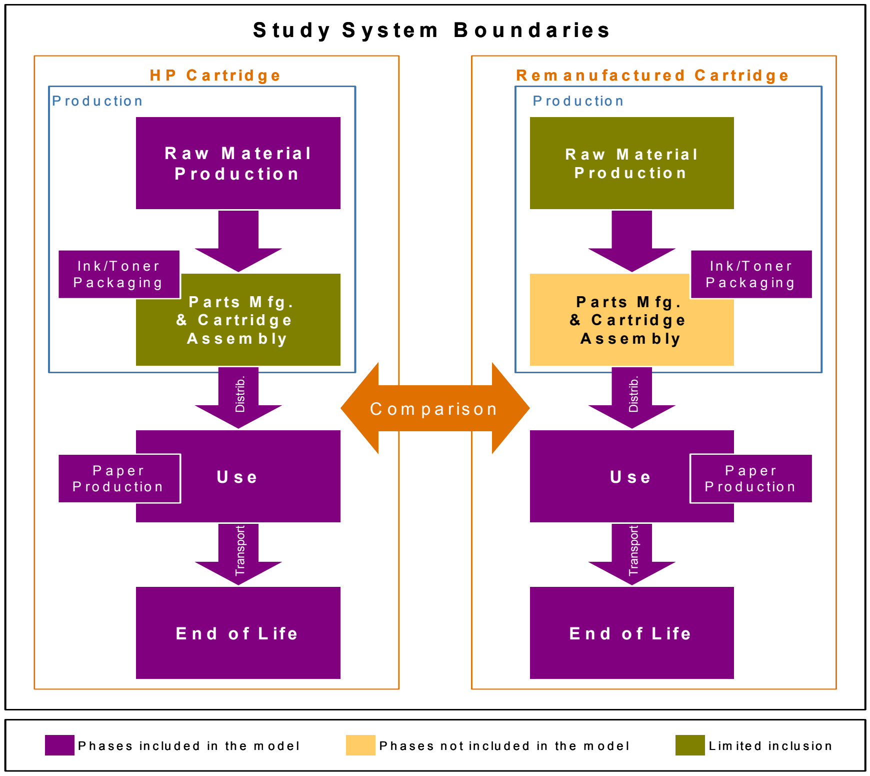
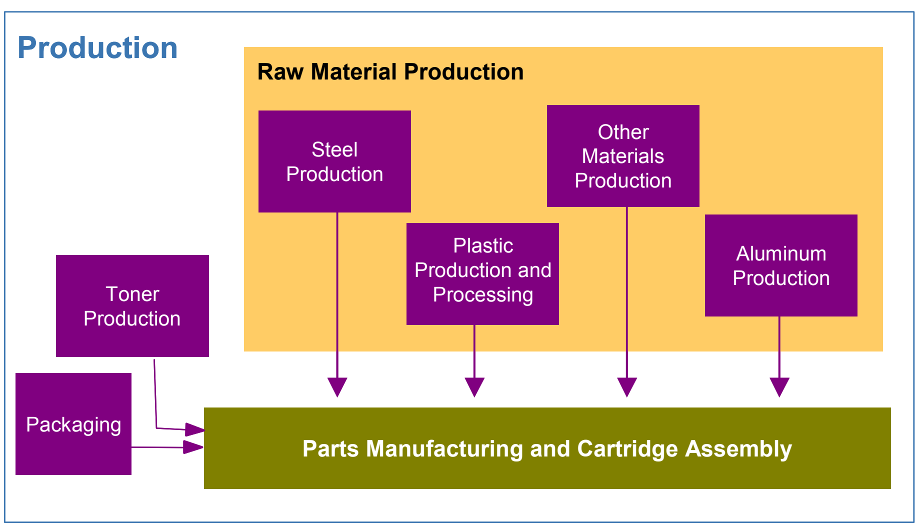


Figure 2: Production System Boundaries



The table below summarises the modelling details of the baseline cartridges and the two remanufactured cartridge scenarios.

Table 1: Summary of all "96A" Cartridge Scenarios (Germany)

		Baseline HP 96A	Baseline R 96A	International Operation	Drill and Fill
Production	**Upstream materials production**	99.5 percent of the raw materials in the Parts and Materials List	Some material impacts as the OPC drum is replaced. Replaced OPC drum is sent to a landfill (50 percent) and WTE plant (50 percent).	Some material impacts as the OPC drum is replaced. Replaced OPC drum is sent to a landfill (50 percent) and WTE plant (50 percent).	No material impacts as the cartridge is recovered. No materials are replaced except for the toner.
	Transportation to manufacturing and assembly	Materials transported 300 miles by truck to the place of manufacture.	Remaufacturing within the same region as the user. Transported 500 miles by truck to the remanufacturing plant from the end user in Germany.	International remanufacturing. Transported approximately 5,700 miles by sea and truck to the remanufacturing plant in Thailand from the end user in Germany.	Local remanufacturing. Transported 100 miles by truck to the remanufacturing plant from the end user in Germany.
	Manufacturing and assembly	Limited process data (i.e., injection molding for the plastic components, which represent 40 percent by mass, was included. The balance of assembly impacts was not.	Limited process data. Sort & discard rate: 20 percent. Those cartridges are sent to a landfill (50 percent) and WTE plant (50 percent).	Limited process data. Sort & discard rate: 20 percent. Those cartridges are sent to a landfill (50 percent) and WTE plant (50 percent).	Limited process data. Sort & discard rate: 50 percent. Those cartridges are sent to a landfill (50 percent) and WTE plant (50 percent).
	Packaging	External packaging. Modelled as recycled cardboard. Internal packaging. Consists of PET, LDPE, aluminium foil, and polyurethane adhesive. Internal packaging. Made from 100 percent post consumer recycled material. Impacts of production not accounted for.	Same as HP 96A baseline.	Same as HP 96A baseline.	Same as HP 96A baseline.
Distribution	**Distribution to end user**	Transported by sea and truck to the end user in Germany from Japan (approximately 5,800 miles).	Transported 500 miles by truck to the end user in Germany.	Transported by sea and truck to the end user in Germany from Thailand (approximately 5,700 miles).	Transported 100 miles by truck to the end user in Germany.
Use	**Printing**	Print mode power consumption: 393W (220 Volt model)	Print mode power consumption: 393W (220 Volt model)	Same as R 96A baseline	Same as R 96A baseline

		Baseline HP 96A	Baseline R 96A	International Operation	Drill and Fill
	Page yield	2,960 pages, the average of 50 HP 96 A cartridges tested in the QualityLogic study.	2,741 pages, the grand average of 30 cartridges each from six 96A model remanufactured cartridge brands (180 cartridges total) tested in the QualityLogic study.	2,428 pages, the average of 30 cartridges tested from the high-end performing 96A model remanufactured cartridge brand in the Quality Logic study.	2,283 pages, the grand average of 30 cartridges tested the low-end performing 96A model remanufactured cartridge brand in the QualityLogic study.
	Number of unusable pages	123 pages, the average of 50 HP 96A cartridges tested in the QualityLogic study.	251 pages, the grand average of 30 cartridges each from six 96A model remanufactured cartridge brands (180 cartridges total) tested in the QualityLogic study.	143 pages, the average of 30 cartridges tested from the high-end performing 96A model remanufactured cartridge brand in the QualityLogic study.	405 pages, the average of 30 cartridges tested the low-end performing 96A model remanufactured cartridge brand in the Quality Logic study.
	Paper type	80 g/m2 paper, with a recycled content of 30 percent.	80 g/m2 paper, with a recycled content of 30 percent.	Same as R 96 baseline	Same as R 96 baseline
End of Life	**End of Life**	Metals are recycled, the remaining cartridge is sent to a waste-to-energy plant; transportation is accounted for.	The OPC drum is recycled, and the remaining cartridge is sent to a landfill (50 percent) and WTE plant (50 percent); transportation is accounted for.	The cartridge is sent to a landfill (50 percent) and WTE plant (50 percent); transportation is accounted for.	The cartridge is sent to a landfill (50 percent) and WTE plant (50 percent); transportation is accounted for.

7) Data Sources

As noted above, data from previous studies were utilized in the development of this LCA. Data from the QualityLogic study (see section 2) were used to define characteristics of the use stage for all four modelled cartridges: the HP and the three remanufactured scenarios. Specifically, measurements of "print quality consistency" (defined as the number of unusable pages produced during printing) and "page yield" in the LCA were derived from actual measurements by QualityLogic, which had examined cartridges purchased through typical distribution channels.

Print cartridge performance was compared based on the printing of one-sided monochrome pages. For the LCA, printing of 100 usable monochrome pages was defined as the "functional unit" (see section 5).

To define the key end-of-life management stage of the cartridges, the LCA posits an environmentally conscious consumer choosing between two disposal alternatives: returning the cartridge to HP's established return and recycling program (Planet Partners) through widely available and free-of-charge return mailing. For the remanufactured cartridges, the LCA evaluated various end-of-life management strategies, including varying degrees of recycling, energy recovery and landfill disposal depending on typical practice within the studied geographies.

As with any life cycle study, there are some limitations to how it should be used. LCA results should not be considered to be the only source of environmental information relating to the environmental performance of a product or process. Also, as is common with an LCA, there are limitations to data quality, especially for the production of upstream sourcing materials, where temporal, geographical, and technological information vary widely. So when hundreds of data sets are compounded into a life cycle system, the result is a snapshot of a system, which has to account for some factor of error.

8) Impact Assessment Data Categories

The life cycle impact assessment is the part of the LCA "aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system."[4] The life cycle impact assessment categories chosen for the study are found in the table below.

Table 2: Life Cycle Impact Assessment Categories

Impact Assessment Category	Reported Unit
Global warming potential	Carbon dioxide (CO_2) gram equivalents
Acidification potential	Hydrogen ion (H+) gram equivalents
Eutrophication potential	Phosphate (PO_4) gram equivalents
Depletion of non-renewable resources	Mega joules (MJ) of energy surplus
Photochemical smog potential	Ethylene gram equivalents
Human toxicity potential	Disability-Adjusted Life Years (DALYs)
Total energy	Mega joules (MJ)
Total waste	Kilograms

This list generates a broad cross section of impacts within different environmental media (i.e., air emissions, water effluents, waste, etc.) and endpoints (vegetation, human health, etc.).

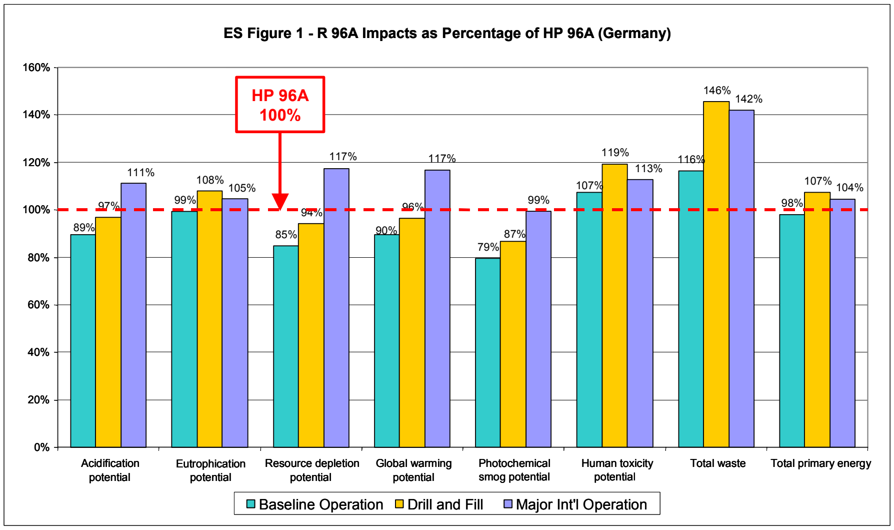
9) Results

Overall, these environmental impact comparisons, presented in Figure 3, do not decidedly favour the HP cartridge or any remanufactured cartridges. The results of certain life cycle impact assessment categories for remanufactured cartridges were less than those associated with the HP cartridge, and greater than the HP cartridge in other instances. All but three of the results differ by less than 20 percent; more than half differ by less than 10 percent. Therefore, no definitive statement can be made about the environmental preferability of one product type over the other – HP or remanufactured.

There was only one instance where a clear difference in environmental impact was observed. Significantly higher estimates of total waste were found for the "international" and "drill and fill" remanufactured cartridge scenarios than the other two product scenarios.

[4] ISO 14040:1997(E), Section 5.3.

Figure 3: Life Cycle Impact Assessment Results as a Percentage of HP 96A

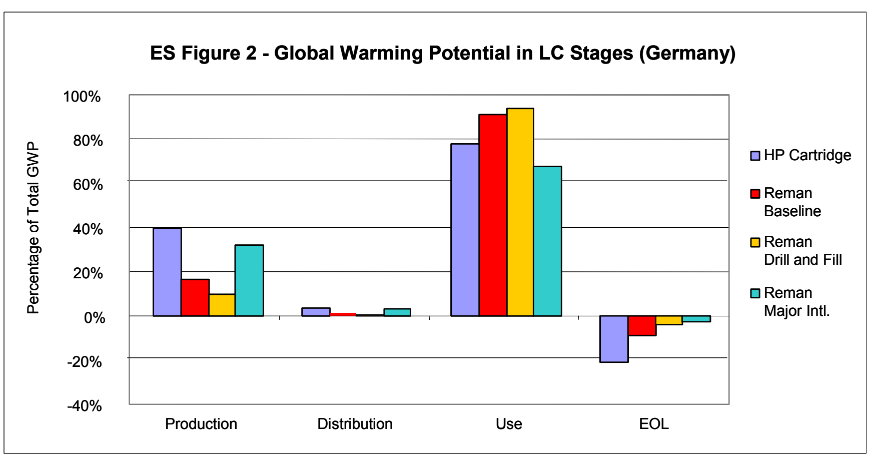


The charts that follow (Figure 4 and Figure 5) show the life cycle stage contributions to overall life cycle impacts for two of these categories: global warming potential (GWP) and total waste. These charts represent the relative share of impact across the four major life cycle stages: production, distribution, use, and end of life.

In comparing GWP results, the use stage accounts for a significant majority of the total life cycle impacts for all four cartridges. The HP cartridge's reliability and print quality consistency at the use stage offsets other life cycle stage impacts when compared to the remanufactured alternatives. Negative results at the end-of-life stage indicate the net benefits gained from recovery of materials or energy for beneficial use. Percent totals may appear to exceed 100 where cartridge recycling or energy recovery programs offset portions of total impact.

Figure 4: Life Cycle Stage Contribution Analysis – Global Warming Potential

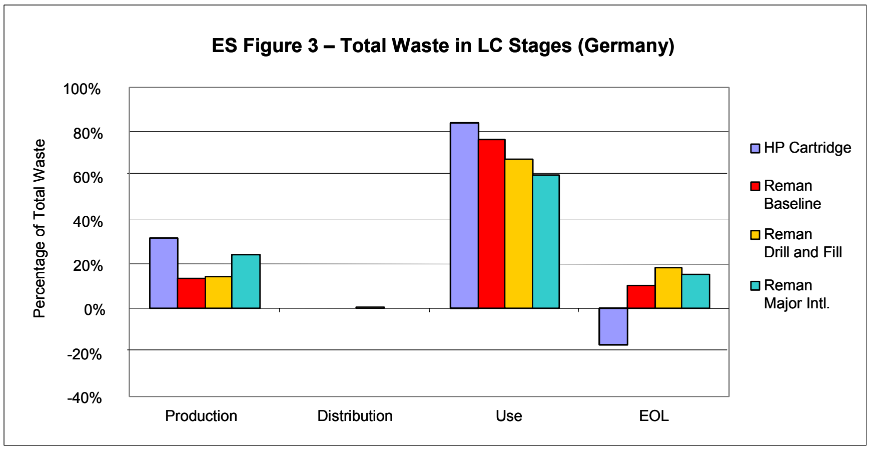
(Impact from generating 100 usable pages; data specific to Germany LCA model)



In comparing total waste results, the volume of waste generated during the use stage accounts for 60-75 percent of the total waste for all four cartridges. The end-of-life management for the HP cartridge (through recycling programs and recovery of materials or energy for beneficial use) offsets the measurement of waste at other stages and affects the graph accordingly. Negative results at the end-of-life stage indicate the net benefits gained from recovery of materials or energy for beneficial use. Percent totals may appear to exceed 100 where cartridge recycling or energy recovery programs offset portions of total impact.

Figure 5: Life Cycle Stage Contribution Analysis – Total Waste

(Impact from generating 100 usable pages; data specific to Germany LCA model)



10) Conclusions

The goal of this study was to compare the environmental performance of HP LaserJet cartridge, with recycling and a representative model of a comparable remanufactured cartridge, and examine the present application of the Reduce-Reuse-Recycle hierarchy to print cartridges. Conventional wisdom has focused on waste management concerns as the driver for product choice – in essence, presuming remanufactured cartridges are better for the environment because they represent recovered (or reused) material. From a practical perspective, however, cartridges are purchased for a specific function – to print pages of sufficient quality to meet the user's needs. This study was designed to provide a comparative assessment of the HP OEM cartridges versus remanufactured cartridges, with a focus on the full life of the products. The results of this study make it clear that a focus on the function and functional output of the cartridge is relevant and important.

Results from the comparison of life cycle impacts of an HP cartridge recycled at end of life and a remanufactured cartridge do not decidedly favour either cartridge. The results of certain life cycle impact assessment categories for remanufactured cartridges were less than those associated with the HP cartridge, and greater than the HP cartridge in other instances. All but three of the results differ by less than 20 percent; more than half differ by less than 10 percent. Therefore no definitive statement can be made about the environmental preferability of one product type over the other. This lack of differentiation is itself a significant finding, and calls into question the commonly promoted belief that remanufactured cartridges create far less environmental impact than OEM cartridges.

Results from this study challenge the school of thought that remanufactured brands are "better" for the environment because they reuse materials in the development of a new cartridge. The study reveals that although material sourcing impacts are significant, critical drivers of environmental impacts over the life cycle are print quality, cartridge reliability and end-of-life management.

- Print Quality Consistency – This and previous studies have demonstrated that the greatest proportion of environmental impacts occur during the use stage, through the consumption of paper. Uneven print quality that results in unusable pages can increase paper consumption due to reprints, significantly increasing paper consumption and its associated environmental impacts. Conversely, a cartridge that consistently produces high quality output will minimize wasted pages.

- Cartridge Reliability – Lower reliability that results in premature cartridge failures reduces the average page yield of a cartridge. Lower page yields result in an increase in environmental impacts per printed page because production, transport and end-of-life disposition impacts are associated with a smaller number of printed pages. Cartridge reliability, therefore, has potential for a considerable decrease in environmental impacts required to produce usable pages.

- End-of-life Management – The benefits of a recycling program, (e.g., recovery of materials and energy from end-of-life cartridges), were clearly demonstrated as an important aspect of the cartridge life cycle.

It can thus be concluded that a cartridge that reliably prints high quality pages, and in particular one that is recycled at end of life, most likely has lower overall environmental impacts than a cartridge that doesn't share these attributes.

A key lesson to be taken from this study is that systems should be compared on a functional basis, not solely a product basis. With the present application of the waste hierarchy to print cartridges (which emphasizes the end of life of the product), remanufactured cartridges may appear to be environmentally preferable to OEM cartridges because reuse is conventionally placed at a higher importance than recycling. However, this narrow perspective fails to account for the production impacts of remanufacturing and further ignores the additional waste and other environmental impacts that could be generated at other stages of the product life cycle, including resources that are wasted because of inefficient printing. This highlights the need to reconsider conventional thinking about cartridge environmental preference. Environmentally based decision-making regarding cartridges, whether original or remanufactured, should consider the cartridge's entire life, and most importantly, take into account the service it provides: reliable printing performance to produce usable pages.

For a copy of the full report, on which this summary is based, please send an email to the following address: laserjetlca@hp.com

11) Definitions

Cartridge Core
Remanufacturing industry terminology for a used cartridge body, used as input in the remanufacturing of cartridges.

First-Cycle Core
An OEM cartridge that has never been remanufactured. Also known as a “virgin core.”

Functional Unit
Quantified performance of a product system for use as a reference unit in a life cycle assessment study (Reference 1).

OEM Cartridge
A cartridge produced by the printer original equipment manufacturer (“OEM”). Also known as an “original cartridge”.

Page Yield
The average number of pages (usable and unusable) printed from a given cartridge type. In the case of this study, the relevant page yield is defined by the observations of QualityLogic. QualityLogic's observed page yields vary from HP specifications because of greater page coverage in their test pages.

Print Quality Consistency
The number of unusable pages produced during printing.

Recycling
Processing entire print cartridges or their components for beneficial use of recovered materials.

Remanufactured Cartridge
For the purposes of this study, a remanufactured toner cartridge is one in which the plastic body, as well as varying numbers of other components, have been taken from a previously used cartridge, refurbished to varying degrees depending on the remanufacturer, and replenished with toner.

Unusable page
Printed page which, as defined by QualityLogic, is "sufficiently flawed such that it would not be circulated to others as a business document and would only be acceptable as a draft page.”

Usable page
Printed page which “may have a minor flaw such as a speck or uneven graphic rendering but the average user would still use it in a typical business document” or “has no apparent artefacts with the identifying rule of thumb being that a user would put this page in his or her resume”, as defined by QualityLogic.

Waste to energy / energy recovery

The management of waste through controlled burning at a facility designed to recover the heat value of waste material for the production of electricity or other beneficial purpose.