Comparative Carbon Footprint Analysis of New and Remanufactured Inkjet Cartridges

HP21 & HP22 New versus Remanufactured

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### Glossary

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<td>CO$_{2\text{eq}}$</td>
<td>The net emissions of the life-cycle expressed as the equivalent amount of carbon dioxide.</td>
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<td>Ecoinvent</td>
<td>Industry-recognised database containing life-cycle phase impacts for numerous materials and products.</td>
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<td>IPCC</td>
<td>Inter-governmental Panel on Climate Change, the international forum defining the global scientific position on global warming.</td>
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<td>LCA</td>
<td>A technique, whereby the various effects of manufacturing, using and disposing of an item or service are evaluated according to a methodology for a stated set of parameters.</td>
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<td>OEM</td>
<td>Original Equipment Manufacturer: the first manufacturer of a new item, holding design specifications and possibly copyright.</td>
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<tr>
<td>SimaPro</td>
<td>Industry-recognised tool providing an interface to the Ecoinvent database for easier assembly of lifecycles including reuse loops, sensitivity analyses and presentation of the results,</td>
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1 Summary

This carbon footprint analysis is conducted for popular HP inkjet cartridges (HP21 Black and HP22 Colour) and for similar generic remanufactured inkjet cartridges. The analysis was based on the real life data provided by a major remanufacturer in Europe. The analysis includes materials, manufacturing/remanufacturing processes, transport, recycling and disposal stages.

Secondary data for the analysis was based on the data available in Ecoinvent database and published literature. SimaPro software package was used for the analysis and carbon impact was assessed by using the methodology of Intergovernmental Panel on Climate Change (IPCC 2007).

Based on the current analysis with the remanufacturing cycle ratio of 1.11 times for each core, it is found that:

- Carbon impact of remanufacturing inkjet cartridge is 0.81 kgCO$_2$eq compared to 1.21 kgCO$_2$eq for manufacturing equivalent new cartridge. This is based on 1.11 remanufacturing cycle. This translates to 0.384 and 0.573 kgCO$_2$eq per cartridge for remanufactured and manufactured, respectively.

- Remanufactured inkjet cartridges have around 33% less carbon impact than the new ones when excluding the use phase.

- Over two third of carbon impact is associated with energy and materials for both remanufactured and new cartridge.

- Saving achieved by EBP in 2009 alone by just remanufacturing generic versions of HP21&22 cartridges is just over 163 tCO$_2$eq based on the remanufacturing cycle of 1.11.

The use phase will also be included in the final analysis once the data required is available after a parallel study to collect the related data. Full analysis will be included in the final report.
2 Introduction

In Life Cycle Analysis (LCA), material and energy balances are used to quantify the emissions, resource use, and energy consumption of all processes required to make the process of interest operate. Process blocks that are included in the boundary of the analysis include raw material extraction, transportation, processing, and final disposal of products and by-products. The results of the inventory are used to evaluate the net environmental impacts so that efforts can be focused on mitigating negative effects.

Carbon footprint can be seen as a subset of LCA and is defined as a "measure of the impact human activities have on the environment in terms of the amount of greenhouse gases produced, measured in units of carbon dioxide (CO₂ eq.)." The carbon footprint can be seen as the total amount of greenhouse gases emitted over the full life cycle of a product or service. It is meant to be useful for individuals and organizations to conceptualize their impact in contributing to global warming.

Environmental concerns with the disposal of cartridges are being addressed, in part, by the remanufacture of cartridges. Remanufacturing is believed to offer significant environmental benefits by reusing the energy and resources expended during original manufactureabc, and by diverting solid waste from landfill and incineration. Remanufacturing involves the disassembly, restoration to like-new condition and reassembly of a used product. There are also "return and recycle" schemes where environmental benefits over remanufacturing are claimedd.

Environmental benefits gained through reusing materials and saving process energies are questioned by the claimed inferior printing during in useef. Possible paper wastages in use phase are seemed to be the cause of concern. That is why a life cycle approach needs to be applied to understand the environmental burden or benefits of remanufacturing cartridges over new ones. This study will address such need including the use phase, complemented by comprehensive user trials among various users (home, small business) over a six month period.
3 Inkjet Cartridge Remanufacturing

3.1 Inkjet Cartridges

Inkjet cartridges, and therefore the industry, can be subdivided into two separate technologies: separate print-head and ink reservoir, and a unified print-head and reservoir.

**Separate print-head and ink reservoir**

In general, this design is favoured by Canon and Epson. The print-head assembly is made of two distinct components: the print-head and an ink reservoir. The print-head is a permanent component in the printer: it contains the majority of the electronics involved with the printing process and the high precision nozzles that inject ink onto paper. The ink reservoir is essentially a small plastic vessel containing ink. Only the ink reservoir is replaced to refill the printer with ink. The ink reservoirs are generally low in value, with only small amounts of electronics and are relatively easy to produce.

**Unified inkjet cartridges**

These cartridge designs are generally favoured by HP, Lexmark and the newcomer Dell. The cartridge contains both an ink reservoir and a high precision print-head. The fully integrated nature of these cartridges make them more complex units than separate print-head cartridges and, as such, have a higher inherent value. The combination of the ink vessel and print-head also makes compatible manufacture of these cartridges more difficult. This has led to a large number of companies remanufacturing these cartridges.

3.2 Industry

This ever-changing technology has had its impact on the remanufacturing industry. The original attempts at inkjet cartridge remanufacture should probably, by definition, be classed as reuse. Early attempts involved simply refilling the cartridges using syringes and bottles of ink supplied to the consumer. Generally these attempts to refill the cartridges produced poor print quality and ink spillages. It has been suggested that the original changes in cartridge design were aimed at preventing these initial attempts at reuse, which were damaging to the printer industry as a whole.

Many early cartridge remanufacturers used similarly crude techniques to refill cartridges. In most cases these techniques produced poor results. Other early attempts at remanufacturing inkjet cartridges involved shipping them to the USA, where the market was more developed, having them filled and then shipped back to the UK. Again, due to the large distances travelled, the results were generally unsatisfactory. The remanufacturing industry quickly invested in R&D to develop
its own remanufacturing techniques. Unwilling or unable to invest in R&D, a significant proportion of the original players have left the industry.

The result of this investment is an industry which has commercially available purpose-built machines for refilling and cleaning inkjet cartridges (Figure 1). Larger remanufacturers also custom-build refilling machines to cope with large throughputs of cartridges. The interview of remanufacturers revealed that know-how was locked into certain key members of their workforce and these, above all, enabled them to compete.

Figure 1: Inkjet cartridge vacuum refilling unit

More recently, cartridges have included ever more sophisticated ‘smart chips’ whose role is to add extra functionality to the cartridge such as indicating ink levels and number of pages printed. There have been wide ranging allegations from the remanufacturing sector that these chips are designed to prevent the reuse of the spent inkjet cartridges. They claim that the chips ‘kill’ the cartridge, preventing it from printing after a certain number of pages or after it has been removed and re-inserted into the printer. We cannot substantiate these allegations, but we are aware of several manufacturers of third-party smart chips which substitute for the OEM chip at the end of the life of the cartridge. Although it is technically possible, by hacking the chip the remanufacturer is breaching the OEM’s intellectual property. Remanufacturers question why these chips are on the cartridges at all: their presence pushes up the cost of the cartridge to both the consumer and the OEM.

Remanufacturers have also raised concerns about the construction of modern inkjet cartridges. The earlier cartridges were easier to open, clean and refill than their modern counterpart. There are ongoing allegations that, in an attempt to prevent remanufacture of the cartridges, the OEMs are incorporating design
features, such as irreversible welds and hidden screws, which prevent effective disassembly and reassembly of the cartridges.

The vast majority of used inkjet cartridges (called cores) end up in landfills. Therefore there is a large scope to increase the number of good quality cores available for remanufacture. However, obtaining quality cores is a constant problem that has resulted in a large number of innovative schemes. The type, scope and complexity of these schemes depend on the size of the remanufacturer.

As a general rule, the quality of the inkjet cartridge core depends on how long the cartridge has been idle. If an inkjet cartridge that has just run out of ink is removed from the machine, refilled and replaced back in the printer within a few hours, then there is a high probability that the cartridge will work. However, if the empty cartridge has been unused for months, the likelihood of successfully remanufacturing the cartridge is low because, over time, the remaining ink in the print-head dries out, blocking the nozzles. This problem also manifests itself in the transport of remanufactured cartridges to the user. To combat this, remanufacturers have invested in developing transport clips to keep the nozzles of the cartridges free from blockages (Figure 2).

Figure 2: Remanufactured cartridges are shipped with transit caps (orange)
3.3 Remanufacturing Process

Whatever the type and shape of inkjet cartridge, the process of remanufacturing starts with the collection of used cartridges called cores. This can be done through local intermediaries or pre-paid postage envelopes provided with the final product. The cores go through various processes such as disassembly, assembly quality control and packaging. If the core is unified inkjet cartridge then there is no disassembly process involved. High level collection and the place of the remanufacturing process within the whole life cycle of a product are depicted in the flow diagram below (Figure 3). It is clear from Figure 3 that manufacturing of a product is required to enable remanufacturing; this is why this analysis also looks at the manufacturing of such product by the OEMs as the core is a part of remanufactured product’s carbon footprint. Products can be remanufactured for a number of times as long as the quality of every component is checked and tested for quality.

Figure 3: Overview of whole life cycle stages of an inkjet cartridge
A detailed process flow and quality procedure for remanufacturing inkjet cartridges is shown in Appendix A.

Since the primary purpose of remanufacturing is to reuse/remanufacture parts, the parts that are not reused enter the remanufacturers' waste stream. The amount of product discarded (as opposed to reused/remanufactured) is important to correctly model the waste stream.

3.4 Environmental Business Products

EBP is one of the world’s leading suppliers of remanufactured inkjet and compatible inkjet cartridges. Established in 1992 and based in London with operations in France, Germany, Holland, Sweden and Spain, EBP employs around 200 staff, and one of the largest collector and remanufacturer of inkjet cartridges in Europe.

EBP makes products under the house brand of Ink Again and specializes in the manufacture of private label brands for leading UK and European high street and mail order channels. The company has developed in-house expertise to produce cartridges that are indistinguishable from the Original Equipment Manufacturers.
4 System Boundary and Scope

4.1 Goal and scope

The goal of this study is to compare the carbon benefit of remanufacturing inkjet cartridges over manufacturing new ones from virgin materials and/or virgin plus recycled materials. The study also intends to highlight the materials and energy benefits of remanufacturing cartridges if there is any. The outcome of the study will be used internally.

There are other published works on this subject in the literature\(^g\)\(^h\). Some include the use phase some do not. End of life scenarios are not clearly defined, neither for the new toner cartridges nor the remanufactured cartridges. This work will include both the “use phase” and the “end of life options”. It also includes a detailed analysis of the supply chain for both manufacturing and remanufacturing activity. The effect of paper wastage during use will be analysed as this has resulted in controversy among the OEMs and remanufacturing practitioners.

Throughout this study, ISO guidelines on Life Cycle Analysis (ISO 14040: Principles and Framework, 14044: Requirements and Guidelines) and PAS 2050:2008 (Assessment of life cycle greenhouse gas emissions of goods and services) is observed.

4.2 Product system and system boundaries

It is important that the project boundaries used in the carbon footprint analysis for the purpose are clearly and appropriately defined, to capture all of the impacts associated with the activity under investigation.

The boundaries of this project encompass all the stages in the life cycle of an inkjet cartridge including the impacts arising from its usage. In order to directly and fairly compare the impacts of manufacturing (OEM) and remanufacturing, the boundaries of both life cycles have to be consistent. When modelling the remanufactured inkjet cartridge, the impact of a new cartridge is included in the carbon footprint. This is simply due to the fact that a new core needs to be manufactured first to enable remanufacturing. This impact is amortised over the remanufactured lifespan. This is shown schematically in Figure 4 where the more

\(^g\) LaserJet Cartridge Environmental Comparison, A life cycle study of the HP96A print cartridge vs its remanufactured counterpart in the UK, First Environment Incorporation, October 2004.

\(^h\) Life Cycle Assessment of Toner Cartridge HP C4127X, Environmental impact from a toner cartridge according to different recycling alternatives, Jonas Berglind & Henric Eriksson, Department of Technology, University of Kalmar, SE - 391 82 Kalmar, Sweden - Environmental Engineering, Final Exam Work 10 p, January 2002.
a product remanufactured from the same core, the lower its environmental burden would be on the final product. A schematic illustration of the system boundaries to calculate the carbon benefits is given in Appendix B.

Figure 4: Schematic representation of amortisation for product core's carbon impact

![Graph showing carbon impact over remanufacturing cycles](image)

**Inclusions/Exclusions**

The followings are included in this study:

- Materials and energy
- Transport covering the whole supply chain (operation only)
- Use phase including paper usage. This will be added to the report after a detailed users' trial conducted to obtain the use phase impacts of a new and remanufactured inkjet cartridge (reported separately to this report).
- End of life (reuse, recycle) including detailed reuse/recycle ratios for each core and any relevant parts.

The following are excluded in this study:

- The circuitry element of the inkjet cartridge
- Waste arising in part manufacturing and product assembly
- Energy burden of recycling by HP Recycling Program (due to lack of data)

**Key assumptions and Limitations**

Following assumptions are made for this study:
• OEM manufacturing is based in Malaysia with local supply chain for the cartridge parts used.

• Transport for refilling ink is not included. Ink for refills is manufactured and supplied locally in the UK. It is assumed that ink for OEM cartridges are locally supplied too.

• Remanufacturing is exercised locally in the UK.

Following limitations applies for this study:

• Ink manufacturing data is taken from Ecoinvent database (printing colour, offset, 47.5% solvent, at plant/kg/RER). This data includes material inputs (solvents, binders, pigments, fillers) and the estimation of energy consumption. Neither emissions to air/water nor solid wastes are included. The functional unit represents 1 kg of printing colour (black and coloured mixed) for the offset printing sector. Composition is based on a survey within Switzerland. The data are used here as European average values.

• For each core and relevant parts, the remanufacturing/recycling ratio was based on the actual data in 2009 by EBP. The data might differ for each remanufacturer.

• OEMs manufacturing energy consumption per cartridge is not available. A life cycle analysis study\(^1\) on HP Toner cartridges (HP C4127X) shows electricity consumption as 10kWh per toner cartridge. This particular model of HP toner cartridge weighs 1.4kg including the toner. We assume that energy consumption is proportional to the mass. The manufacturing electricity consumption of an inkjet cartridge (50g) should then be 0.34 kWh of electricity per unit.

• Waste scenario for the new product is based on the HP Recycling Program. See Section 4.4 for detailed explanations. The remanufactured cartridges data for UK recycling rates, available in Ecoinvent database, are used. This has set recovery rates for each material type: paper, plastics etc; the remaining waste is sent to landfill and incineration (83% and 17%, respectively).

### 4.3 Functional Unit

The functional unit chosen is the number of usable pages printed per cartridge. Since the function of a cartridge is to print pages, this would allow the comparison of the new and remanufactured inkjet cartridges. However, for this interim report, the functional unit is chosen to be one inkjet cartridge.

The number of pages printed per cartridge will be defined by a parallel study, comparing new and remanufactured cartridges in operation by 54 different users.

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\(^1\) Life Cycle Assessment of Toner Cartridge HP C4127X, Environmental impact from a toner cartridge according to different recycling alternatives, Jonas Berglind & Henric Eriksson, Department of Technology, University of Kalmar, SE - 391 82 Kalmar, Sweden - Environmental Engineering, Final Exam Work 10 p, January 2002.
over a six month period. The users will vary from home use to small business users that are the major users of inkjet cartridges.

Definition of “usable pages” will be defined by each user. The details of the study will be available in a separate report.

4.4 Inventory

The study deals with the very popular HP21 black and HP22 colour inkjet cartridges. The components identified are:

- Ink reservoir (ink case)
- Sponge
- Transit cap
- Packaging
- Ink

Details of the materials for each cartridge are given in Table 1 in Appendix C.

The Transport phase is included in the analysis. It was assumed that HP inkjet cartridges are manufactured in Malaysia. Transport stages included:

- Typical distances travelled by new cartridges to the consumer in the UK
- Typical distances for sea freight from Malaysia
- Typical European distance from the UK for core collection
- Average haulage distances within the UK
- The fate of printer cartridges at the end of their life in the UK

The details of transport scenarios are given in Table 2 in Appendix C.

End of life options are an important part of a life cycle. In this study new and remanufactured cartridges go through different end of life options:

- For remanufactured inkjet cartridges, remanufacturing and recycling data is based on the units dealt with in 2009 by EBP for 2009 (Table 4 in Appendix C).

- For new cartridges, HP Recycling Program is modelled. According to HP, as of December 2008, 125 million HP inkjet print cartridges have been returned and recycled since the inkjet cartridge recycling program began in 1997, representing a weight of 12.2 million pounds. HP recycled 46.2 million pounds of HP print cartridges in 2008 alone. It is difficult to

\[ \text{http://www.hp.com/sbso/product/supplies/cartridge-recycling.html} \]

\[ \text{http://www.hp.com/sbso/product/supplies/printer-ink-refill.html} \]
calculate the recycling rate for inkjet cartridges based on this data. However, data published by HP as part of global citizenship initiatives, states that 64% of the materials are recovered for recycling and 31% recovered for energy in 2009. It is also stated that their recycling program covers 88% of the market. Whilst industry consultation by the UK Market Transformation Program (MTP)\(^1\) suggests that 6-7% of cartridges are returned to OEMs, marketing sources have suggested 3% (Figure 5), making the average used 5%.

- It was also highlighted in the MTP report that the OEM consultation indicates that 95% of the mass of spent cartridges collected by an OEM is diverted from landfill - breaking down into 56% recycled and 39% incinerated for energy, which compares with HP figures above. Details of the end of life scenario used in the analysis for new cartridges by HP are given in Table 3 in Appendix C (assumptions for landfill is 50%, See Figure 6).

Figure 5: End of life options usually available to a printer cartridge\(^a\).

\(^1\) http://www.hp.com/hpinfo/globalcitizenship/datagoals.html#environment&productreuserecycling
\(^a\) Waste considerations relating to printer cartridges, BNICT23, UK Market Transformation Program, www.mtprog.com
\(^\text{m}^\) Waste considerations relating to printer cartridges, BNICT23, UK Market Transformation Program, www.mtprog.com
4.5 Data Sources and Collection

All data related to remanufactured inkjet cartridges is collected from EBP based on their remanufactured inkjet units, energy (electricity and heat) consumption in 2009. All components were weighed individually. Majority of the cores are sourced from the UK and the Europe. The split between the two is provided.

For new inkjet cartridges there is a limited amount of information available from the OEMs. The majority of the data is collected from the published literature. Recycling efficiency of HP’s Recycling program was calculated from published data on the number and weight of inkjet cartridges recycled.

The rest of the data requirement is obtained from Ecoinvent database (ver. 2.1) which was available with SimaPro, an LCA tool by Pré Consultants*.  

* http://www.pre.nl/
5 Carbon Impact Assessment

This is a stage wherein a LCA understanding and evaluation of the magnitude and significance of the potential environmental impact of a product takes place. In this study, as explained in the goal and scope, we would like to take a carbon impact (CO$_2$) of the remanufactured inkjet cartridges and compare it with the new ones. In this case we can use the methodology developed by the Intergovernmental Panel on Climate Change (IPCC) to look at the global warming potential over a 100 years (GWP$_{100}$) of these two activities in terms of CO$_2$eq.

5.1 Footprint Calculations

The literature review on the life cycle of cartridges reveals that a controversy exists between Original Equipment Manufacturers (OEMs) and remanufacturers. While remanufacturers highlight the benefit of remanufacturing in terms of materials and energy saving, OEMs, on the other hand, emphasise the whole life cycle of the product including the "use phase". OEMs claim that remanufactured cartridges are not as good as new ones: Hence they result in paper wastage and related additional use to obtain the same quality of printing or service. We therefore modelled the "use phase" of an inkjet cartridge in our analysis. The use phase includes the environmental burden of a printer for a given amount of paper usage.

In this interim report all the calculations made exclude use phase, as related data will be available once the user trials are completed. As a base case scenario we assume that each core is remanufactured once. There might be opportunities to remanufacture more than once but OEMs strongly challenge this, so, for the benefit of the doubt, our analysis includes only single cycle.

The comparison of the impacts of new and remanufactured cartridges is shown in Figure 7 where potential carbon saving per 1.11 times remanufacturing cycle is also given. A new inkjet cartridge has 1.21 kgCO$_2$eq while the remanufactured one has 0.81 kgCO$_2$eq. Remanufacturing represents a benefit of 33% over new, excluding the use phase, which will be included in the final report after the trial study. This is based on a 1.11 times remanufacturing cycle, i.e. each of OEM cartridges is remanufactured 1.11 times. The carbon impact of remanufacturing activity also includes the environmental burden of the new cartridge as, without the core from a new cartridge, remanufacturing would not exist. For the same token, remanufacturing prevents the manufacturing of new cartridges so there needs to be 2.11 new cartridges to make a comparison. A very detailed view of process stages modelled for the new and remanufactured cartridges are shown in Appendix D. A one to one comparison of new and remanufactured cartridge is shown in Figure 8.

Figure 7: Comparative analysis of OEM and Remanufactured toner cartridges without the use phase for the remanufacturing cycle of 1.11 times.

Figure 8: One to one comparison of OEM and remanufactured toner cartridges (also displaying contributions from remanufacturing activity and the core).

Major life cycle stages of new and remanufactured inkjet cartridges are shown in Figure 9 and Figure 10, respectively. Manufacturing is the major contributor to
overall carbon footprint for the new cartridges, while carbon impact of core has the major impact for the remanufacturing process. HP’s recycling program has almost identical carbon impact to remanufacturing activity (0.20 and 0.22 kgCO$_2$eq, respectively) but the end products are materials and energy in the case of former and a new cartridge for the latter. Although recycling activity brings carbon benefit, very low collection rates by the OEMs, which is assumed 5% in this study, and the fact that most of the new manufactured cartridges ended up in landfills, becomes carbon positive activity. From the point of view of producers’ responsibility, carbon burden of all cartridges ending up in landfills are assigned to OEMs.

Figure 9: Carbon impact of major life cycle stages of new HP21 inkjet cartridge

Figure 10: Carbon impact of major life cycle stages of remanufactured HP21 inkjet cartridge
More detailed analysis of carbon impacts by individual processes are shown for new and remanufactured inkjet cartridges in Figure 11 and Figure 12 respectively. Energy and materials are the major contributors in each case, about two thirds of the total impact.

Figure 11: Specification of total carbon impact by process for new HP21 black inkjet cartridge

![Figure 11: Specification of total carbon impact by process for new HP21 black inkjet cartridge](image)

Figure 12: Specification of total carbon impact by process for remanufactured HP21 black cartridge

![Figure 12: Specification of total carbon impact by process for remanufactured HP21 black cartridge](image)

Based on the data provided, EBP saved over 163 tonnes of CO$_2$eq by remanufacturing a generic version of the popular HP21&22 inkjet cartridges in 2009 alone (Figure 13). Although the HP22 colour inkjet cartridge is not
especially modelled in this study, it is thought that it would have similar carbon saving based on the very similar inventories (Table 1 in Appendix C).

Figure 13: Carbon saving obtained through remanufacturing HP21 & 22 cartridges by EBP in 2009 alone

5.2 Recommendations

Recommendations will be available in the final report after the use phase data is modelled in the whole life cycle.
6 Conclusions

Carbon footprint analysis of remanufacturing inkjet cartridges over new cartridges was conducted using the SimaPro software package. The analysis excluded the use phase until the user trials are completed.

Based on the preliminary analysis the following conclusions are made:

- Accumulated carbon impact of remanufacturing inkjet cartridge is 0.81 kgCO₂eq compared to 1.21 kgCO₂eq for manufacturing equivalent new cartridge based on 1.11 remanufacturing cycle.

- Remanufactured inkjet cartridges have about 33% less carbon impact than the new ones when excluding the use phase.

- Over two thirds of carbon impact is associated with energy and materials for both remanufactured and new cartridge.

- Saving achieved by EBP in 2009 alone, by simply remanufacturing generic versions of HP21&22 cartridges, is just over 163 tCO₂eq based on the single cycle remanufacturing.

Notes for the Reader:

This relative assessment has been conducted under the guidelines of PAS2050:2008. This is the current standard for the interpretation of the relative carbon footprint of remanufactured products, although these guidelines are still open to review and are not universally accepted. It is the intellectual position of others including EBP that the treatment of emissions associated with reuse and remanufacture (PAS2050:2008 8.6) is conceptually flawed. While recycled materials is acknowledged through recycled content ratio in a product, full recycling of a product (the core) via remanufacturing and reuse is burdened with the original product. In line with the waste hierarchy, remanufacturing and reuse has higher environmental benefit than recycling materials. Hence, any core that comes to end of life should be treated as %100 recycled, i.e. no environmental burden attached to them from the original product except processes related to their recovery. The data produced through this study would indicate that the carbon footprint of complete remanufacturing cycle equates to only 19% of the total original inkjet cartridge carbon footprint. For full details see www.ebpgroup.com/cf.
Appendix A: Quality Control

Quality control procedures for the remanufactured inkjet cartridges

1. Collected empty cartridges
   - Visually inspected and recorded on system
   - Scrap (storage & preparation for recycling)
   - Scrap (transportation to recycler)
   - Scrap (recycled)

2. Purchased empty cartridges
   - Production Batch creation & preparation
   - Production Batch residual ink removed (cartridge)
   - Production Batch Cartridges washed (with warm demineralised water)
   - Production Batch stand for several hours in plastic trays

3. Production Batch Cartridges meet fill spec
   - Cartridges stored in tray until enough to make a rework batch
   - Production Batch stand for several hours in plastic trays
   - Production Batch print tested

4. Production Batch print tested
   - Does cartridge meet print test spec
   - Does cartridge meet fill spec
   - Production Batch filled with ink

5. Production Batch filled with ink
   - Does cartridge meet fill spec
   - Does cartridge meet fill spec
   - Production Batch shipped to customer

6. Shipped to customer choice of packing
   - Packed in customers choice of packing
   - Stored in plastic trays & shipped to packing department
   - Cleaned and prepared for packing

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Appendix B: System Boundary

Schematic of system boundaries for manufacturing and remanufacturing to calculate carbon footprint
Appendix C: Data Tables

Table 1: Major components of HP inkjet cartridges

<table>
<thead>
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<tr>
<td>Organics</td>
<td>8.40</td>
<td>8.40</td>
</tr>
<tr>
<td>Corrugated paper</td>
<td></td>
<td>20.00</td>
</tr>
<tr>
<td>PET</td>
<td>23.30</td>
<td>60.00</td>
</tr>
<tr>
<td>Polystyrene foam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organics</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>Corrugated paper</td>
<td></td>
<td>60.00</td>
</tr>
<tr>
<td>Total</td>
<td>32.30</td>
<td>2.80</td>
</tr>
</tbody>
</table>

Table 2: Transport distances modelled in the study

<table>
<thead>
<tr>
<th>Distance, km</th>
<th>UK, local</th>
<th>from EU to UK</th>
<th>from Malaysia to UK</th>
<th>Malaysia, local</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Cartridge</td>
<td>300</td>
<td>-</td>
<td>10536</td>
<td>200</td>
</tr>
<tr>
<td>Remanufactured Cartridge</td>
<td>300</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cartridge Core</td>
<td>300</td>
<td>1460</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3: Calculation of end of life scenario for new cartridges by HP

<table>
<thead>
<tr>
<th></th>
<th>Materials recovered for recycling</th>
<th>Energy recovery</th>
<th>Landfill</th>
<th>Remanufacturing (Reuse+Recycling+Landfill)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP Recycling Program</td>
<td>64.00%</td>
<td>31.00%</td>
<td>5.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>EoL per cartridge*</td>
<td>3.2%</td>
<td>1.6%</td>
<td>47.8%&lt;sup&gt;§&lt;/sup&gt;</td>
<td>47.50%&lt;sup&gt;§&lt;/sup&gt;</td>
</tr>
<tr>
<td>EoL per cartridge excluding reman (OEM)</td>
<td>6.10%</td>
<td>2.95%</td>
<td>90.95%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

* Based on 5% return rates to HP, and 50% landfill disposal. <sup>§</sup> Assume 50% disposal rate to landfill. <sup>§</sup>CORE for remanufacturing stream

Table 4: End of life options for HP21&22 cores at EBP in 2009

<table>
<thead>
<tr>
<th>Core type</th>
<th>Remanufactured</th>
<th>Scrapped (recycled)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP21 Black (virgin)</td>
<td>87.6%</td>
<td>12.4%</td>
<td>100%</td>
</tr>
<tr>
<td>HP22 Colour (virgin)</td>
<td>77.5%</td>
<td>22.6%</td>
<td>100%</td>
</tr>
<tr>
<td>HP21&amp;22 (reman)</td>
<td>11.0%</td>
<td>89.0%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Appendix D: Modelled Process Flows

New inkjet cartridge (cut-off point is 2%, i.e. processes contributing to overall footprint less than 2% are not shown)
Remanufactured inkjet cartridge (cut-off point is 2%)