Life Cycle Assessment of a Solid Ink Printer Compared with a Color Laser Printer

Total Lifetime Energy Investment and Global Warming Impact

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Executive Summary

This report summarizes the Life Cycle Assessment of a 40 ppm color solid ink printer and a comparable 42 ppm color laser printer under similar operating conditions. The study was conducted by Xerox Corporation and underwent a detailed peer review[1] to confirm that it adhered to generally-accepted Life Cycle Assessment methodologies. The study assessed the total lifetime energy invested in the manufacture, transportation, use, and end-of-life of the two printers. Global warming impacts were also studied. The assessment concludes that over the product life cycle, the solid ink printer studied exhibited approximately 30% lower Cumulative Energy Demand and Global Warming Potential than the laser printer and created approximately 90% less post-consumer waste.

Goal and Scope

Background

Laser printing technology creates an image by fusing powdered toners to paper. Color laser printers typically include replaceable parts such as photoconductors, transfer rollers, fuser rollers, fuser oilers, and supplies such as toner cartridges and waste toner bottles. The life expectancy of these replaceable parts and supplies is dependent on either the number of pages printed or the amount of each color used per print. Typically in the life of a laser printer, multiple sets of the replaceable parts and supplies are required.

Solid ink printing technology is a relatively new technology, with the first commercial printer introduced in 1991. It creates an image by applying melted ink to paper where it instantly solidifies. Solid ink sticks are melted into the printhead which jets the ink onto the print drum. Paper is passed between a roller and the print drum under pressure and the image is transferred from the print drum to the paper. Since the ink sticks are solid, there is no need to contain the ink in a cartridge, leaving nothing to dispose of when the ink stick has been consumed. The drum maintenance unit is the only scheduled maintained item in the solid ink printer. All remaining parts, including the printhead, are designed to last the lifetime of the device. As a result, solid ink technology requires fewer replacement parts and supplies than laser technology, thus reducing the number of items that need to be manufactured, transported to the customer and ultimately disposed of.

Methodology

A Life Cycle Assessment is an evaluation of the environmental impacts of a product or service over all stages of its life. A Life Cycle Assessment model typically begins with the extraction of raw materials to create the components of a product, and continues through its manufacture, use, and end-of-life disposition; including transportation steps along the way. Various categories of environmental impacts are typically evaluated including: Cumulative Energy Demand, Global Warming Potential, ecological and human toxicity, impacts to air and water quality, and depletion of raw materials.

A Life Cycle Assessment is a well-recognized technique with international standards defining its use. There are four distinct steps of a Life Cycle Assessment:

1. Goal definition and scope.
2. Life cycle inventory of the inputs and outputs that flow to and from the environment during every step of the product's life.
3. Impact assessment that characterizes the effect of the inputs and outputs on the impact categories.
4. Interpretation of results to determine major contributors to the outcome, as well as sensitivity and uncertainty analysis.

1. The full Life Cycle Analysis that this paper summarizes was peer reviewed to ensure it adhered to ISO standards by Scott Matthews and Deanna Matthews of Avenue C Advisors LLC. They are professors of engineering at Carnegie Mellon University, but their review does not represent an official review by CMU.

Goal of Study

The goal of this study was to quantify the differences in environmental impact between current models of two printing technologies, solid ink and conventional color laser. The study was completed using a transparent, internationally recognized Life Cycle Assessment method. The impact categories assessed in this study were Cumulative Energy Demand (CED) and Global Warming Potential (GWP). Cumulative Energy Demand is the total lifetime energy invested in the manufacture, transportation, use, and disposal of a product. Global Warming Potential is a measure of greenhouse gas contribution to global warming of these same activities and is expressed as equivalent carbon dioxide. In the process of completing the Life Cycle Assessment, an inventory of post-consumer consumables waste was calculated. While the impacts of paper use in printing are important, they were excluded from the analysis as they were assumed to be equal for both devices. This study is intended to help designers reduce environmental impacts of future printers and customers make educated printer use and purchase decisions.

Functional Unit

For the purposes of this technology comparison it was assumed that both devices have equal print quality, monthly print volumes, and lifespan: 7,500 prints per month over a four year life. All results and impacts reported for this study are for the entire assumed life of the products, a functional unit of 360,000 prints.

System Boundaries

The scope of this assessment began with the extraction of raw material inputs and the associated processing required to manufacture the printing device and consumables. The study included the use of the device, the packaging and transport of the consumable items (such as cartridges), and their disposal. The included laser consumables were: print cartridges, fusers, transfer kits, and toner collection bottles. The solid ink printer consumables were ink and drum maintenance kits. Service activities during the active life of the product were excluded. The inputs and outputs associated with these excluded steps were assumed to be roughly equivalent between the solid ink and laser printers.

While the impacts associated with the manufacture, transport, and disposal of the paper used for printing is very important, they were excluded from the analysis as they were assumed to be equal for both devices.

Life Cycle Inventory

Assumptions

In order to fill gaps in the available information and simplify the study, a number of assumptions where made during the Life Cycle Inventory phase. Based on market distribution data for these types of products, a 60% US/40% European split was assumed, with energy mix and transportation distances determined accordingly. The solid ink printer is manufactured in Penang, Malaysia. The laser printer is labeled as being manufactured in China and for the purposes of this comparison was assumed to have been made in the major industrial city of Suzhou. Based on the print cartridge's labeled country of origin of Japan, it was assumed that they were manufactured in Tokyo. These locations were used for the calculation of ocean freight distances to the Europe and the United States markets. Materials extraction was assumed to occur 100 miles from the parts manufacturing site. The parts manufacturing site was assumed to be 100 miles from the final assembly site.

The impact of the end-of-life disposition of the products and consumables was calculated using the US Environmental Protection Agency (EPA) Waste Reduction Model (WARM).[2] For this calculation it was assumed that 25% of laser consumables were recycled locally. Although solid ink consumables can be recycled, to be conservative in this comparison, it was assumed that none were. Corrugated packaging for both products was assumed to be 60% recycled content and 40% virgin content, based on internal data. To simplify the WARM model, all packaging waste was modeled as corrugated cardboard and based on EPA statistics for paper packaging it was assumed that 66% of the packaging materials were recycled.[3]

2. U.S. Environmental Protection Agency (2009). *Waste reduction Model* [Version 10]. Available from the EPA: http://www.epa.gov/climatechange/wycd/waste/calculators/downloads/WARM_v10.zip

3. U.S. Environmental Protection Agency Office of Resource Conservation and Recovery (2009, Table 21). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2008.* Retrieved from http://www.epa.gov/wastes/nonhaz/municipal/pubs/msw2008data.pdf

Data Sources

With the exception of end-of-life, the analysis was conducted using SimaPro7, a commercially available and widely used software tool. Internal Xerox manufacturing data was used when available. "Industry average" data from the SimaPro databases was used when Xerox data for material inputs and the manufacturing activities was unavailable. Data from the SimaPro databases was used to account for the manufacture of the raw materials and the processing of these materials in to printer and consumables parts. The energy associated with assembling these parts into printers and consumables was based on internal Xerox data. Xerox data was also used for the specialized processes of turning raw materials into toner and ink.

Operating energy consumption was calculated for both machines using the International ENERGY STAR® Typical Electricity Consumption test method, which is designed to simulate the energy consumption patterns during a typical office work week.[4] The Typical Electricity Consumption test procedure job length was modified to achieve the average monthly print volume of 7,500 images, but otherwise the ENERGY STAR® protocol was followed. The model utilized measured energy consumption values for both machines.

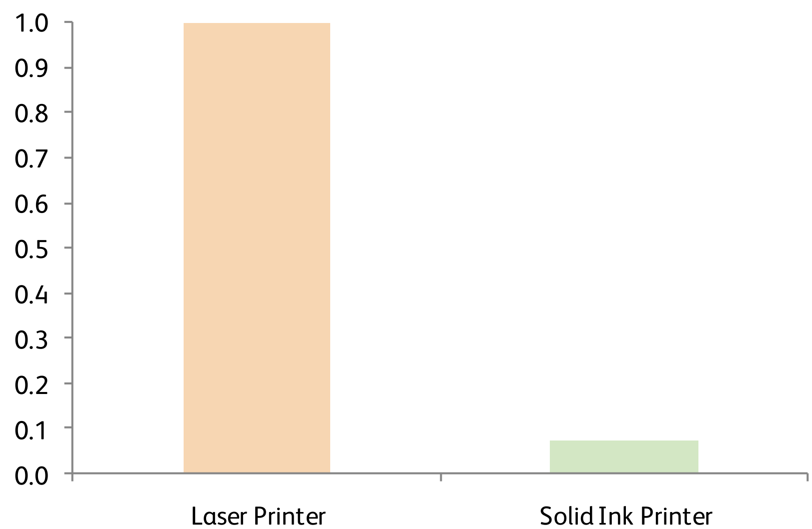
Impacts and Inventories Measured

Prior internal assessments indicate that paper and electricity consumption at the customer site are two large contributors to the environmental impacts of office printing. Since, as previously described, paper use was excluded, two metrics were chosen to evaluate the impact of electricity consumption in the larger context of the life cycle of these two printing technologies. These impacts were Cumulative Energy Demand and Global Warming Potential. In addition to these impacts, an inventory of post-consumer consumables waste was also calculated.

Post-Consumer Waste Inventory

In the process of completing the Life Cycle Assessment, an inventory of post-consumer consumables waste was calculated. This value represents the amount of consumables and consumables packaging, by mass, that a customer must dispose of over the life of the product. It was found that the solid ink printer creates approximately 90% less post-consumer waste than the laser printer (Figure 1).

Figure 1: Relative Post-Consumer Waste Generation



4. U.S. Environmental Protection Agency. *ENERGY STAR® Qualified Imaging Equipment Typical Electricity Consumption (TEC) Test Procedure*. Retrieved from http://www.energystar.gov/ia/partners/manuf_res/Imaging%20Equipment%20TEC_Test_Procedure.pdf

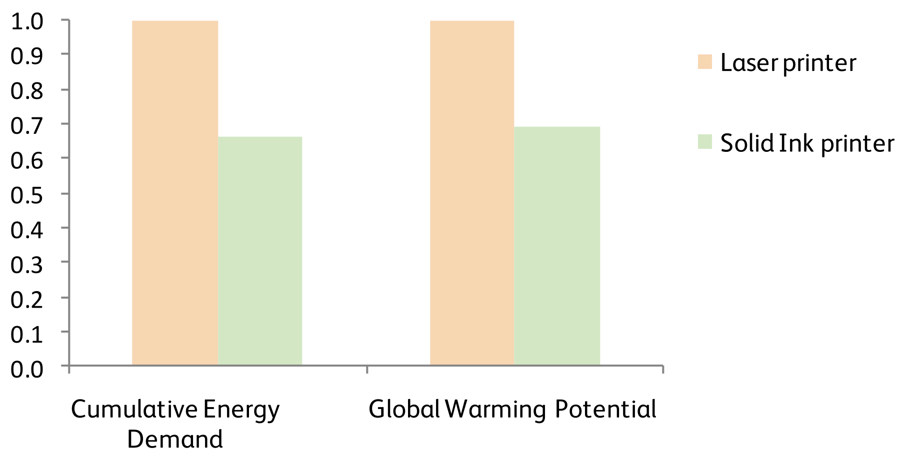
Life Cycle Impact Assessment

Results

The Impact Assessment is used to convert the Life Cycle Inventory (the inputs and outputs of the two printers modeled) to indicators that describe the impact on the environment. In this case, the impacts selected were Cumulative Energy Demand and Global Warming Potential.

Figure 1 shows the normalized contribution of the Cumulative Energy Demand and Global Warming Potential from each printer (Laser = 1). The solid ink printer was found to have reduced Cumulative Energy Demand and Global Warming Potential compared to the color laser printer. Expressed as percentage difference, the solid ink printer exhibited approximately 30% lower Cumulative Energy Demand and Global Warming Potential than the laser printer.

Figure 2: Relative Contribution of Solid Ink Printer Compared to Color Laser Printer (Color Laser =1)



Interpretation of Results

Relative Contribution

The relative contribution of Cumulative Energy Demand and Global Warming Potential varies across the life cycle categories between the two products. Figure 3 and 4 show the relative contribution of the Cumulative Energy Demand and Global Warming Potential expressed across these life cycle categories:

- Use-Phase Electricity: the electricity powering the machine during its day-to-day customer use
- Packaging: the material acquisition and manufacturing of the packaging for both the printer and replaceable units
- Transport of goods and parts in all life cycle stages except end-of-life
- Customer Replacement Unit (CRU): the material acquisition and manufacturing of the customer replaceable units including consumables (ink, toner and cartridges, etc.)
- Printer: the material acquisition and manufacturing of the device itself (excluding consumables and packaging)
- End of Life: the impact offset by recycling some of the materials and sending the rest to the landfill

The largest contributor to the solid ink printer Cumulative Energy Demand and Global Warming Potential was use-phase electricity, but this impact was more than offset by the solid ink printer's low impact in the other categories when compared to the laser printer. The laser printer's impacts were more evenly distributed between categories with the largest Global Warming Potential impact being contributed by use-phase electricity and the largest Cumulative Energy Demand impact being contributed by customer replaceable units. The smaller packaging, transport, and CRU environmental impacts of solid ink can all be contributed to the minimal consumables needed to support printing with this technology.

Figure 3: Relative Contribution of Cumulative Energy Demand by Category

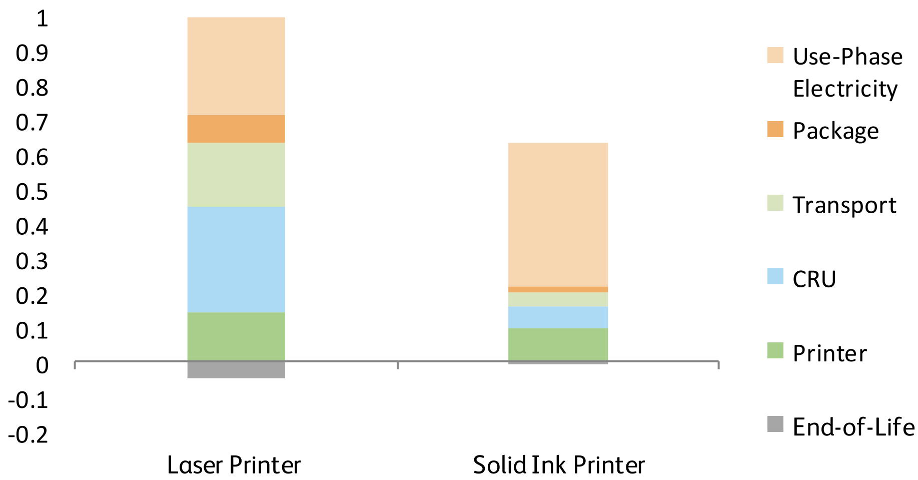
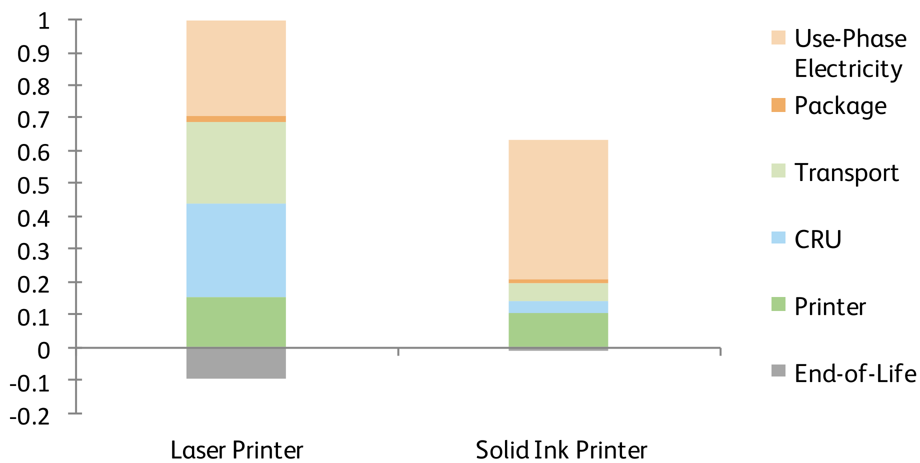


Figure 4: Relative Contribution of Global Warming Potential by Category



Sensitivity Analysis

Life Cycle Assessments (LCAs) are complex mathematical models based on directly measured product characteristics, such as material masses and energy consumption; third party material and process databases; and assumptions made by the LCA practitioner based on research and common industry practices. Due to these complexities, some level of uncertainty in the results is inherent. In an effort to quantify the impact of the major assumptions made in this technology comparison, a sensitivity analysis was completed. This sensitivity analysis measured the output of the Life Cycle Impact model as the inputs were varied. Figure 5 compares the baseline assumption set previously described with alternative assumption sets for the laser and solid devices. All results were normalized against the laser device with the baseline assumptions.

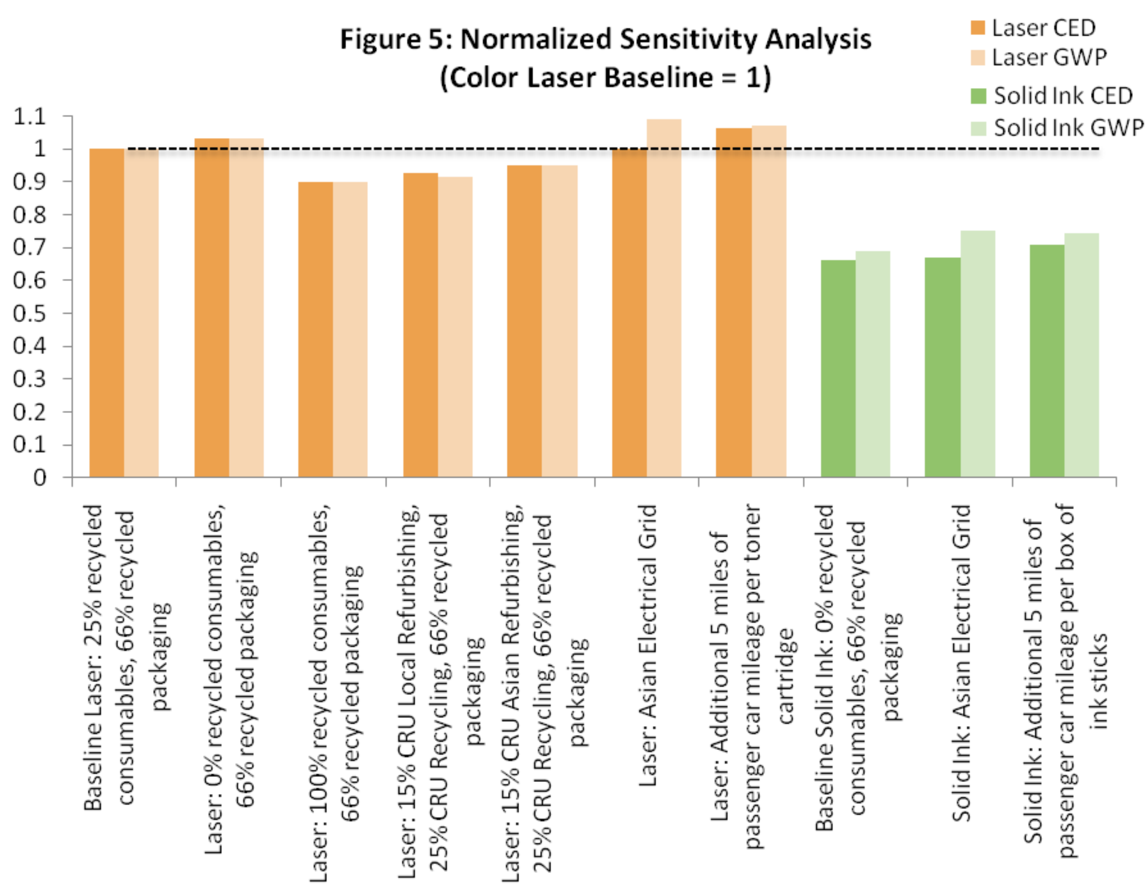
The end-of-life of printer consumables is a frequently discussed printing sustainability topic. Many printer manufacturers, including Xerox, run programs that take back consumables for responsible disposal at the end of their useful life. Due to varying levels of customer participation in these programs and variations in the specifics of how each consumables is processed when it does reach a recycler or remanufacturer, it is important to consider variation in the end-of-life assumptions. To explore the influence of end-of-life assumptions on the larger quantity of consumables required by the laser printer , four alternative assumption sets were modeled for the laser device.

This sensitivity analysis found that even if 100% of the laser consumables were locally recycled the solid ink printer maintained a Global Warming Potential and Cumulative Energy Demand advantage greater than 23%. Further investigation found that if 15% of laser printer consumables were locally refurbished, 25% were locally recycled, and the remaining 60% went to the landfill, the solid ink printer still held an advantage of over 24% in both GWP and CED. If refurbishing or recycling do not occur locally, the benefit of these programs is reduced due to the environmental impact of transportation. For example, transporting 15% of the laser consumables to Japan for remanufacturing while recycling 25% locally, increases the solid ink advantage to over 27% for both GWP and CED. (Figure 5).

In order to be conservative and simplify the end-of-life calculations, it was assumed that 100% of the materials in the laser consumables were recyclable and 100% of the refurbished cartridges could be reused with no new parts or other inputs. If the recycling and refurbishing processes were not 100% efficient as assumed, the reduction in life cycle impact due to recycling and refurbishing would be less.

The materials and processes used in the SimaPro databases were primarily based on European manufacturing data using European electricity. In an effort to quantify the impact of the Asian countries of origin for the printers and consumables and these countries' associated electrical infrastructure, the quantity of European electricity used in the model was calculated. The appropriate Chinese or Japanese electricity was substituted for this European electricity, and the change in impact was calculated. Malaysian electricity data was not available, so China was used as a surrogate. The impact of the country of origin for the electricity was found to have little impact on the conclusion of the study when applied to both printers simultaneously (Figure 5).

The transportation associated with the numerous possible customer consumables purchasing methods will impact the printer lifecycle. For simplicity, this "last mile" was ignored in the baseline comparison. Each printer and consumable was assumed to travel a typical distance by freight truck from a regional port to the customer site. In reality, customers will purchase varying quantities of consumables per transaction and these consumables may be delivered in variety of ways including parcel carrier or the customer's passenger car. This sensitivity analysis found that while customers traveling 5 miles in a typical gasoline passenger car to purchase each print cartridge or box of ink had an environmental impact, it did not change the outcome of the study when applied to both printers equally (Figure 5).



Conclusion

Over the product life cycle, the solid ink printer studied had approximately 30% lower Cumulative Energy Demand and Global Warming Potential and approximately 90% less post-consumer waste than a comparable laser product.

These results are primarily driven by the design of the solid ink printer, which does not require a cartridge for the ink. Due to this fundamental difference in technology, the solid ink printer produces less waste in the customer environment, uses less energy, and contributes less to global warming than a similar laser printer over its life cycle. This study will help designers understand potential areas of improvement for both printing technologies, and help customers make educated decision when purchasing and using their printing devices.

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