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The Environmental Impact Of The Retail Photoprocessing Industry In Santa Clara County: 1996 Vs. 2006

Benoit Delaveau
San Jose State University

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THE ENVIRONMENTAL IMPACT OF THE RETAIL PHOTOPROCESSING
INDUSTRY IN SANTA CLARA COUNTY:
1996 VS. 2006

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San José State University

In Partial Fulfillment

of the Requirement for the Degree

Master of Science

by

Benoit Delaveau

May 2011

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The Designated Thesis Committee Approves the Thesis Titled
THE ENVIRONMENTAL IMPACT OF THE RETAIL PHOTOPROCESSING
INDUSTRY IN SANTA CLARA COUNTY:
1996 VS. 2006

by

Benoit Delaveau

APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

SAN JOSÉ STATE UNIVERSITY

May 2011

Dr. Katherine Kao Cushing

Department of Environmental Studies

Dr. Gary Klee

Department of Environmental Studies

M. Steven Noble

Photo Marketing Association

ABSTRACT

THE ENVIRONMENTAL IMPACT OF THE RETAIL PHOTOPROCESSING INDUSTRY IN SANTA CLARA COUNTY: 1996 VS. 2006

By Benoit Delaveau

Consumer digital cameras appeared on the market in 1994. Consequently, the photoprocessing industry experienced a downturn beginning in 2000, with a sudden drop in activity. This study focuses on the evolution of the retail photoprocessing industry between 1996 and 2006 and evaluates its four major environmental impacts: (1) energy use, (2) associated greenhouse gas emissions (GHG), (3) silver discharge, and (4) water consumption. The main method used for data analysis is based on the ISO 14040 standard for Life Cycle Assessment. The study utilizes data from: (a) impact quantification for two photoprocessing labs in Santa Clara County, and (b) a census of retail photoprocessing labs in Palo Alto Regional Water Quality Control Plant (RWQCP) service area, based on wastewater permits. The analysis indicates that the changes in the activity of local retail photoprocessors correspond to a 43% reduction in energy consumption, a 69% reduction in GHG emissions, a 71% reduction in silver discharge, and a 68% decrease in water consumption. However, concurrent changes in the way people consume photography indicate that county-level reductions in energy use and GHG associated emissions have been displaced due to increased use of other electronic devices, like digital cameras.

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LIST OF ABBREVIATIONS

BAWQCB:	Bay Area Regional Water Quality Control Board
CMP:	Code of Management Practices (for Silver Dischargers)
CO ₂ e:	Carbon Dioxide equivalent (emissions)
CPAU:	City of Palo Alto Utilities
C-41:	Kodak Flexicolor film process
EPA:	(U.S.) Environmental Protection Agency
EP-2 and EP-3:	Kodak Ektaprint color print process
GHG:	Greenhouse Gas
LCA:	Life Cycle Assessment
LCD:	Liquid Crystal Display
LED:	Light Emitting Diode
MGY:	Million Gallons per Year
NPDES:	(U.S.) National Pollutant Discharge Elimination System permit program
OLED:	Organic Light-Emitting Diode
OSHA:	(U.S.) Occupational Safety & Health Administration
PG&E:	Pacific Gas and Electricity
PMA:	Photo Marketing Association
POTW:	Publicly Owned Treatment Works
RA-4/RA-2:	Kodak Rapid Access color print process
RWQCP:	Regional Water Quality Control Plant
SIC (codes):	Standard Industrial Classification issued by OSHA

UWMP: Urban Water Management Plan

Introduction

1.1. Motivations

In the early 2000s, the search for simplification, automation, and optimization of the photographic process eventually led to modern digital photography. This technology resulted in a decline of chemical processing, allowing the instant gratification of on-camera screen visualization and, later, digital social networking on sites like Facebook, Shutterfly, and Flickr. In April 2005, Flickr had 27 million users and hosted 4 million photos. By April 2007, Flickr was hosting 400 million photos. This figure reinforces the year 2006 as the beginning of the mature digital photography era (Cox, 2008).

The hidden consequence of the digital photography revolution means that today's popular photography practices have eliminated the need for conventional processing process, which photographers have used for almost two centuries. The retail photoprocessing industry, commonly called "one-hour-printing shops," experienced a downturn by the end of the year 2000, with a significant drop in the volume of film processed. The majority of snapshots are now shot digitally and only viewed directly on screen. However, since 2002, the retail photoprocessing industry started fulfilling a growing demand: quality prints and photo albums from digital media such as CD, memory cards, or files uploaded from Internet sites.

While the social consequences of the digital photography switch have already been studied, this study focuses on the change that the local retail photoprocessing industry experienced and the direct consequences, in terms of the local environmental

impact. The characterization of the local retail photoprocessing industry activity will help to better explain the local environmental consequences that followed the technological progression of consumer photography from film to digital imaging. More broadly, this research is a case study on digital photography that could help anticipate other future consumer technological changes and foresee their environmental consequences.

1.2. Literature Review

1.2.1. History Timeline

In 1837, Louis Daguerre (1787-1851) invented the first viable chemical process to permanently record and fix an image. Two years later, the French government sponsored the invention called the Daguerreotype—named after the inventor—as a “free gift to the World.” Daguerre published a step-by-step manual to explain in great detail how to replicate the process.

From the early days of the Daguerreotypes to digital photography, the barriers that prevented the expansion of photography, complexity, cost, and toxicity, were mostly technological. For decades, the complex chemical processes and the convoluted methods necessary for accessing the final images limited the use of photography to professionals only.

Figure 1. Unknown Woman with Black Gloves. Portrait on Daguerreotype estimated from the period 1850-1855. From Benoit Delaveau personal collection.

Many different photography-related techniques were invented over the past 174 years of photographic history. The majority of these processes and related equipment are now obsolete. A closer look at historical photography technology reveals what caused some processes to be commercially successful and their subsequent decline or failure a few years later. Over two centuries of photo history, the processes have been technologically modified and re-invented to progressively bring photography to the masses with simpler, faster, and cheaper methods, just as the earlier inventors like Daguerre and Niepce envisioned photography as a “spontaneous reproduction” of the natural world (Batchen, 1999, p. 90).

In the early 1950s, as color photography became popular, only relatively clean processes such as the Kodak chromogenic, Kodacolor, and Ektacolor could answer to the limitless need of popular imagery. Eastman Kodak Co. worked to improve these modern color photography processes between 1954 and 2004, reducing significantly the amount of energy, silver, and water needed to process photographic film and papers (Coote, 1993).

Starting in 2002 and 2003, the majority of photo hobbyists as well as professionals stopped using conventional film technology and embraced digital cameras while reinforcing the strong social roles of photography (Sverisson, 1998). The technological transition was so sudden that all the main players of the photo industry, including Eastman Kodak Co., Fujifilm Co., Agfa GmbH, Polaroid Co., Ilford Ltd, and Konica Corp., all of which dominated the global photography market for decades, ended up in financial trouble.

With the rise of electronic communication, only digital photography could respond to the ever-growing need of photography on the Internet. Digital photography became the dominant system in both professional and popular imaging and remains so today. U.S. market data from Photo Marketing Association International (PMA), the leading professional organization for the industry, show that, from 1996 to 2008, nationwide film processing went down from 715 million to 50 million rolls yearly, while digital camera sales went up from 0.1 million to 30 million units at the same time. The downturn of film processing and the rise of digital cameras are illustrated in Figure 2.

Figure 2. U.S. Photo Industry Market 1996 to 2008. Adapted from market numbers published in “U.S. Photo Industry 2008: Review and Forecast,” by Photo Marketing Association International, 2008, Jackson, MI.

Today, instant gratification is no longer an abstract vision. It drives the demand curve. With the camera embedded in their smart phones, photographers around the globe instantly share snapshots with their friends, uploading photos on social network sites like Facebook. For example, on Halloween 2010, 339 million pictures were uploaded to Facebook in a single day (Times, 2010).

1.2.2. A Modern Industry Based on Kodak Processes

Throughout the history of the photo industry, different processes have been used, but since the late 1970s, the industry standard processes are based on Eastman Kodak technologies, both for color film (C-22/C-41) and color paper (EP-2/RA-4). The historical evolution of these processes is of interest, because from the early industrial phase, the photoprocessing industry constantly innovated to reduce its water and energy consumption per roll of processed film. For the photoprocessing industry, fewer resources always meant lower costs and therefore greater profits.

The American inventor and philanthropist, George Eastman, started his company in 1878, supplying photographic dry-plates to local photographers. Modeled on similar companies in Europe, Eastman's business plan was to produce ready-to-use (sensitized) glass photographic plates for the U.S. market. The genius of Eastman relied on expanding the activity of the company to the production of processing chemicals, photopaper and equipment. This expansion would happen in parallel with the primary aim to create and support a new industry of processing film and plates to a new market demographic: amateur photographers. Eastman founded Eastman Kodak company with the vision of offering user-friendly cameras and film systems to amateur photographers, who could have film locally processed by independent wholesalers or retail photolabs. These labs and shops would in turn use Kodak professional equipment. Within his lifetime, George Eastman built one of the largest American chemical companies.

George Eastman was seventy-two in 1926. By 1926 he employed more than fifteen thousand people. Kodak, the name he coined, had become one of the three largest photographic companies in the world. 'You press the button, we do the

rest' was translated into dozen languages. Genuinely committed to research, Eastman's laboratories had helped make the American chemical industry self-sufficient during the world war, and Kodak was moving towards world leadership in the manufacture of chemicals. (Wensberg, 1987, p. 96)

Constantly re-inventing and optimizing its photographic systems, Eastman Kodak Co. was leading—in fact creating—the photo business in the U.S. Following the snapshot moments, family shots captured with a Kodak camera on Kodak film were processed by Kodak's processing laboratories, and then printed on Kodak photographic paper. Kodak's dominance of the American photo market—at that time one of the largest market for all consumer goods—prepared the company to expand its dominance globally in the 1950s. The innovation capacity of Kodak's Japanese and German rivals was severely impeded by WWII, and Kodak used the window of opportunity to conquer the two other large markets, Europe and Asia. “Before the war, Eastman Kodak had been overshadowed only by Agfa in Germany and Konishiroku [Konica] in Japan. Now [1961] it reigned supreme, its share of the American market is more than 90 percent” (Wensberg, 1987, p. 97).

Thanks to the invention of dye-forming couplers, or chromogenic development, it became possible to create the three primary colors (cyan, magenta, yellow) necessary to obtain a color photographic image in a single processing step, the color developer. Based on this unique technology, the first generation of Kodacolor film was introduced in 1942, and the Ektacolor print paper, based on the same principle, was presented in 1955.

Before 1954, Kodak color film technology was a monopoly. The first chromogenic color film, Kodacolor, was sold with an advance charge for processing in a Kodak affiliated lab. An agreement between Kodak and the U.S. Federal Government signed in 1955 ended that commercial practice. Kodak was forced to open its technology to other players (Times, 1955). By the late 1970's, all Kodak competitors (Agfa-Gevaert, Konica and Fujifilm) agreed to use the same color processes and the same chromogenic technology (C-41 and EP-2/RA-4). In fact, the entire global photo industry started using the processes established by Kodak.

1.2.2.1. Kodacolor Film Process

Following the first anti-trust case of 1955, Kodak agreed to publish its C-22 process specifications and started to sell photochemical kits for the process of Kodacolor film. These were sold to photolabs completely independent of Eastman Kodak company. With Kodak process C-22, it took about 50 minutes to develop color negative film (not including drying time). Seven liters of processing solution and 50 to 200 liters of warm wash water were necessary to process a batch of 12, 35mm, 20-exposures Kodacolor rolls, averaging 16 liters of water consumption per film processed. Kodacolor process C-22 specification is in Table 1 below.

Table 1

Kodak Process C-22 Sequence (1955)

Step	Name	Time	Temp.	Capacity
		min. : sec.	°F	
1	DEVELOPER	14:00	75 °F	6 films per liter
2	STOP BATH	4:00	73-77 °F	12 films per liter
3	HARDENER	4:00	73-77 °F	12 films per liter
4	WASH 1	4:00	73-77 °F	7 to 14 liters per min.
5	BLEACH	6:00	-	12 films per liter
6	WASH 2	4:00	-	7 to 14 liters per min.
7	FIXER	8:00	-	12 films per liter
8	WASH 3	8:00	-	7 to 14 liters per min.
9	PHOTO-FLO	1:00	-	12 films per liter
TOTAL WET TIME		50:00		

Note. Adapted from “Make your own color prints,” by Bagby, 1961, New York: McGraw-Hill, p. 42. Not copyrighted. Eastman Kodak Co. published the original data in the commercial brochures available in 1961.

In the early 1960's, following the launch of the new Kodacolor II film, C-22 was replaced by a new process: Kodak Flexicolor C-41. It was designed for use with processing machines that would allow chemical replenishment proportionate to the surface of the film processed. In optimal normal conditions, a C-41 processing machine needed a volume of 0.360 liters of replenishment processing solution and 6.5 to 7.5 liters of warm wash water, in order to process each 35mm, 20-exposures roll of Kodacolor

film; this averaged 7 liters of water consumption per roll of processed film. The new generation process was not only three times shorter but also conserved 50% of the water required only a few years before. Kodak Flexicolor C-41 specification is summarized in Table 2 below.

Table 2

Kodak Flexicolor Process C-41 Sequence (1962)

Step	Name	Time	Temp.	Replenishment rate
		Min. : sec.	°F	ml per film
1	DEVELOPER	3:15	100 °F	100 ml per film
2	BLEACH	6:30	75-105 °F	84 ml per film
3	WASH 1	3:15	-	7 to 14 liters per min.
4	FIXER	6:30	-	84 ml per film
5	WASH 2	3:15	-	7 to 14 liters per min.
6	STABILIZER	1:00	-	84 ml per film
TOTAL WET TIME		23:15		

Note. Adapted from “Color printing; materials, processes, color control,” by D. A. Engdahl, 1967, Philadelphia: Chilton Books, p. 50. Not copyrighted. Eastman Kodak Co. published the original data in the commercial brochures available in 1961.

The most recent version of the Kodak negative film process chemistry was introduced in 2006: Kodak Flexicolor C-41-RA. It was designed to be used by small to medium capacity (10 to 200 rolls/hours), automated processing machines generally used by retail photoprocessing locations like drugstores or photo stores. No running water is

necessary to wash the film; instead, a chemical step called a *stabilizer* makes the image permanent. In optimal conditions, a C-41-RA processing machine needs a volume of 0.100 liters of processing solution per roll of 35mm film. Kodak C-41-RA specification is shown in Table 3 below.

The latest (2006) Kodak C-41-RA is processing a roll of film 7 times faster, using less energy per film processed, and consuming about 1,000 times less water than the original Kodak C-22 process from 1955.

Table 3

Kodak Process C-41-RA Sequence (2007)

Step	Name	Time	Temp.	Replenishment rate
		Min. : sec.	°F	ml per film
1	DEVELOPER	3:15	100 °F	13 ml per film
2	BLEACH	1:00	95-105 °F	3.5 ml per film
3	FIXER	2:00	-	15 ml per film
4	FINAL RINSE	1:00	-	27 ml per film
TOTAL WET TIME		7:15		

Note. Adapted from the commercial technical guide “Kodak Processing Manuals: Z-101 Process C-41SM and Process RA-2SM,” p. 2.1, Eastman Kodak Co., 2009. Not copyrighted.

1.2.2.2. Kodak Ektacolor Paper Process

Before 1955, when Kodak processing facilities were the only industrial photolabs operating in the country capable of producing color photo prints with high productivity output, the company did not disclose any aspects of its proprietary technology.

Following the first Kodak anti-trust federal action from 1955, Kodak's commercial name for its color printing paper switched from Kodacolor P-122 to Kodak Ektacolor Type C.

The name Type C print is still commonly used to define a color chromogenic print.

“Kodacolor Types I, II and III were used exclusively by Kodak for making prints from amateur's negatives until 1955 when ‘Type C’ paper was made available to photographers using Ektacolor sheet film introduced in 1948. After 1959 Color Print Type C became known as Ektacolor paper in accordance with a [new marketing] ruling” (Coote, 1993, p. 162).

The first Kodak Ektacolor process that was widely used when the photo industry commercially escalated was called *Kodak Ektaprint*; it appeared in the early 1960s with the introduction of the first Kodak resin-coated color paper, Ektacolor 20 RC. With the new resin-coated paper structure, Kodak color process entered the modern era of mass color photography. “Wet processing time was reduced to 20 minutes and drying only added another minute or two” (Coote, 1993, p. 164).

With the perfection of resin-coated color print papers, Kodak Ektacolor 37 RC was designed with a new Ektaprint chemical process named EP-3. This particular process was designed for automated continuous photoprocessors, allowing a larger output than the previous systems, which were only designed to be used manually in tanks.

Wet processing time became a reasonable 10 minutes; however, the water consumption was still high, compared to today's standards. See the specification of Kodak EP-3 summarized in Table 4 below.

Table 4

Kodak Process EP-3 Sequence (1967)

Step	Name	Time	Temp.	Replenishment rate
		Min.: Sec.	°F	
1	DEVELOPER	3:30	88 °F	800 - 1000 ml/m ²
2	STOP BATH	1:00	86-90 °F	800 ml/m ²
3	BLEACH-FIX	1 :30	-	800 ml/m ²
4	WASH	2:00	-	4 to 8 liters/min.
5	STABILIZER	1:00	-	800 ml/m ²
TOTAL WET TIME		10 :00		

Note. Adapted from “Color printing; materials, processes, color control,” by D. A. Engdahl, 1967, Philadelphia: Chilton Books, p. 81. Not copyrighted. Eastman Kodak Co. published the original data in the technical literature available in 1967.

In a move to dominate the retail processing market, Kodak totally redesigned its Ektaprint process with the introduction of the Ektaprint Rapid Access (RA) process in 1986. It became possible to get a color print from negative film in less than 4 minutes, without running water, thanks to a new dye stabilization technology. The critical final wash, based on running wash water, was replaced by chemical stabilization, without any

compromise on long-time permanence of the prints. Kodak color printing technology was ready to enter retail shops all around the world.

In an ultimate optimization in 2006, Kodak shortened the sequence of the original RA-4 process to only 2 minutes of wet time (see Table 5), beating all digital printing systems available at that time, in terms of productivity. With the latest Kodak RA-2 paper process, the volume of water necessary to process a surface of one square meter was limited to less than 0.3 liters, down from 10 liters per square meter with the original Kodak process EP-3. To process Kodak color prints, 30 times less water was needed in 2006, compared to 1967. Time to access the print went from 10+ minutes in 1967 to less than 2+ minutes in 2006, reducing significantly the energy consumption per print.

Table 5

Kodak Process RA-2 Sequence (2007)

Step	Name	Time	Temp.	Replenishment rate
		Min.: sec.	°F	ml/m ²
1	DEVELOPER	0:25	104 °F	64.6 ml/m ²
2	BLEACH-FIX	0:25	104 °F	26.4 ml/m ²
3	STABILIZER	1:30	95-104 °F	193.7 ml/m ²
TOTAL WET TIME		10:00		

Note. Adapted from the commercial technical guide “Kodak Processing Manuals: Z-101 Process C-41SM and Process RA-2SM,” p. 2.1, Eastman Kodak Co., 2009. Not copyrighted.

1.2.3. Size of the U.S. Photoprocessing Industry

In a recent study of the U.S. photoprocessing industry, the U.S. Environmental Protection Agency (EPA) estimates that 296 million square-feet or 700 million rolls of color film, based on Kodacolor process C-41, and 4,130 million square-feet of color photopaper, based on Kodak Ektacolor process EP-2/RA-4, were processed per year between 1994 and 1996 at the peak of production (Matuszko, 2005). These figures include the retail photoprocessing stores (drugstores and independent retail labs) that are credited with 20% to 30% of the total market, which are the focus of this study; as well as wholesale labs (more industrialized and centralized facilities collecting rolls from non-equipped point of sales) that historically had the core of market share. Only the retail photoprocessing part of the industry is the focus of this study, covering the retail locations that are equipped with onsite photoprocessing equipment.

As noted previously, the digital photography revolution started in early 2000. By 2006 the majority of U.S. amateur and professional photographers were using digital cameras. According to PMA, 67% of the U.S. households were equipped with a digital camera in 2006, while only 42% were using them in 2004 (PMA, 2008). Mark DeSimone, president of Qualex, Inc., Druham, NC, a subsidiary of Eastman Kodak, estimated that the U.S. market declined from an average of 700 million rolls in the mid 90s to only 50 million rolls in 2008. This was less than a tenth of the film volume processed a decade before (Lansky, 2008).

1.2.4. U.S. Photoprocessing Industry Energy and Water Use

Energy consumption was not a concern before the recent move for energy conservation to fight global warming. As a consequence, the energy consumption of the photoprocessing has not been documented. However, the water consumed by the photoprocessing industry has always been a major historical concern, due to the massive volume of fresh water needed in the 1950s to process early generations of color film and paper.

The U.S. EPA estimates that the photoprocessing industrial activities created a wastewater discharged of 2,260 million gallons per year (MGY) in 1994, in order to process 716 million rolls of film. These figures were almost flat for the years 1994, 1995 and 1996. By 2003, the rise of digital cameras already significantly impacted the film market, and subsequently the photoprocessing wastewater discharge was down to 1,840 MGY (EPA, 2006). These data include the retail photoprocessing stores as well as wholesale labs.

1.2.5. U.S. Regulation of Silver (Ag) in Wastewater Discharge

Many chemicals found in photoprocessing solutions can impact human health, especially with direct skin contact or ingestion. Numerous guides and operator booklets have been published to educate photographers on how to handle photoprocessing solutions from use to discharge (Rempel, 1992; Shaw, 1991). Other components of photoprocessing solutions were also known for their non-biodegradability, like formaldehyde, used to formulate the stabilizer and the final rinse bath in earlier Kodak

EP-3 and C-22/C-41 processes. By the late 1990s, however, many of the most controversial components were replaced in recent Kodak Ektacolor and Ektaprint processes and other compatible chemicals. For example, formaldehyde was phased out in the early 2000s; and in the bleach bath EDTA was replaced by PDTA, a component that has similar capability but is biodegradable. Thanks to these improvements in photo chemistry, the EPA's latest report about the photography industry, "Technical Support Document for the 2006 Effluent Guidelines Program Plan," concludes that discharge of silver accounted for 99% of the current toxic load discharged by the photoprocessing industry (EPA, 2006).

Beginning in 1990, Publicly Owned Treatment Works (POTW), commonly named *wastewater treatment facilities* had stringent limits in their National Pollutant Discharge Elimination System (NPDES) permits, regulated by the federal Clean Water Act (1972, 1977). As a consequence, among other pollutants, regulators started to monitor the level of silver compounds and their effluents, and pointed the photoprocessing industry as a significant contributor. A study published in 1997 by Purcell and Peters estimated that in 1978, 25.5% of the total amount of silver compounds discharged into the environment originated from the photoprocessing industry. Other sources of silver identified included dentists, medical imagery (x-ray) facilities, scientific labs, and other industries like windows and mirror manufacturers.

In modern color photoprocessing, based on chromogenic developers (Kodak EP-2/RA-4, C-41 and E-6), silver is removed from the sensitized material (film or photo paper depending of the process) during the process. Silver in its ionic state (silver

thiosulfate ions, predominantly $\text{Ag}(\text{S}_2\text{O}_3)_2^{-3}$ and $\text{Ag}(\text{S}_2\text{O}_3)_3^{-5}$ is carried out by the overflow of used photoprocessing solutions, mainly bleach, fixers, stabilizers and wash waters (Purcell & Peters, 1998). Without the treatment of a silver recovery unit, these solutions are discharged in domestic drains and end up in local wastewater facilities. The unstable silver thiosulfate ions quickly convert to silver sulfide and settle in the wastewater sludge or in the water treatment facility outflow, which is discharged after secondary or tertiary treatment in the environment. Purcell and Peters insist that an “effective use of silver recovery technologies in the photographic processing industry could result in effluent streams from the facility generally containing less than 3ppm total silver” (Purcell & Peters, 1998, pp. 543-544). They therefore recommend this option of control at the source, as a general way to mitigate silver pollution.

Luoma, Ho and Bryan studied the toxicity of silver compounds in specific environment of estuary zones. They focus their study on the San Francisco Bay, internationally known for its record-high silver contaminant levels. Their conclusion clearly observes, “Toxicity for sensitive marine species occurs at absolute concentration as low as those observed for any non-alkylated metal, partly because bioaccumulation increases so steeply with contamination. The environmental window of tolerance to Ag in estuaries could be narrower than for many elements. The chemistry and bioavailability of Ag contribute to its high toxicity in marine and estuarine waters” (Luoma, Ho, & Bryn, 1995, p. 44).

According to another study by Warila, Vatterman and Passino-Reader, published in 2001, plankton, bivalves, fishes, and other forms of marine life are highly sensitive to

traces of ionic silver in the environment. In its ionic form, as silver thiosulfate carried by silver-bearing used photoprocessing solutions, silver is highly toxic to aquatic organisms even at very low concentrations. The scientific consensus is that the ionic state of silver is not stable, and when discharged in a water treatment stream, it quickly converts to silver-sulfide compounds – whose eco-toxicity is lower than the primary form. Whatever form silver takes, the scientific community has come to the agreement that the presence of silver compounds in estuary or wetland environments has a potential for a significant disturbance of the entire food chain and ecosystem. Some species, however, are more susceptible to silver poisoning than others, like clams for instance. Warila, Vatterman and Passino-Reader conclude the study by noting that in the San Francisco Bay Area, salmon may be one of the species that could be affected by silver pollution, “The highest Ag concentrations predicted in water may pose chronic risks to early survival and development of salmonids” (Warila, 1991, p. 440).

After almost three decades of research and controversy on silver and the environment, repeated studies indicate that the ionic silver discharged by the photoprocessing industry is rapidly transformed in sulfide compounds, whose ecotoxicity on fish particularly have been proven relatively mild. However, the original ionic form of silver discharged in photoprocessing effluents is a major potential source of natural disruption for almost all types of marine life, plants included.

Ultimately, the photographic industry’s response to environmental pressure was organized in 1997, in the form of an industry-wide silver control voluntary program, summarized in the document, “Code of Management Practices for Silver Dischargers”

(CMP). In the introduction of the CMP published by the Silver Council, the photography industry explains the motivations to recover silver from all used process solutions as follows: “1. Silver is a non-renewable resource 2. Some sewage treatment plants and states restrict the amount of silver that can be discharged 3. Silver has economic value. Depending of the size of the facility, 90% to 99% of the silver can be recovered either by investing in recovery systems or by collecting the processing solutions overflow and send it to specialized treatment facilities” (Silver Council, 1997, p. 1). It is significant to note that none of the official reasons that motivated the photography industry’s plan to control its silver discharge mention ecotoxicity or environmental concerns.

By contrast, in the report “Silver Reduction Pilot Program,” published by the Palo Alto Regional Quality Water Control Plant, the four reasons listed to implement the program are: (1) high exceedance in the concentration of silver in the wastewater facility effluents (over 400% of the authorized limit of 2.3 micrograms per liter), (2) evidences of higher concentration of silver in clams (*Macoma Balthica*) collected at Sand Point 1 km south of the wastewater plant discharge channel, (3) the fact that silver is considered a precious metal and its recovery at the point of discharge would have “the most significant economic incentive to implement a source reduction,” and (4) the fact that “most of the silver comes from a single source—photoprocessing” (Palo Alto RWQCP, 1991, p. 3).

The photography industry never acknowledged the potential environmental risks associated with its silver discharge into the environment, citing the body of research that in its free ionic form—the more toxic form—silver is not stable in the environment; this supported the idea that there was a limited environmental threat associated with

photoprocessing activities. Years of data collection, however, show abnormal silver concentration in sediments, plants and clams around several points of sewage discharge, even when these water treatment facilities use tertiary treatment.

By 2000, some Publicly Owned Treatment Works reported the benefits of the implementation of the silver control program, envisioned a few years before in the photo industry CMP. In its 2006 report, the EPA notes, “Four POTWs documented loading reductions of 20 to 52% over historical baseline after the CMP implementation” (EPA, 2006, p. 22). The level of silver pollutants in San Francisco Bay, where a majority of Santa Clara County (zone of research) wastewater ends, has been a subject of study for decades. The measured levels of silver in San Francisco Bay water have always been considered very high. A.R. Flegal, C.L. Brown, S. Squire, J.R.M. Ross, G.M. Scelfo, and S. Hibdon, explain the historical problem this particular water basin had with silver accumulation. The authors critically review 20+ years of silver monitoring in the San Francisco Bay, and acknowledge a decline in silver within sediments, as well as in sampled living organisms over the years. In their latest study from 2007, despite noticeable progress the level of silver toxicity on marine life, they estimate that the level of silver pollution in San Francisco Bay is still significant.

The remarkable consistency in biological response in two independent and separate episodes (seen in *C. amurensis* in the North Bay and *M. petalum* in the South Bay) also strongly points to silver as a potential disrupter of reproduction in bivalves at concentrations well below those typically used in toxicity tests. (Flegal et al., 2007, p. 46)

The authors conclude that the policies in place are efficient, but a long-term monitoring program must be maintained to understand the evolution of silver pollution in the San Francisco Bay (Flegal et al., 2007).

1.2.6. Life Cycle Assessment on Photography

In Michael Muir's thesis, "Lifecycle Assessment for Strategic Product Design and Management" digital and film photography are compared in terms of environmental impact. He notes, "Simplistically, one might say that the use of a digital camera has a lesser environmental burden than the use of a reloadable film camera, because the image produced as a result of using a digital camera avoids chemicals in film development" (Muir, 2006, p. 7). In Muir's study the entire lifecycle from camera and equipment production to their end of product life [usability] is aggregated. Muir used a Life Cycle Assessment (LCA) approach to compare film and digital photography impact in four categories: (1) energy use, (2) greenhouse emission, (3) water use, and (4) waste generation. Muir's study was derived from public LCA databases, as well as private data provided by Eastman Kodak Co., the only U.S. company that is involved in the manufacturing of conventional film/paper material, as well as digital cameras.

According to Muir, a film-based photographer whose film is processed by a retail photoprocessing store uses 60% more energy and produces 70% more greenhouse emissions than if the same photographer used a digital camera and viewed the photographs on a computer with an LCD monitor—two of the 10 usage scenarios explored in the study. In this case, a functional unit of one 4x6" print produced by a retail

photolab from color film is compared to a functional unit of 10 minutes of display time on a computer equipped with an LCD screen.

In terms of water use, the digital camera/LCD screen scenario consumes 35 times more water than the conventional film/print option, even when the water cost of manufacturing all the needed electronic equipment is statistically weighted; since equipment like computers are used for many other tasks during their lifetime. The manufacturing processes of electronics, microprocessors, LCD screens and CCD sensors are still highly intense in terms of water use. The assumptions made by Muir in this scenario is 10 minutes of display time and 2 minutes of processing/uploading time per image with a PC lifetime of 331,200 minutes.

While Muir's study aggregates the main impact of the two systems during the entire product lifecycle, it should be noted that some impacts have global consequences, such as global warming emissions; while some others have local consequences, like energy consumption or water use. This research contrasts Muir's comparative LCA on film/digital photography but differs in the following:

- The focus is on local impacts only: energy consumption, silver discharge, and water use.
- This study is based upon real field data collected at the point of sale / processing, rather than database information.

1.3. Study Questions

The goal of this study is to quantify and study the changes that occurred between 1996 and 2006 concerning energy, silver discharge, and water consumption for the retail photoprocessing industry within the limits of the County of Santa Clara, California. Comparing 1996 and 2006, respectively, will provide evidence for significant measurable changes.

Specific goals of the study include: (1) quantification of the amount of energy used, (2) quantification of CO₂e emissions generated to produce this electricity, (3) quantification of the total water used, and (4) estimate of the silver inventory for the years 1996 and 2006, respectively. A comparison of the results calculated between the two years studied evaluates the evolution of the impact and potential environmental consequences.

The overarching study questions addressed by this research:

- (1) How much energy and water were consumed for two case study retail photoprocessing labs in Santa Clara County in 1996 versus 2006? What quantity of associated CO₂e emissions were generated? How much silver was discharged?

- (2) How much energy and water were consumed by the retail photoprocessing industry in Santa Clara County in 1996 versus 2006? What quantity of associated CO₂e emissions were generated? How much silver was discharged?

(3) What are the implications of county-level findings for the retail photoprocessing industry nationally and the larger photo industry?

Results of the literature review indicate that the technological switch from film to digital cameras led to significant reduction in energy consumption, lowering total silver-based discharge in the environment, and a decrease in overall local water consumption between 1996 and 2006.

Research Design

2.1. Definitions

The U.S. Environmental Protection Agency defines the photoprocessing industry as follows: “Establishments that are engaged in providing the following services: portrait photography for the general public, commercial photography, commercial art or graphic design; or photo finishing” (EPA, 2006, pp. 19-21). The EPA definition includes four Standard Industrial Classification (SIC) codes (7221, 7335, 7336, 7384). The SIC codes identify segments of the industry that are regulated by the U.S. Occupational Safety and Health Administration classifications (OSHA) from the U.S. Department of Labor.

This study focuses on the retail photoprocessing industry, which is defined as shops, stores, drugstores and super stores offering onsite photoprocessing services. The primary family of businesses that is the focus of this study is SIC 7384 (Photofinishing Laboratories). As professional photographers may also have participated in photoprocessing commercial activity, SIC 7335 (Commercial Photography) and SIC 7221 (Photographic Studios) were included to collect the data for this study.

However, contrary to the EPA definition, establishments classified under SIC 7336 (Commercial Art and Graphic Design) are not included in this study, as activities in this sector are not relevant to photoprocessing.

2.2. Zone of Study

The zone of study is the County of Santa Clara, California (see Figure 3). Santa Clara County is an area also referred to in popular culture as “Silicon Valley.”

Figure 3. Map of the San Francisco Bay Area, and Santa Clara County. Original drawing published in the County of Santa Clara Annual Report, 2009. Digitally transformed and enhanced to add all the study related information (legends, study zone borders and the two data collection locations). Not copyrighted.

Santa Clara County's population was 1,682,585 (U.S. Census Bureau, 2000) including 15 incorporated cities: Campbell, Cupertino, Gilroy, Los Altos, Los Altos Hills, Los Gatos, Milpitas, Monte Sereno, Morgan Hill, Mountain View, Palo Alto, San José, Santa Clara, Saratoga and Sunnyvale (County of Santa Clara, 2009).

This particular zone of study is relevant to the study's research questions on several levels:

- (1) Since the concentration of silver-related pollution was considered very high in the south of the San Francisco Bay, the city of Palo Alto regional water quality control plant—located within the study zone—was the first POTW in the country to implement a pilot program to control silver emissions at the source of production (photoprocessing locations), as early as 1991.
- (2) The majority of the outflow of the two main POTWs that operate in the study zone is discharged into the San Francisco Bay, an estuary marine environment known to be highly polluted with heavy metals due to its topography; among these pollutants are silver compounds generated by photoprocessing activities. An unusual portion of the San Francisco Bay water outflow is by evaporation, making it highly susceptible to heavy metal pollution, with concentration naturally occurring over the years (U.S. Army Corps of Engineers, 1996).
- (3) Water supply is particularly scarce in this region, especially during spring and summer seasons, when the photoprocessing industry activity peaks and therefore demands more water. Under the current round of Urban Water Management Plans (UWMP) due by July 1, 2011, local water agencies must identify how they plan to reduce

their potable water use by 20% per capita by 2020, in accordance with the 2009 legislation, California SBX7 7 (Association of California Water Agencies, 2009, para. 1).

2.3. Data Acquisition

This research targets data from two specific years, 1996 and 2006. In 1996 film photography and photoprocessing activity were at their peak, before the popular success of digital cameras. According to PMA, 67% of the U.S. households were equipped with a digital camera in 2006, while only 42% were using digital in 2004. Therefore, 2006 is seen as the year that the digital camera market became mature in the U.S. (PMA, 2008).

The first phase of data collection involved acquiring data from two photoprocessing labs and conducting an analysis of energy consumption, silver discharge inventory, and water use audit, based on the labs available records (Sections 3.1. and 3.2.). To assess study questions 2 and 3, the study conducted a census of the retail photoprocessing locations within a portion of the study zone for the years 1996 and 2006, respectively using Palo Alto Regional Water Quality Control Plant (RWQCP) permit database. From this database, the number of retail photoprocessing business per capita was estimated. From the same database, the study then calculated the associated volume of spent silver-bearing photoprocessing solution discharged yearly for Palo Alto RWQCP service area (Section 3.3.).

With these two sets of quantitative data, in Section 3.4., the retail photoprocessing industry total use of energy consumption, silver discharge, and water usage is calculated for the years 1996 and 2006, respectively, for the County of Santa Clara, California.

To assess study question 3, I built on my own culture of the photography industry, my previous education in photography related sciences, and my numerous informal discussions with local photoprocessing businesses managers and other photo industry colleagues whom I met the past two years while visiting the professional tradeshow organized in the U.S. (PMA) and in Europe (Photokina).

2.3.1. Case Study LCA at the Facility Level

This study focuses exclusively on energy use, CO₂e related emissions, silver discharge, and water consumption of two selected retail photoprocessing facilities. The ISO 14040 directives and recommendations are used in this study as a framework to assess a limited range of data that are site specific.

Life Cycle Assessment is an ISO (International Standard Organization) standardized framework, designed to investigate industry's environmental impacts and use of resources. The methodology is published under the references ISO 14040, titled, "Environmental management - Life cycle assessment - principles and Framework." The document was originally published in 1996 and revised in 2006. As described in ISO 14040, Life Cycle Assessment is a standardized approach based on four precisely defined steps: goal and scope definition, inventory analysis, impact assessment and interpretation of results, which have been developed to "better understand and address the possible impacts associated with products, both manufactured or consumed" (ISO 14040, 2006, p. V).

Data collection and the evaluation process are comparable to ISO 14040 procedures; but they differ in the fact that the system boundaries are strictly limited to the two sites studied. The two production sites are chosen according to three prerequisites: (1) they are located within the study zone, (2) they operated in 1996 as well as in 2006, and (3) they were still in business in 2010, the time of data acquisition. Although other businesses were approached to participate as point of data collection, only these two retail photoprocessing facilities qualified with all three prerequisites.

The goal for each site-specific data collection is to quantify and compare the environmental impact generated by a typical retail photoprocessing business in the years 1996 and 2006. The environmental impact categories are energy use, CO₂e emissions, water consumption, and silver discharge. The objective quantifies and illustrates how the transition to digital cameras has modified the uses and needs of the local photoprocessing industry for these resources.

The two sites selected are very different in nature: The first (Lab #1) is the largest photoprocessing facility in the San Francisco Bay Area region, which is still operating at the date of the study. Lab #1 is located in downtown Palo Alto, California. The second (Lab #2) is a smaller, family-operated retail business that also survived the downturn of the industry. Lab #2 is located in downtown San José, California. The names and exact locations of these two businesses are not disclosed in honor of the agreement with Lab #1 and Lab #2 owners, both of whom agreed to disclose the needed data regarding their businesses.

The two site-specific data collections have system boundaries defined as follows: Quantification of the flow is limited to the location of the photoprocessing production site and the equipment dedicated to commercial photography processing and printing. For example, electricity and water use is only evaluated for the photoprocessors in use during the two years studied, 1996 and 2006, respectively. Each site-specific dataset is based on information recorded by staff members and the local water quality control agency permit database.

Each site-specific dataset is published as part of this thesis, written for the Department of Environmental Studies of San José State University, in partial fulfillment of the requirement for the degree master of science. The thesis is available to all the participant business owners, as well as the thesis committee.

The functional unit used in this study is defined as follows. Each impact is normalized and related to a unit of 25 pieces of 4x6” prints. The logic for this choice derives from the average print size produced from a roll of processed film, which has been 4x6” since the end of 1980s. Although orders from digital files have a more variable number of prints, digital camera users are still ordering predominantly 4x6” prints. Results anticipate an overall decrease in the local photoprocessing environmental impact, in the four areas studied, due to the public transition to digital cameras.

2.3.2. Census at the Wastewater Plant Level

In 1989, the city of Palo Alto wastewater facility discharged an estimated 4,000kg of metal in the San Francisco South Bay. As a result of this documented violation of the

U.S. Federal Clean Water Act, the city of Palo Alto was required by the Bay Area Regional Water Quality Control Board (BAWQCB) to start a pilot source reduction program covering the five cities within its service area (East Palo Alto Sanitary district, Los Altos, Los Altos Hills, Mountain View, Palo Alto and Stanford University). The city of Palo Alto ordinances went into effect by September 30, 1991, regulating for the first time in the country all the facilities that were using photoprocessing chemicals (EPA, 1993).

The Palo Alto RWQCP permit database is the primary source used to conduct the census of the photoprocessing facilities operating in 1996 and 2006, within its zone of service. In 1996, their procedures and records were already fully operational since the program had been implemented in 1991. The retail photoprocessing facilities are isolated from other type of facilities using photoprocessing solutions with their SIC code registration number, as described in Section 2.1. All the facilities registered with SIC codes 7384 (Photofinishing Laboratories), 7335 (Commercial Photography), 7221 (Photographic Studios) within the Palo Alto RWQCP permit database are included in this study census.

In the Palo Alto RWQCP database, the photolabs are divided into two different types: The “hauling” facilities are where all the silver-bearing effluents are collected by an approved refiner subcontractor, to be treated at a central offsite location. The “permitted” photolabs own or lease a silver recovery unit and run it as part of their process, to recover the silver content of their outcoming effluents themselves. The two

types of photolabs receive an annual permit and must declare the volume of silver-bearing solutions that were either hauled offsite or treated onsite (see Appendix 1: RWQCP Hauling Certification and Appendix 2: RWQCP Annual Report for Silver Treatment).

With complete access to this database, I was able to assess the number of retail photoprocessing facilities in 1996 and 2006, respectively, as well the volume of silver-bearing solutions that each facility had declared using during these two years. These data are compiled in Section 3.3., to estimate the evolution of the retail photoprocessing industry activity within Palo Alto RWCQP service area between 1996 and 2006, respectively.

Another water treatment agency that operates as RWQCP within Santa Clara County is the San José / Santa Clara Water Pollution Control Plant. Lab #2 is connected to the San José / Santa Clara Water Pollution Control Plant. Starting in 1995, San José officially qualified silver as “pollutants of particular concern due to their potential on the South Bay” (City of San José, 2006, p. 11). Like Palo Alto, in the San José water treatment service area, a maximum allowable discharge limit concentration of 1 mg/L was established. Regulations modeled from the City of Palo Alto pilot test obligates all photoprocessing operators in San José to acquire a permit; but also to provide regular monitoring data about their silver recovery installations if they treat their silver-bearing photoprocessing solution on site. This mandatory monitoring includes an analysis of all their photoprocessing solution discharged by an independent laboratory (City of San José,

2006). The San José silver permit database was not surveyed due to the size of the anticipated volume of data from such a large community, the later implementation date of the monitoring program (1995), and the quasi-similar legislation framework, compared to the City of Palo Alto for the same metric.

2.3.3. Scaling Methodology

Three steps were necessary to scale the impact studied in this research and estimate findings for the entire County of Santa Clara.

(1) The impacts related to photoprocessing activity (energy use and greenhouse gas emissions related, silver discharge and water consumption) are evaluated at the facility level, by conducting an assessment of Lab #1 and Lab #2 activity in Sections 3.1. and 3.2. Data are normalized according to the chosen functional unit and related to the volume of silver-bearing photoprocessing solutions used annually by Lab #1 and Lab #2.

(2) A census of all photoprocessing facilities operating in the city of Palo Alto RWQCP service area is conducted using the silver control permit database. The volume of silver-bearing photoprocessing solutions used annually in the service area is calculated in Section 3.3., including the five cities covered by the service area of Palo Alto municipal wastewater facility (East Palo Alto Sanitary district, Los Altos, Los Altos Hills, Mountain View, Palo Alto and Stanford University).

(3) In order to estimate the total impact for the entire County of Santa Clara, the volume of silver-bearing photoprocessing solutions used annually (estimated in step 2 for the five cities of Palo Alto RWQCP service area) is expanded, according to a population

ratio between Palo Alto RWQCP service area and Santa Clara County. The basis of this calculation use population data from the 2000 census. The volume of silver-bearing photoprocessing solutions used annually for the entire Santa Clara County is then related to the normalized impact calculated in step 2 from Lab #1 and Lab #2 assessments. These volumes then estimate the photoprocessing industry energy use, Greenhouse Gas (GHG) emissions related to energy, silver discharge and water consumption at the county level. The same calculations are computed for the years 1996 and 2006, respectively. The results between the two periods are then compared in Section 3.4.2., to analyze the differences and respond to the three study questions formulated in Section 1.3.

2.3.4. Units and Notations

These study assessments are based on metric units listed as follows.

Water (input) and water (output)-----	liters (L)
Photoprocessing solutions -----	liters (L)
Energy (electricity) -----	kilowatts hour (kWh)
Emissions (CO ₂ e) -----	kilograms (kg)
Silver (Concentration) -----	milligrams per liter (mg/L)
Silver (Total emission) -----	grams (g)

2.4. Study Limitations

This study is designed to estimate only local environmental impacts within the study zone, Santa Clara County. Energy generation, CO₂e emissions, silver discharge, and water use are environmental impact categories that are of significant local importance. Comments regarding links from local to global impacts, in terms of the transition to digital photography, will be included—especially regarding global warming emissions.

This study, however, is not quantifying photoprocessing related to environmental impacts that are not occurring during the time-frame (years 1996 and 2006), or whose consequences are not impacting the study zone (Santa Clara County). For example, the expected increased volume of e-waste generated by the use of digital cameras is not studied, since it is likely to have an impact outside of the study's time frame and the study zone. The global impact generated by producing film, or the photopaper used for the printing process are also not studied for the same reasons.

2.5. Significance

Following years of downsizing due to a transition from film cameras to digital cameras that started in early 2000, the remaining retail photoprocessing facilities focused on providing a convenient way to print high quality photo prints from digital files. The consensus among photo professionals is that the future of this industry is in digital printing. Consequently, the future of the photoprocessing industry depends entirely on

improving the convenience and the costs of the digital printing services it provides consumers.

Current digital printing technologies use conventional photosensitized paper, the same material that was also used to print from film. Therefore, the environmental impact generated at the lab level is similar whenever prints originate from film or digital cameras. This study aims to measure what the environmental impact were before and after the digital camera market switch at the lab level.

In 2010, Hewlett-Packard, Epson, Noritsu and Fujifilm presented a new generation of commercial photo printers—drylabs—based on inkjet technologies. For the first time in the history of color photography, a printing technology that was not based on traditional silver-halide sensitized material started to be seen as a credible alternative to classic, wet photoprocessing technologies, offering a competitive productivity output as well as a comparable cost reduction per print. Since alternative printing technologies are now available, it is crucial for the retail photoprocessing industry to re-assess the environmental impact linked to the conventional processing methods used for the past four decades, based on Kodak processes described in Section 1.2.2.

Energy use is critical to monitor since global warming has become a state priority with AB32, the California Global Warming Solutions Act of 2006. AB32's goal is to revert to 1990 levels of CO₂e emissions by 2020. As electricity generation is a major source of CO₂e, it is important to study whether the photoprocessing industry will prevail with California's goals.

The controversy around silver discharged by the photoprocessing industry in the San Francisco Bay is no longer argued, since the implementation of the source control monitoring policies were proven efficient in reducing large quantities of silver found in the surrounding wetland environment. If the photoprocessing industry could switch to a new generation of printing process that does not use silver-bearing solutions, the benefits could be twofold, since the silver recovering processes in place are complex and costly; and they imply transportation and energy-intensive processes that, by themselves, are linked to major environmental issues.

The photoprocessing industry water use is of particular importance since water supply is scarce in the region of the San Francisco Bay Area (see Section 2.2.). Drylabs may be the next technological innovation for this industry in the near future, if the volume of water consumed using conventional printing technologies are considered unsustainable.

Results

3.1. Case Study LCA Lab #1

The following sections are labeled and organized in accordance with ISO standards (ISO 14040, 1997).

3.1.1. Lab #1 Inventory Analysis

3.1.1.1. Lab #1 Description

The following LCA studies the environmental impact (electricity use and GHG emissions linked to electricity generation, silver discharge and water use) related to retail photoprocessing activities for one specific photoprocessing store located in downtown Palo Alto, California. Standardized LCA methods are applied to process the data collected for the years 1996 and 2006, respectively. The characterization of this specific retail photoprocessing business, defined as Lab #1, and the evolution of its photoprocessing commercial activity between the years 1996 and 2006, reveals the environmental consequences that followed the technological switch of consumer photography from film to digital cameras. Figure 4 displays Lab #1 location and main building.

Figure 4. Lab #1 Main Building as in March 2010. Photo by Benoit Delaveau.

A typical retail photo business uses two main production equipment systems, a film processor and a printer/paper processor. Lab #1 production equipment includes processors for the two years studied, as detailed bellow.

A film processor is a type of equipment that is designed to process film encapsulated within a roll cartridge. A film processor is solely dedicated to processing film, therefore it is not used for print orders from digital cameras. In 1996, Lab #1 was equipped with a large capacity film processor, an Agfa FP3-72; it has a nominal process capacity of 72 rolls of 35mm [24-exposures] per hour. In 2006, Lab #1 used a smaller

film processor from the same manufacturer, an Agfa FP210 with a nominal process capacity estimated to 30 rolls of 35mm [24-exposures] per hour (Agfa FP210, 2001).

Figure 5 shows the Agfa FP210 film processor installed in March 2010.

Figure 5. Agfa FP210 Film Processor as Installed in March 2010 at Lab #1. Photo by Benoit Delaveau.

A printer/paper processor is a type of equipment used to produce regular size 4x6" or larger size color prints. In 1996 Lab #1 was equipped with three printer/paper processors, two Agfa MSC 3.2 for prints size 4x6" and 5x7", and one enlarger/paper processor, Agfa ML2000 for sizes up to 12x18". Lab #1 started offering printing services to digital camera customers as early as 2001, when a new generation of printer/paper processors (Agfa D-Lab) were installed. In 2006, Lab #1 printer/processors included two Agfa D-Lab 2 (size up to 12x18") and one Agfa D-Lab 3 (regular prints 4x6" and up to 8x12"). Between the two years studied (1996/2006), the overall total hourly printing capacities were the same between the two years (Agfa D-Lab 2, 2001; Agfa D-Lab 3, 2001). Figure 7 shows the Agfa D-Lab 3 in production at Lab #1, as of March 2010. Table 6 below summarizes Lab #1 production equipment list.

*Figure 6. Agfa D-Lab 3 Printer/paper Processor as Installed in March 2010 at Lab #1.
Photo by Benoit Delaveau.*

Table 6

1996 / 2006 Lab #1 Production Equipment List

	Film processor (C-41)	Printer/Processor (RA-4)
1996	Agfa FP3-72	Agfa MSC 3.2 Agfa MSC 3.2 Agfa ML-2000
2006	Agfa FP210	Agfa D-Lab 2 Agfa D-Lab 2 Agfa D-Lab 3

3.1.1.2. Lab #1 Functional Unit and Flows

The chosen functional unit (F.U. = 25^{ex} 4x6" prints or an equivalent surface of photo paper) makes printing services comparable, whether the input is from film or digital media; and therefore makes the comparison between the years 1996 and 2006 possible and quantifiable.

Quantification of the flows is limited to the location of the photoprocessing production site and the related equipment, which is dedicated to commercial photography processing and printing. For example, electricity and water consumption are only evaluated for the photo production equipment in use during the two years studied, 1996 and 2006. The site-specific data come from technical information recorded by staff members, and Lab #1 local water agency permit records.

3.1.1.3. Lab #1 System Boundaries

Lab #1 processors were plugged into electricity and water main supply lines provided by the City of Palo Alto Utilities (CPAU). Overflow from the processors, defined as the used photochemistry solutions, are separated between non-silver-bearing (developer) and silver-bearing solutions (fix, bleach-fix and stabilizer). The silver-bearing solutions are confined within the building until treated in a silver recovery unit. Once the residual liquid waste meets the local silver regulation threshold, it is drained into Palo Alto's main wastewater facility. The system boundaries chosen for this study are limited to Lab #1 main building facility, which integrates all the processor listed in Section 3.1.1.1., as well as the silver recovery unit.

3.1.1.4. Lab #1 Flowcharts

The flowcharts for Lab #1 are organized as follow: Symbolized by the “INPUT” arrows at the top of Figures 7 and 8 are the raw materials that the processors (2) and (3) consume. Each processor needs fresh water, energy (electricity), and photoprocessing chemistry, C-41 for the film processor and RA-4 for the printer/paper processors. In 1996, images were taken only on film (1), which is illustrated on the left of Figure 7 and Figure 8. In 2006, upcoming orders were sent to Lab #1 either from film or digital files, as illustrated on the left of Figure 8.

Listed as “OUTPUT” are the byproducts of the two processors, liquid waste (processor overflows or used photoprocessing solution), CO₂e emissions (an indirect byproduct linked to electricity generation), and silver discharge. Originally embedded in the host material (photosensitized film or paper products), up to 99% of the silver is recovered from the used processing chemistry solutions by the silver recovery unit (4). The unrecovered part (less than 1%) is discharged within the treated effluent in the main drain toward the City of Palo Alto wastewater treatment plant. The silver recovered is sent for purification, and then sold at market price for reuse. The two outgoing arrows illustrate the two distinct paths for the recovered and non-recovered silver. At the end of the processing process, Lab #1 customers receive a stack of color prints, with the processed negative film strips where the photographs were originally taken with a film camera, as illustrated as step (5) in Figures 7 and 8.

The main differences between Figure 7 (1996) and Figure 8 (2006) in Lab #1 flowcharts are:

- Figure 8 shows the upgrade of the printer/paper processors to a digital printer/paper processor.
- Figure 8 illustrates the acceptance of digital camera files as input. In the case of orders from digital cameras, the images are provided to Lab #1 by customers on digital media like memory cards, CDs, or sent over the Internet. The files are directly processed by the digital printer/paper processor. In this case, the film processor is not used, since the digital files are directly accepted by the digital printer/paper processor.

Figure 7. Flowchart Lab #1 in 1996. Digitally created for this study. Equipment icons are based on photographs or illustrations by Benoit Delaveau. Not copyrighted.

Figure 8. Flowchart Lab #1 in 2006. Digitally created for this study. Equipment icons are based on photographs or illustrations by Benoit Delaveau. Not copyrighted.

3.1.1.5. Lab #1 Data Normalization

The source of data available to estimate the production output of the retail photoprocessing business defined as Lab #1 is a daily record of the fresh photoprocessing solutions mixed to feed each processor, for the years 1996 and 2006, respectively. Staff members responsible to prepare the fresh photoprocessing solutions were directed by management to fill-out mixing forms as part of their duty, documenting the date of mixing, type and volume of chemistry pack used, and which processors were fed. The mixing forms were compiled at the end of the year by the facility manager in order to establish the annual report sent to the City of Palo Alto wastewater facility, to renew the facility permit. The annual reports, as well as the daily mixing forms are the sources used to estimate the production of Lab #1 for the years 1996 and 2006.

3.1.1.6. Lab #1 Production Calculations

Two strategies are used to estimate Lab #1 annual production: First, the film processing production is estimated using data from the film processor; second, the print production is estimated using data from the printer/paper processors.

Principles used to calculate Lab #1 film production: In order to maintain the optimal processing activity for each surface unit processed, either in the film processor or the printer paper/processor, a small amount of fresh photo solution is pumped into the processor's tanks. The number of rolls processed with the film processor for a given time period is directly proportional to the volume of fresh film photoprocessing solutions

(C-41) mixed by Lab #1 staff during the same period. The precise volume of fresh photo solution per film processed – called the replenishment rate – is specific to each step of the process and the type or/brand of photochemistry used. Lab #1 film production is estimated from the daily mixing record of bleach C-41, since the variability of this particular step is very unlikely; contrary to the other steps (developer, fixer, or stabilizer), which require occasional adjustments in their replenishment rates, to compensate for variations in production.

Assumptions made to calculate Lab #1 film production in 1996: Lab #1 production relied on one Agfa FP3-72 that was running on a variant of Kodak C-41 process, called Agfa Process AP72, with an estimated replenishment rate for the bleach equal to 0.005 L per film 135 24-exposures (Agfa 71/72, 2002). According to Lab #1 records, the total volume of fresh bleach solution mixed in 1996 is equal to 360 liters.

Assumptions made to calculate Lab #1 film production in 2006: Lab #1 production relied on one Agfa FP210 that was running on Fuji Hunt Envirochem ADM FP, with an estimated replenishment rate for the bleach bath equal to 0.005 L per film 135 24-exposures (Fujihunt, 2006). According to Lab #1 records, the total volume of fresh bleach solution prepared in 1996 is equal to 65 L.

For each year, an estimate of the total film processing output is calculated, based on the following formula:

$$\text{Number of roll processed (N)} = \frac{\text{Volume of fresh C-41 Bleach prepared (V - liter)}}{\text{Replenishment rate per roll (R - liter/film)}}$$

Estimates of the total film processing output for the years 1996 and 2006, respectively, are summarized in Table 7 below.

Table 7

Number of Rolls Processed by Lab #1 in 1996 and 2006

	Volume of Fresh C-41 Bleach Prepared (V - liters)	Replenishment Rate per Film 135 24-Exposures (R - liter/film)	Number of Film Rolls Processed (N - films) = V / R
1996	360 L	0.005 L	360 / 0.005 = 72,000 films
2006	65 L	0.005 L	65 / 0.005 = 13,000 films

Lab #1 film processing total output is estimated to be 72,000 rolls for the year 1996 and 13,000 rolls for year 2006.

Principles Used to Calculate Lab #1 Print Production

The surface of photo paper processed for a giving time period is directly proportional to the volume of fresh photoprocessing solutions (RA-4) mixed during the same period.

Lab #1 print production is estimated from the Lab #1 daily mixing record of RA-4 color developer.

Assumptions Made to Calculate Lab #1 Print Production in 1996

Lab #1 production relied on three Agfa printer/paper processors that were running on a compatible version of Kodak RA-4 process called Agfa Process AP94LR, with an estimated replenishment rate for the color developer equal to 0.160 L per square meter of paper processed (A&O, 2007). During low seasons, lab operators often have to increase the developer replenishment rate in order to keep the adequate level of chemistry activity and compensate for oxidation. A realistic replenishment rate equal to 0.250 L per square meter is selected as the basis of the following estimates. According to Lab #1 records, the total volume of fresh color developer solution mixed in 1996 is equal to 6,250 L.

Assumptions Made to calculate Lab #1 Print Production in 2006

Lab #1 production relied on three Agfa printer/paper processor that were running on a compatible version of Kodak RA-4 process called Fuji Hunt RA60 with an estimated replenishment rate for the color developer bath equal to 0.060 L per square meter of paper processed (Fujihunt, 2006). A realistic replenishment rate equal to 0.200 L per square meter is selected as the basis of the following estimates. According to Lab #1 records, the total volume of fresh CD solution mixed in 2006 is equal to 798 L.

For each year, an estimate of the surface of photopaper output is calculated using the following formula:

$$\text{Surface of paper processed (S - m}^2\text{)} = \frac{\text{Volume of fresh RA-4 Developer prepared (V - L)}}{\text{Replenishment rate per surface unit of paper (R - L / m}^2\text{)}}$$

The result is expressed as surface of paper in square meters. Results are normalized in functional units (F.U. = 25^{ex} 4x6" prints), according to the formula below:

$$\text{Number of F.U. produced} = \frac{\text{Surface of paper processed (S - m}^2\text{)}}{\text{C = Surface of 1 F.U. (m}^2\text{)}}$$

$$\text{With } C = 25 \times 0.102 \text{ m} \times 0.152 \text{ m} = 0.3876 \text{ m}^2/\text{F.U.}$$

Estimates of the total F.U. printed for the years 1996 and 2006 respectively, by Lab #1 are summarized in Table 8.

Table 8

Number of F.U. Printed by Lab #1 in 1996 and 2006

	Volume of Fresh RA-4 Developer Prepared (V - liter)	Replenishment Rate per 1 m ² of Photo Paper (R - liter/m ²)	Surface of Photo Paper (S - m ²)	Number of F.U. C = 0.3876 m ² /F.U.
1996	6,250 L	0.250 L/m ²	$6,250 / 0.250 = 25,000 \text{ m}^2$	$25,000 / C = 64,500 \text{ F.U.}$
2006	798 L	0.200 L/m ²	$798 / 0.200 = 3,990 \text{ m}^2$	$3,990 / C = 10,294 \text{ F.U.}$

Lab #1 print production is estimated to 64,500 F.U. for the year 1996 and 10,294 F.U. for the year 2006.

3.1.1.7. Lab #1 Normalized Data

Calculations made from the film processor data estimate total film processed in 1996 at 72,000 rolls and 13,000 rolls in 2006. Calculations made from the printer/paper processor data estimate the total print production at 64,500 F.U. in 1996 and 10,294 F.U. in 2006.

The average number of prints per roll of film is about 25, so it is possible to use the equivalence 1 roll processed = 1 F.U. printed. Thus, Lab #1 two production estimates—one using the film processor data and the other using the printer/paper processors data—

are within a 12% margin. Because the two estimates are in the same range endorses the notion that the principles used to assess Lab #1 production are valid.

In order to take into account that the amount of film processed declined in use with the switch to digital cameras, the estimate from the printer/paper processor is used and rounded. For the purpose of this study, Lab #1 annual production is estimated at 65,000 F.U. for the year 1996, and 10,000 F.U. in 2006.

3.1.1.8. Transportation

All the photoprocessing equipment studied is located in the same retail store in downtown Palo Alto. No transportation is involved inside the system boundaries. Customers drop their rolls of film or their memory card for the content to be printed and come back to obtain the prints at the same location a few hours or days later. Transportation impacts related to customer mobility is outside the study system boundaries.

Transportation related to the production supplies (photopaper, photochemistry, spare parts) are not quantified in this study, because deliveries were usually grouped with other commercial goods linked to the retail activity of Lab #1. Typically, Lab #1 would receive a delivery from Agfa Photo or Fujifilm with photochemistry packs for the photoprocessing equipment, mixed with film and other products sold by the retail department. The hauling and impact generated from the discard of the solid waste of the photochemical packaging is also not evaluated in this study, due to a lack of reliable source of data.

3.1.2. Lab #1 Environmental Impact Assessment

3.1.2.1. Lab #1 Energy Calculations

Energy consumption is calculated adding the base load consumption of each processor for the number of hours they were operated annually.

Principles used to calculate Lab #1 energy consumption: Despite having many different components, a processor's electricity consumption comes mainly from heating the photoprocessing solutions at a precise temperature during the production periods, 6 days a week, 8 hours a day. An average power consumption is estimated for each processors according to technical literature (Agfa, 2001).

Assumptions made to calculate Lab #1 energy consumption in 1996: After review of the technical literature, the Agfa MSC printer/paper processor average load is estimated at 5 kWh, when all the sub-systems are running in production. The average power consumption for the film processor Agfa FP3-72 is estimated at 5 kWh (Agfa, 2001). Lab #1 had a total of five pieces of photoprocessing equipment working simultaneously in 1996, during 314 days, 8 hours per day.

Assumptions made to calculate Lab #1 energy consumption in 2006: The Agfa D-Lab printer/paper processor average load is estimated at 5 kWh. The average power consumption for the film processor Agfa FP210 is estimated 3.5 kWh (Agfa, 2001). Lab #1 had a total of five pieces of photoprocessing equipment working simultaneously in 2006, during 312 days, 8 hours per day.

The amount of kWh consumed per year by all processors at Lab #1 is calculated by multiplying the number of production hours for the years 1996 and 2006, respectively,

by the average power consumption of each processor. The total electricity consumption is divided by the number of F.U. for the given year. The formula below illustrates the calculation, and the results are presented in Table 9 below.

$$\text{Total electricity / F.U. (kWh/F.U.)} = \frac{\Sigma (\text{electricity load - kWh}) \times \text{Hours (hours)}}{\text{Total F.U. per year}}$$

Table 9

Lab #1 Energy Consumption Estimate

	Film Processor	Print/paper processors	Total (kWh)	Consumption (kWh per F.U.)
1996	5 kWh x 1 unit x 8 hours x 314 days = 12,560 kWh	5 kWh x 3 units x 8 hours x 314 days = 37,680 kWh	50,240 kWh	0.78 kWh/F.U.
2006	3,5 kWh x 1 unit x 8 hours x 312 days = 8,736 kWh	5 kWh x 3 units x 8 hours x 312 days = 37,440 kWh	46,176 kWh	4.18 kWh/F.U.

For the year 1996, 0.78 kWh/F.U. were consumed, while 4.18 kWh/F.U. were consumed in 2006.

3.1.2.2. Lab #1 CO₂e Emissions

The CO₂e emissions generated to produce the electricity consumed by Lab #1 processors for the years 1996 and 2006 respectively, are estimated.

Principles used to calculate Lab #1 CO₂e emissions: Lab #1 annual electricity consumption calculated in Section 3.1.2.1 is documented according to the power mix of the City of Palo Alto Utilities (CPAU, 2002; CPAU, 2006). Once separated by type of electricity generation, CO₂e emissions for each portion is calculated according to their CO₂e efficiency. The power mix documents the percentage of electricity that is produced from powerplants fed with natural gas, coal, hydro or nuclear energy. The CO₂e

efficiency is the typical amount of CO₂e generated per kWh produced for each type of powerplant. Given the power mix and CO₂ efficiency, total CO₂e emissions related to Lab #1 consumption is calculated.

Assumptions used to calculate Lab #1 CO₂e emissions: CPAU power mix is not available for years prior to 2002. We used the data available for 2002 to calculate 1996 CO₂e emissions. CPAU power mix is summarized in Table 10.

Table 10

City of Palo Alto Estimated Power Mix for 1996/2006

Natural Gas	16.00%	1.00%
Nuclear	5.00%	0.00%
Large Hydro	71.00%	88.00%
Coal	3.00%	1.00%
Renewable	5.00%	10.00%

CO₂e efficiency data comes from a study that was published in 2006 by the U.S. Department of Energy and Environmental Protection Agency (DEO/EPA, 2000, p. 10). CO₂e efficiency data are summarized in Table 11.

Table 11

Typical CO₂e Efficiency for Electricity Production in the U.S.

Natural Gas	0.450 kg CO ₂ e per kWh
Nuclear	0.030 kg CO ₂ e per kWh
Large Hydro	0.025 kg CO ₂ e per kWh
Coal	1.000 kg CO ₂ e per kWh
Renewable	0.020 kg CO ₂ e per kWh

The energy consumption that comes from each primary source of electricity is calculated for each year studied, for each group of equipment. Then each subtotal is multiplied by the CO₂e efficiency of each source of energy. The total amount of CO₂e is aggregated to calculate the estimated annual CO₂e emissions associated with the electricity use of Lab #1 processors. Details are shown in Table 12 for the year 1996 and Table 13 for the year 2006. The formula below denotes the calculation method:

$$\text{Total CO}_2\text{e / F.U. (kg/F.U.)} = \frac{\sum (\text{Electricity (kWh)} \times \text{Energy Mix (\%)} \times \text{CO}_2\text{e Efficiency (kg/kWh)})}{\text{Total F.U. per year}}$$

Table 12

Lab #1 CO₂e Emissions Associated with Electricity Consumption in 1996

Film Processor	Print/paper Processors	CO ₂ e (detailed)	CO ₂ e Total
Natural Gas	Natural Gas	Natural Gas	
12,560 kWh x 16% = 2010 kWh	37,680 kWh x 16% = 6,029 kWh	(2010 + 6029) x 0.450 kg/kWh = 3,618 kg	
Nuclear	Nuclear	Nuclear	
12,560 kWh x 5% = 628 kWh	37,680 kWh x 5% = 1,884 kWh	(628 + 1,884) x 0.030 kg/kWh = 75 kg	
Large Hydro	Large Hydro	Large Hydro	
12,560 kWh x 71% = 8,918 kWh	37,680 kWh x 71% = 26,753 kWh	(12,560+37,680) x 0.025kg/kWh = 892 kg	
Coal	Coal	Coal	
12,560 kWh x 3% = 377 kWh	37,680 kWh x 3% = 1,130 kWh	(377 + 1,130) x 1.000 kg/kWh = 1,507 kg	
Renewable	Renewable	Renewable	
12,560 kWh x 5% = 628 kWh	37,680 kWh x 5% = 1,884 kWh	(628 + 1,884) x 0.020 kg/kWh = 50 kg	6,142 kg or 0.094 kg/F.U.

Table 13

Lab #1 CO₂e Emissions Associated with Electricity Consumption in 2006

Film Processor	Print/paper Processors	CO ₂ e (detailed)	CO ₂ e Total
Natural Gas	Natural Gas	Natural Gas	
8,736 kWh x 1% = 87 kWh	37,440 kWh x 1% = 374 kWh	(87 + 374) x 0.450 kg/kWh = 207 kg	
Nuclear	Nuclear	Nuclear	
8,736 kWh x 0% = 0 kWh	37,440 kWh x 0% = 0 kWh	(0 + 0) x 0.030 kg/kWh = 0 kg	
Large Hydro	Large Hydro	Large Hydro	
8,736 kWh x 88% = 7,688 kWh	37,440 kWh x 88% = 32,947 kWh	(7,688+32,947) x0.025 kg/kWh = 1,016 kg	
Coal	Coal	Coal	
8,736 kWh x 1% = 87 kWh	37,440 kWh x 1% = 374 kWh	(87 + 374) x 1.000 kg/kWh = 461 kg	
Renewable	Renewable	Renewable	
8,736 kWh x 10% = 874 kWh	37,440 kWh x 10% = 3,744 kWh	(874 + 3,744) x 0.020 kg/kWh = 92 kg	1,776 kg or 0.177 kg/F.U.

For the year 1996, 0.094 kg of CO₂e per F.U. were required, while 0.177 kg of CO₂e per F.U. were required in 2006.

3.1.2.3. Lab #1 Silver Inventory

The silver flow is carried out by a silver-bearing processing solution, typically bleach-fix and stabilizer for the printer/paper processor (RA-4), and bleach fixer and stabilizer for the film processor (C-41). The photo industry best practice recommends a silver recovery method that allows a typical recovery rate of 99%. This section estimates (1) the portion of silver that is discharged in the environment from the facility Annual Report for Silver Treatment and (2) the amount of silver recovered with the silver recovery unit using a typical recovery rate published in technical literature.

Principles Used to Estimate Lab #1 Silver Discharge

At Lab #1 facility, all the silver-bearing solutions from the different processors are collected to a silver recovery unit that uses the principle of electrolysis. The unit is capable of recovering silver from the silver-bearing solutions until a concentration below 0.001 g/L is reached. Once treated, the remaining solutions are drained into the City of Palo Alto wastewater treatment facility.

Assumptions Used to Estimate Lab #1 Silver Discharge in 1996

According to the Lab #1 Annual Report for Silver Treatment, in 1996, a volume $V_{1996} = 20$ liters per day of treated silver-bearing effluents were discharged from the silver recovery unit into the main water system. Every month, samples from the outcoming treated silver-bearing effluents were analyzed by Sequoia Analytical, a certified independent laboratory in Redwood City, California, following a U.S. EPA approved method. For the year 1996, the results of these tests show that Lab #1 effluents had been

consistently at or below the detection limit of 0.001 g/L, with an average analyzed concentration equal to 0.00025 g/L. The value 0.00025 g/L is used for the estimate as the average concentration (C_{1996}) for all the treated silver-bearing solutions drained. The formula below estimates the total mass of silver (M_{1996}) discharged into the local water system.

Assumptions Used to Estimate Lab #1 Silver Discharge in 2006

According to the Lab #1 Annual Report for Silver Treatment, in 2006, a volume $V_{2006} = 3$ liters per day of treated silver-bearing effluents were discharged from the silver recovery unit to the main water system. Samples from the outgoing treated silver-bearing effluents were analyzed by Sequoia Analytical, with no accidental results above a concentration of 0.001 g/L. The 0.00025 g/L threshold is used for the estimate as the average concentration (C_{2006}) for all the chemicals drained. The total mass of silver (M_{2006}) discharged in the local environment is estimated using the formula below. Results are presented in Table 14.

$$\text{Mass of Silver discharged} = \frac{(\text{Volume} \times \text{number day} \times \text{Silver concentration})}{\text{Total F.U. per year}}$$

$(M - \text{g/F.U.})$

Table 14

Lab #1 Silver Discharge Estimate for 1996 and 2006

	Daily Volume of Treated Silver- Bearing Solution V (liter per day)	Number of Production Days D (day)	Average Concentration C (g per liter)	Total M = V x D x C (g per F.U.)
1996	20 L (Total = 6,280 L)	314 days	0.00025 g/L	1.57 g or 2.3×10^{-5} g/F.U.
2006	3 L (Total = 936 L)	312 days	0.00025 g/L	0.24 g or 2.4×10^{-5} g/F.U.

Total silver discharged in the environment is estimated to 2.3×10^{-5} g/F.U. in 1996 and 2.4×10^{-5} g/F.U. in 2006.

Principles Used to Estimate Lab #1 Silver Recovered

Lab #1 uses a silver recovery unit designed, maintained and serviced by Hallmark Refining Corporation, a company based in Washington State. The exact model of the electrolytic system is BFX 1002. The 1995 Hallmark service manual describes the process as follows:

“This silver recovery method applies a direct current across two electrodes in a silver-bearing solution. Metallic silver deposits on the cathode. Sulfite and thiosulfate are oxidized on the anode. Approximately 1 gram of sodium sulfite is oxidized for every gram of silver deposited. Considerable agitation and a large plating surface area can achieve good plating efficiency and the silver is 90-98 percent pure. The cathode is removed periodically, and with it the unpure silver metal is removed. The HRC ELECTRO Series of silver recovery systems are designed to utilize the maximum amount plating surface in the cell. The cathode is a stainless steel cylinder in continuous motion, during the plating process. This creates a high level of agitation and maximizes the silver yield.” (Hallmark, 1995, p. 3).

The unpurified silver deposit on the cathode, made of 90% pure silver, is sent for purification from Lab #1 to Hallmark headquarters every month. Hallmark refines the silver deposit. Every year, Hallmark provides Lab #1 owners with the quantity of silver refined. Typically, the precious metal is sold for reuse at market price. The amount of silver recovered is estimated using data from a study published by another reputable silver recycling provider from the Bay Area (ECS Refining, Santa Clara, California). According to ECS Refining, the silver concentration of silver-bearing solutions coming from a typical printer/paper processor equals to $C_{RA4} = 1.5 \text{ g/L}$, while the silver concentration from silver-bearing solutions coming from a typical film processor is equal to $C_{C41} = 2.5 \text{ g/L}$ on average (ECS, 1998)

Assumptions Used to Estimate Lab #1 Silver Recovered in 1996

According to the Lab #1 Annual Report for Silver Treatment, in 1996, a volume $V_{1996} = 20 \text{ liters per day}$ or $V_{\text{total } 1996} = 6,280 \text{ L}$ of silver-bearing solutions were treated with the

silver recovery unit. A conservative rate of 99% recovered silver is used. From the total of 6,280 L of silver-bearing photoprocessing solution collected, a typical ratio of 2/5 came from the film processor with a silver concentration of 0.0025 kg/L and 3/5 from the printer/paper processor with a silver concentration of 0.0015 kg/L. This ratio is estimated using Lab #1 daily mixing forms, comparing the volume of solutions mixed for the film processor and the volume mixed to feed the printer/paper processors.

Assumptions Used to Estimate Lab #1 Silver Recovered in 2006

According to the Lab #1 Annual Report for Silver Treatment, in 2006, a volume $V_{2006} = 3$ liters per day or $V_{\text{total } 2006} = 936$ liters of silver-bearing solution were treated with the silver recovery unit. The conservative rate of 99% recovered silver is used. From the total of 936 L of silver-bearing used photoprocessing solution collected, a ratio of 1/4 came from the film processor with a silver concentration of 0.0025 kg/L and 3/4 from the printer/paper processor with a silver concentration of 0.0015 kg/L. This ratio has been estimated using Lab #1 daily mixing forms. Results are presented in Table 15.

Table 15

Lab #1 Recovered Silver

	Film Processor	Printer/ Paper processor	Silver
1996	$V_{\text{film}} = 6,280 \times 2/5$ $= 2,512 \text{ L}$ $C_{\text{film}} = 0.0025 \text{ kg/L}$ $T = 99\% \times (V_{\text{film}} \times C)$ $T_{\text{film}} = 6.217 \text{ kg}$	$V_{\text{paper}} = 6,280 \times 3/5$ $= 3,768$ $C_{\text{paper}} = .0015 \text{ kg/L}$ $T = 99\% \times (V_{\text{paper}} \times C)$ $T_{\text{paper}} = 5,595 \text{ kg}$	11.812 kg Recovered
2006	$V_{\text{film}} = 936 \times 1/4$ $= 234 \text{ L}$ $C_{\text{film}} = 0.0025 \text{ kg/L}$ $T = 99\% \times (V_{\text{film}} \times C)$ $T_{\text{film}} = 0.579 \text{ kg}$	$V_{\text{paper}} = 936 \times 3/4$ $= 702 \text{ L}$ $C_{\text{paper}} = .0015 \text{ kg/L}$ $T = 99\% \times (V_{\text{paper}} \times C)$ $T_{\text{paper}} = 1.042 \text{ kg}$	1.621 kg Recovered

Estimates show that 11.8 kg of silver were recovered from Lab #1 silver recovery unit in 1996 while 1.6 kg were recovered in 2006.

3.1.2.4. Lab #1 Water Use

The total amount of water consumed by the five processors in use at Lab #1 for the years 1996 and 2006 respectively, is calculated from the daily record of the fresh photoprocessing solutions mixed to feed each processor.

Principles Used to Estimate Lab #1 Water Use

Following several site visits and discussions with staff members, the total volume of

water needed to operate the processors is estimated doubling the volume of the fresh photoprocessing solution mixed to feed the processors.

Assumptions Used to Estimate Lab #1 Water Use in 1996

According to the Lab #1 daily mixing record, in 1996 a volume of $V_{\text{sol. film 1996}} = 6,896$ L of film processing solutions (C-41) and a volume of $V_{\text{sol. paper 1996}} = 19,846$ L of paper processing solutions (RA-4) were used. Adding these two numbers, a total 26,742 liters of photoprocessing solutions were used for 1996. The volume of fresh water needed to clean and operate the processors $V_{\text{maint. 1996}}$ on top of the photoprocessing solution is estimated as $V_{\text{maint. 1996}} = V_{\text{sol. film 1996}} + V_{\text{sol. paper 1996}}$. Total water consumption is calculated following the formula below.

Assumptions Used to Estimate Lab #1 Water Use in 2006

According to the Lab #1 daily mixing record, in 2006 a volume of $V_{\text{sol. film 2006}} = 1,317$ L of film processing solutions (C-41) and a volume of $V_{\text{sol. paper 2006}} = 4,038$ L of paper processing solutions (RA-4) were used. The volume of fresh water needed to clean and operate the processors $V_{\text{maint. 2006}} = V_{\text{sol. film 2006}} + V_{\text{sol. paper 2006}}$. Total water consumption is calculated following the formula below for both years.

$$\begin{array}{rcl} \text{Total Water use} & = & \frac{V_{\text{sol. film}} + V_{\text{sol. paper}} + V_{\text{maint.}}}{\text{Total F.U. per year}} \\ \text{(L/F.U.)} & & \end{array}$$

Table 16

Lab #1 Water Consumption Estimate for 1996 and 2006

	Film Processor $V_{\text{sol. film}}$	Printer/ Paper processor $V_{\text{sol. paper}}$	Maintenance (100% of total) $V_{\text{maint.}}$	Total $V_{\text{sol. film}} + V_{\text{maint.}}$
1996	DE: 964 L BL: 360 L FX: 2,726 L STAB: 2,846 L Total: 6,896 L	DE: 6,250 L BLX: 3,945 L STAB: 9,651 L Total: 19,846 L	26,742 L	53,484 L or 0.82 L/F.U.
2006	DE: 297 L BL: 65 L FX: 435 L STAB: 520 L Total: 1,317 L	DE: 798 L BLX: 940 L STAB: 2,300 L Total: 4,038 L	5,355 L	10,710 L or 1.07 L/F.U.

Total water consumption is estimated to 0.82 L of water per F.U. in 1996, and 1.07 L of water per F.U. in 2006.

3.1.3. Lab #1 Comparative Assessment

A summary of the findings is presented in the Table 17 below.

Table 17

Lab #1 Assessment Summary

	Yearly Production	Electricity Consumption Associated	CO ₂ e Emissions from Electricity	Silver Discharge in the Environment	Water Use
1996	65,000 F.U. or 207 F.U./day	50,240 kWh/year or 0.77 kWh/F.U.	6,142 kg or 0.094 kg/F.U.	1.57 g or 2.310^{-5} g/F.U.	53,484 L or 0.82 L/F.U.
2006	10,000 F.U. or 32 F.U./day	46,176 kWh/year or 4.61 kWh/F.U.	1,776 kg or 0.177 kg/F.U.	0.24 g or 2.410^{-5} g/F.U.	10,710 L or 1.07 L/F.U.

The results are summarized in the Figures 9 and 10 below.

Figure 9. Lab #1 Total Impact 1996 vs. 2006. Compares the total consumption of energy, associated CO₂e emissions, silver discharge, and the total amount of water used between the two years studied at Lab #1. Base 100 is applied to 1996 quantities (black bars).

Figure 10. Lab #1 Impact per F.U. 1996 vs. 2006. Compares the relative consumption of energy, associated CO₂e emissions, silver discharge, and the amount of water used per functional unit between the two years studied at Lab #1. Base 100 is applied to 1996 quantities (black bars).

The equipment in use is designed to print about 1,500 ex, 4x6" prints per hour. Only a fraction (about 5%) of this nominal capacity is used in 2006. It makes use of such equipment highly inefficient in terms of energy use. Even if the total annual consumption changed marginally between the years 1996 (50,240 kWh) and 2006 (46,176 kWh), the energy consumption per F.U. has more than quadrupled in 10 years. This result has consequences in terms of greenhouse gas emissions, a concern that has gained momentum and increased visibility since 2006. Even considering the

improvements that have been made on the way electricity was produced between 1996 and 2006 for the City of Palo Alto, GHG emissions from processing each F.U. at Lab #1 almost doubled in 10 years (0.094 kg/F.U. vs. 0.177 kg/F.U. of CO₂e). The electricity consumption is the same for a facility that produces only one-sixth of what it used to produce 10 years before.

The system in use to recover silver from the used photoprocessing solutions is the same between the two periods studied. It is designed to recover about 99% of the metal contained in the overflow solutions. Data show that Lab #1 usually reached above 99% recover ratio. It is established that about 1.6 g of silver were discharged in the environment in 1996, while only less than 0.25 g of silver were discharged in 2006. Despite the challenges attached to running a silver recovery unit with a small volume of overflow, Lab #1 was able to keep its silver recovery rate per F.U. between the two years studied at a very high level.

The study shows a decline in total water consumption from 53,484 L to 10,710 L. The decline in water consumption at Lab #1 facility is highly correlated with the decline of production. Per F.U., the consumption shows a deterioration of the efficiency respectively 0.82 L/F.U. (1996) and 1.07 L/F.U. (2006). Even if the water consumption is directly related to the surface of photo-sensitized material processed, proper maintenance of the equipment required 20% more water per F.U. in 2006 than in 1996.

3.2. Case Study LCA Lab #2

3.2.1. Lab #2 Inventory Analysis

Lab #2 assessment follows the same structure and methodology detailed in Section 3.1, dedicated to Lab #1. Lab #2 detailed formula and calculations are not included, since they are identical to Lab #1 assessment.

3.2.1.1. Lab #2 Description

The following LCA studies the environmental impact (electricity use and GHG emissions linked to electricity generation, silver discharge and water use) related to onsite commercial photoprocessing activities for a retail photoprocessing site, which is located in downtown San José, California.

In 1996, Lab #2 operated in downtown San José on 2nd Street. In June 2006, Lab #2 moved to a different location on 4th Street. Figure 11 is a photograph of Lab #2 current location (2010).

Figure 11. Lab #2 as Seen in 2010 from the Customer Counter. Photo by Benoit Delaveau.

During the two years of interest, Lab #2 operated equipment similar to that of Lab #1. In 1996, Lab #2 was equipped with a medium capacity film processor (Agfa FP3-50) with a nominal process capacity of 50 rolls of 35mm [24 exposures] per hour. In 2006, Lab #2 was equipped with a new film processor from Noritsu (Noritsu V50) also with a nominal process capacity estimated at 50 rolls of 35mm [24 exposures] per hour (Noritsu, 2006). The main difference between the two pieces of equipment is a significant reduction in the process duration, due to an upgrade to the latest version of the Kodak C-41 process used in the 2006 processor. In 1996, the Agfa machine was using AP-71/C-41B chemistry with an access time equal to approximately 12 minutes.

In 2006, the more recent Noritsu V50 used an accelerated version of the Kodak process named C-41-RA, with access time about seven minutes (see Section 1.2.2.1 for details). In 1996 and 2006, Lab #2 was also operating a slide film processor, an Agfa AP-44. All silver-bearing solutions of these processors were collected for silver recovery by a subcontractor. As Lab #2 was not equipped with on-site silver recovery unit, it was qualified as a “hauling” facility.

In 1996, Lab #2 was only providing traditional processing services from film. Lab #2 was equipped with one Agfa/Copal ML 2.3 printer/processor for print sizes 4x6” to 6x8”. In 2006, Lab #2 switched to a next generation digital printer/processor capable of printing from both negative film strips and files from digital cameras. Lab #2 started offering digital printing services in 2004, when the facility acquired a new Fujifilm Frontier 340 digital printer/paper processor. In 2006, Lab #2 was equipped with one Fujifilm Frontier 340 – a machine that was considered the standard in quality output by many professionals (Fuji Photo Film, 2002). The overall total hourly printing capacity is comparable between the two years studied, for both film processing and the printing equipment. Table 20 summarizes the production equipment list.

Table 20

1996 and 2006 Lab #2 Production Equipment List

	Film Processor (C-41 and E-6)	Printer/ Processor (RA-4)
1996	AGFA FP3-50 AGFA FP1-44	AGFA/COPAL ML 2.3
2006	NORITSU V50 AGFA FP1-44	FUJI FRONTIER 340

3.2.1.2. Lab #2 Functional Unit and Flows

The functional unit (F.U. = 25^{ex} 4x6" prints) selected for the Lab #1 assessment is also used for the Lab #2 study. The results of the two assessments are comparable, since the commercial services provided by both facilities are expressed using the same functional units for the same time periods (1996 and 2006).

Quantification of the flows is limited to the location of the photoprocessing production site and the photoprocessing equipment used by Lab #2, listed in the previous section. All silver-bearing photoprocessing solutions are bottled in dedicated 25 gallon containers until a certified hauling and recycling company transfers it to a treatment facility. For both years studied, the subcontractor that handled the silver-bearing solutions for Lab #2 is ECS Refining, Santa Clara, California. The site-specific data

presented in the following sections have been compiled on information from the local water agency permit.

3.2.1.3. Lab #2 System Boundaries

Data collection is limited to the photoprocessing units that were in production at Lab #2 for the years 1996 and 2006 (Section 3.2.1.1.). Pacific Gas and Electricity (PG&E) provides electricity for the photoprocessing equipment studied; and the City of San José Municipal Water provides fresh water. The system boundaries chosen for this study are limited to the Lab #2 main building facility.

3.2.1.4. Lab #2 Flowcharts

The Lab #2 flowcharts are very similar to those from the Lab #1 assessment. Input and output at the top and bottom of the charts, respectively, are the same as described in Section 3.1.1.4. Step 4 illustrated in Figures 12 and 13 show that Lab #2 silver-bearing solutions are collected from the processors in dedicated 25 gallon containers. The nature of the printing activities changed for Lab #2 in 2006, after digital files were included in the list of media accepted to obtain color prints as shown in Figure 13.

Figure 12. Lab #2 Flowchart in 1996. Digitally created for this study. Equipment icons are based on photographs or illustrations by Benoit Delaveau. Not copyrighted.

Figure 13. Lab #2 Flowchart in 2006. Digitally created for this study. Equipment icons are based on photographs or illustrations by Benoit Delaveau. Not copyrighted.

3.2.1.5. Lab #2 Production Calculations

Unlike the Lab #1 assessment, no records documenting the volume of fresh photoprocessing solutions used by Lab #2 were available. The production was estimated from Lab #2 self-declared volume of silver-bearing photoprocessing solution documented in its 1996 and 2006 silver discharge permits. The Lab #2 manager retained a copy of the permit forms for the years 1996 and 2006 on file, along with internal records documenting the number and dates that the 25 gallon containers of used silver-bearing photoprocessing solution were sent to ECS Refining.

Principles Used to Calculate Lab #2 Production

To estimate Lab #2 production, the ratio of silver-bearing photoprocessing solutions volume per functional unit (S) was determined from the Lab #1 data. Since the processors and the type of photoprocessing chemistry in use at Lab #2 are similar to Lab #1, the ratios S_{1996} and S_{2006} can be used to estimate Lab #2 total production.

Assumptions Used to Calculate Lab #2 1996 Production

According to the Lab #2 records, in 1996, a total volume equal to $V_{1996} = 3,762$ L of silver-bearing solution was collected by ECS Refining. From the Lab #1 assessment, it can be extrapolated that in 1996, a total volume of 6,280 L of silver-bearing solution was produced to process a total of 65,000 F.U. or $S_{1996} = 6,280 / 65,000 = 0.097$ L of silver-bearing solution per F.U. produced.

Assumptions Used to Calculate Lab #2 2006 Production

According to Lab #2 records, in 2006, a total volume $V_{2006} = 980$ L of silver-bearing solution was collected by ECS Refining. From Lab #1 assessment, in 2006 a total

volume of 936 L was produced for 10,000 F.U. or $S_{2006} = 936 / 10,000 = 0.094$ L of silver-bearing solution per F.U. produced. The following formula was used to calculate the estimated number of F.U. produced by Lab #2 in 1996 and 2006. The results are summarized in Table 19.

$$\text{Number of F.U. (N) F.U.} = \frac{\text{Volume of used silver-bearing photo solution (V) (L)}}{\text{Typical volume of used photo solution per F.U. (S) (L per F.U.)}}$$

Table 19

Number of F.U. Processed by Lab #2 in 1996 and 2006

	Volume of Used Photoprocessing Solution V (liter per year)	Silver-bearing Used Photoprocessing Solutions Volume per F.U. S (liter per F.U.)	Number of Film Processed N = V / S (F.U.)
1996	3,762 L/Year	0.097 L/F.U.	3,762 / 0.097 = 38,783 F.U.
2006	980 L/Year	0.094 L/F.U.	1,480 / 0.094 = 10,425 F.U.

3.2.1.6. Lab #2 Normalized Data

As shown in Table 19, the production of Lab #2 is estimated to 38,783 F.U. in 1996 and 10,425 F.U. in 2006. Since these numbers are estimates, Lab #2 total production is averaged to 39,000 F.U. in 1996, and 10,500 F.U. in 2006.

3.2.1.7. Transportation

As in the Lab #1 assessment, the impact of transportation related to customer mobility, production supplies (photochemistry, spare parts), and hauling the silver-bearing processing solution from Lab #2 to the treatment facility are outside the study system boundaries.

3.2.2. Lab #2 Environmental Impact Assessment

3.2.2.1. Lab #2 Energy Calculations

As in the Lab #1 assessment, energy consumption is calculated according to an average base load consumption for each processor in use. Results are presented in Table 20 below.

Table 20

Lab #2 Energy Consumption Estimate

	Film Processor	Print/paper Processors	Total	Consumption per F.U.
1996	5 kWh x 2 units x 8 hours x 314 days = 25,120 kWh	5 kWh x 1 unit x 8 hours x 314 days = 12,560 kWh	37,680 kWh	0.97 kWh/F.U.
2006	5 kWh x 2 units x 2 hours x 312 days = 6,240 kWh	5 kWh x 1 unit x 8 hours x 312 days = 12,480 kWh	18,720 kWh	1.78 kWh/F.U.

For the year 1996, 0.97 kWh/FU were used while 1.78 kWh/FU was used in 2006.

3.2.2.2. Lab #2 CO₂e Emissions

CO₂e emissions generated to produce the amount of electricity consumed by Lab #2 processors for the years 1996 and 2006 are evaluated according to the methodology detailed in Section 3.1.2.2. for Lab #1 assessment. Lab #2 annual electricity consumption calculated in Section 3.2.2.1. is documented according to the power mix of PG&E, the Lab #2 electricity supplier (PG&E, 2006). Once separated by type of electricity generation, CO₂e emissions is calculated according for each portion applying to the CO₂e efficiency documented in Section 3.2.2.2. Given the power mix and

CO₂e efficiency, total CO₂e emissions related to Lab #2 electricity consumption is calculated.

The power mix is published by PG&E for 2006; and data published for 2002 are used as the basis for the 1996 calculations. PG&E power mix is presented in Table 21. Details of CO₂e calculations are shown in Table 22 for 1996 and Table 23 for 2006.

Table 21

PG&E Estimated Power Mix for 1996 and 2006

Natural Gas	50.00%	40.00%
Nuclear	16.00%	24.00%
Large Hydro	10.00%	22.00%
Coal	12.00%	2.00%
Renewable	12.00%	12.00%

Table 22

CO₂e Emissions Associated with Lab #2 Electricity Consumption in 1996

Film Processor	Print/paper Processors	CO ₂ e (detailed)	CO ₂ e Total
Natural Gas	Natural Gas	Natural Gas	
25,120 kWh x 50% = 12,560 kWh	12,560 kWh x 50% = 6,280 kWh	(12,560 + 6,380) x 0.450 kg/kWh = 8,478 kg	
Nuclear	Nuclear	Nuclear	
25,120 kWh x 16% = 4,020 kWh	12,560 kWh x 16% = 2,010 kWh	(4,020 + 2,010) x 0.030 kg/kWh = 181 kg	
Large Hydro	Large Hydro	Large Hydro	
25,120 kWh x 10% = 2,512 kWh	12,560 kWh x 10% = 1,256 kWh	(2,512 + 1,256) x 0.025 kg/kWh = 94 kg	
Coal	Coal	Coal	
25,120 kWh x 12% = 3,014 kWh	12,560 kWh x 12% = 1,507 kWh	(3,014 + 1,507) x 1.000 kg/kWh = 4,521 kg	
Renewable	Renewable	Renewable	
25,120 kWh x 12% = 301 kWh	12,560 kWh x 12% = 1,507 kWh	(301 + 1,507) x 0.020 kg/kWh = 36 kg	13,310 kg or 0.341 kg/F.U.

Table 23

CO₂e Emissions Associated with Lab #2 Electricity Consumption in 2006

Film Processor	Print/paper Processors	CO ₂ e (detailed)	CO ₂ e Total
Natural Gas	Natural Gas	Natural Gas	
6,214 kWh x 40% = 2,486 kWh	12,480 kWh x 40% = 4,992 kWh	(2,486 + 4,992) x 0.450 kg/kWh = 3,365 kg	
Nuclear	Nuclear	Nuclear	
6,214 kWh x 24% = 1,491 kWh	12,480 kWh x 24% = 2,995 kWh	(1,491 + 2,995) x 0.030 kg/kWh = 135 kg	
Large Hydro	Large Hydro	Large Hydro	
6,214 kWh x 22% = 1,367 kWh	12,480 kWh x 22% = 2,746 kWh	(1,367 + 2,746) x 0.025kg/kWh = 103 kg	
Coal	Coal	Coal	
6,214 kWh x 2% = 124 kWh	12,480 kWh x 2% = 249 kWh	(124 + 249) x 1.000 kg/kWh = 374 kg	
Renewable	Renewable	Renewable	
6,214 kWh x 12% = 746 kWh	12,480 kWh x 12% = 1,498 kWh	(746 + 1,498) x 0.020 kg/kWh = 45 kg	4,022 kg or 0.383 kg/F.U.

In 1996, 0.341 kg of CO₂e per F.U. was required, while 0.383 kg of CO₂e per F.U. was required in 2006.

3.2.2.3. Lab #2 Silver Inventory

Lab #2 was a “hauling” facility where all the silver-bearing photoprocessing solution was collected in 25 gallon containers and hauled to a specialized reprocessing silver refining facility. In 1996 and 2006, the certified hauling and silver refining company, working as a Lab #2 subcontractor, was ECS Refining, Santa Clara, California. This section estimates: (1) the portion of silver that was discharged in the environment and (2) the amount of silver recovered with the silver recovery unit, using the methods used in the Lab #1 assessment in Section 3.1.2.3. It is reasonable that ECS Refining achieved similar performance as Lab #1, reaching a threshold concentration equal to 0.0025 g/L on average in residual silver concentration for the discarded refined photoprocessing solutions. The calculations based on these assumptions are summarized in Table 24 below.

Table 24

Lab #2 Silver Inventory

	Film Processor	Printer/ Paper processor	Silver
1996	$V_{\text{film}} = 3,762 \times 2/5$ $= 1,541 \text{ L}$ $C_{\text{film}} = 0.0025 \text{ kg/L}$ $T = 99\% \times (V_{\text{film}} \times C)$ $T_{\text{film}} = 3.814 \text{ kg}$	$V_{\text{paper}} = 3,762 \times 3/5$ $= 2,257$ $C_{\text{paper}} = 0.0015 \text{ kg/L}$ $T = 99\% \times (V_{\text{paper}} \times C)$ $T_{\text{paper}} = 3,352 \text{ kg}$	7.166 kg Recovered (about 0.94 g or 2.410^{-5} g/F.U. discharged)
2006	$V_{\text{film}} = 980 \times 1/4$ $= 245 \text{ L}$ $C_{\text{film}} = 0.0025 \text{ kg/L}$ $T = 99\% \times (V_{\text{film}} \times C)$ $T_{\text{film}} = 0.606 \text{ kg}$	$V_{\text{paper}} = 980 \times 3/4$ $= 735$ $C_{\text{paper}} = 0.0015 \text{ kg/L}$ $T = 99\% \times (V_{\text{paper}} \times C)$ $T_{\text{paper}} = 1.091 \text{ kg}$	1.697 kg Recovered (about 0.25 g or 2.510^{-5} g/F.U. discharged)

Total silver discharged in the environment is estimated to 0.94 g in 1996 (2.4×10^{-5} g/F.U.) and 0.25 g (2.5×10^{-5} g/F.U.) in 2006.

3.2.2.4. Lab #2 Water Use

From the Lab #1 assessment, it is established that for each liter of used silver-bearing photoprocessing solution $V_{\text{silver effluent}}$, about 5 liters of fresh solutions V_{sol} had been prepared. The amount of fresh solution prepared at Lab #2 is estimated by multiplying the known volume of silver-bearing used solution by a factor of five.

Water used for the maintenance of the processors equals 100% the estimated V_{sol} , following the same methods used for Lab #1 assessment. Table 25 below details the calculations.

Table 25

Lab #2 Water Consumption Estimate for 1996 and 2006

	Silver-Bearing Overflow $V_{\text{silver effluent}}$ (liter / year)	Fresh Solutions Prepared $V_{\text{sol.}} = 5 \times V_{\text{silver eff.}}$ (liter / year)	Maintenance 100% of $V_{\text{sol.}}$ $V_{\text{maint.}}$ (liter / year)	Total $V_{\text{sol.}} + V_{\text{maint.}}$ (liter / year)
1996	3,762 L	18,810 L	18,810 L	37,620 L or 0.96 L/F.U.
2006	980 L	4,900 L	4,900 L	9,800 L or 0.93 L/F.U.

These numbers correspond to 0.96 L of water per F.U. in 1996, and 0.93 L of water per F.U. in 2006.

3.2.3. Lab #2 Comparative Assessment

A summary of the findings is presented in Table 26.

Table 26

Lab #2 Assessment Summary

	Yearly Production F.U	Electricity Consumption Associated	CO ₂ e Emissions from Electricity	Silver Discharged in the Environment	Water Use
1996	39,000 F.U. or 124 F.U./day	37,680 kWh/year or 0.97 kWh/F.U.	13,310 kg or .341 kg/F.U.	0.94 g or 2.4×10^{-5} g /F.U	37,620 L or 0.96L/F.U.
2006	10,500 F.U or 33 F.U./day	18,720 kWh/year or 1.78 kWh/F.U.	4,022 kg or .383 kg/F.U.	0.25 g or 2.5×10^{-5} g/F.U	9,800 L or 0.93L/F.U.

The following analysis is based on the results calculated in the previous sections.

The results are presented in the Figures 14 and 15.

Figure 14. Lab #2 Total Impact 1996 vs. 2006. Compares the total consumption of energy, associated CO₂e emissions, silver discharge, and the total amount of water used between the two years studied at Lab #2. Base 100 is applied to 1996 quantities (black bars).

Figure 15. Lab #2 Impact per F.U. 1996 vs. 2006. Compares the relative consumption of energy, associated CO₂e emissions, silver discharge, and the amount of water used per functional unit between the two years studied at Lab #2. Base 100 is applied to 1996 quantities (black bars).

Lab #2 electricity consumption was divided by two, between 1996 and 2006, while the total production was divided by four. The amount of electricity needed per functional unit went up from 0.97 kWh/F.U. to 1.78 kWh/F.U., doubling the amount of energy needed per F.U. in 2006. This result follows a pattern studied in the Lab #1 assessment; however, because of the Lab #2 policy to run its film processors only two hours a day in 2006, Lab #2 limited the increase in energy per F.U. CO₂e emissions linked to the production of the electricity consumed by Lab #2 is significantly higher than that of Lab #1, since the energy mix of the provider (PG&E) relied more heavily on powerplants using natural gas while Lab #1's supplier (CPAU) energy mix was coming from large hydro power.

Lab #2 has a different silver workflow than Lab #1, since it was a “hauling” facility; while Lab #1 was a “permitted” facility. In the Lab #2 case, all the silver-bearing solution was sent to the subcontractor. As a result of the different silver flow, Lab #2 did not directly discharge any silver into the environment. However, the Lab #2 subcontractor, ECS Refining did discharge silver compound as part of the refining process. Applying the same recovered/discharged silver ratio that was documented in the Lab #1 assessment, the Lab #2 silver outflow is estimated by proxy. The amount of silver recovered and discharged into the environment is directly proportionate to a photolab production, so the numbers estimated for Lab #2 are similar to those for Lab #1.

While Lab #2 production output was divided by a factor of 4, water consumption is estimated down by almost the same ratio. Water consumption is directly proportionate to the volume of production. Lab #2 total water consumption averages 1 liter per F.U., as

expected from a typical retail photolab operating with this type of processors during the timeframe of the study.

Between 1996 and 2006, Lab #2 lost 75% of its processing business. With careful management to adapt best practices in production, lowering output volume, Lab #2 proportionally reduced its environmental impact. The only resource that demonstrates a significant loss in productivity is electricity consumption, following the same pattern already documented in the Lab #1 assessment (see Section 3.1.3.).

3.3. Census in Palo Alto RWQCP Service Area

As noted in Section 2.3., the service area covered by the city of Palo Alto RWQCP is of special interest, since it is the first area in the U.S. where a source reduction program was implemented in 1991. Palo Alto RWQCP service area includes East Palo Alto sanitary district, Los Altos, Los Altos Hills, Mountain View, Palo Alto and Stanford University limits. From the 2000 U.S. Census, the total population of Santa Clara County was about 1,682,585; whereas, the population of the City of Palo Alto RWQCP service area was about 226,000 (Association of Bay Area Governments, 1997). Therefore, Palo Alto RWQCP service area represented about 13% of Santa Clara County's total population. According to the Palo Alto RWQCP annual report, the facility treated about 25 million gallons of wastewater every day, originating from domestic and industrial sources, before releasing it into the San Francisco Bay.

The City of Palo Alto ordinances regulating silver in wastewater went into effect September 30, 1991. All the facilities that were using photoprocessing silver-bearing chemical solutions had to be registered and acquired a permit for emissions (EPA, 1993). As academic researcher, I was granted access to the City of Palo Alto RWQCP permit database to establish a census of the photoprocessing facilities operating during the years 1996 and 2006, respectively. These data are considered public record; however, in order to protect the confidentiality of each business considered, the business names, exact addresses and contact information have not been disclosed. Margaret Zittle, Engineer Technician III from the Environmental Compliance Division at the City of Palo Alto Public Works Department, manages this specific database and was the contact person for this study. In September, October, and December of 2010, Zittle provided the aggregated data from the database, according to the query set-up for this study.

3.3.1. Photoprocessing Facility Census in 1996

Two types of facilities are identified in the Palo Alto RWQCP database. Those who subcontracted the silver recovery process from their silver-bearing solutions effluents are labeled “hauling” facilities, while the facilities equipped with a silver recovery unit are labeled “permitted” facilities. The hauling certification form asked each facility manager to evaluate the anticipated photoprocessing silver-bearing solutions volume hauled or treated per month. This included all fixer, bleach-fix and stabilizer from all photoprocessing equipment in use (see Appendix 1: Palo Alto RWQCP Hauling Certification Form, Appendix 2: Palo Alto RWQCP Annual Report for Silver

Treatment). The data are also aggregated to total the amount of photographic silver-bearing solutions used annually for the Palo Alto RWQCP service area.

Despite the fact that in 1996 the pilot source reduction program was already in place for five consecutive years, some “hauling” facilities, while identified, did not report a number for their anticipated monthly volume. These facilities whose consumption volume is unknown are listed as “non-documented,” while those who did properly fill out their annual reports are labeled “documented.” It is possible that many of these non-documented facilities were not in production mode during the year 1996; they were either in a business transition or already on their way to permanent closure. Others may have had a seasonal or occasional use of photoprocessing solutions, which created an additional challenge for the manager to self-declare a precise amount on the monthly permit form. These non-documented facilities represented a very small volume; therefore, in this study calculation, they were counted in the facility census with consumption equal to zero. For the year 1996, the number of “hauling”, “non-documented” facilities is 12 over the 50 registered, or 24% of the total.

“Permitted” facilities are usually larger than the hauling ones, with several photoprocessing units connected to a silver recovery unit. For the year 1996, all the “permitted” facilities that were under tight mandatory installation control are “documented.” In their “Annual Report for Silver Treatment,” the permitted facility manager is responsible to report the monthly volume of all silver-bearing overflow solutions used annually, as the “hauling” facilities. In addition, for the “permitted”

facilities, an independent lab is required to analyze a sample of the outflow of the treated effluent monthly and record the silver content of the solution. The facility manager must report all these monthly analyses and provide the official statements (Appendix 1 and 2).

In 1996, based on the data from Palo Alto RWQCP database, a total of 50 photoprocessing facilities were registered within Palo Alto RWQCP service area, producing an estimated total amount of 2,324,984 liters of silver-bearing solution effluents for that year; all of it officially processed to collect 99% of the silver content before discharged, either on site or in other remote processing sites. See results in Table 27 below.

Table 27

1996 Palo Alto RWQCP Photoprocessing Facilities Census

	Hauling Non- documented	Hauling Documented	Permitted Non- documented	Permitted Documented	Total
Number of facilities (#)	12	28	none	10	50
Efluent volume (L)	N.A.	1,054,903	none	1,270,081	2,324,984

Note. Original data from Palo Alto RWQCP Silver Permit Database. October 2010.

3.3.2. Photoprocessing Facility Census in 2006

In 2006, as the photoprocessing industry was in crisis around the world – due to the huge success of digital cameras – the local industry in Palo Alto was also in the process of adapting to the changing market. The data available from the city of Palo Alto RWQCP database shows that 2006 was a period of rapid change. The number of non-documented facilities totals 11 out of the 24 registered for the year 2006, or 46% of the total. Many of these non-documented facilities were either already closed by the end of the year or on their way to eliminating photoprocessing services. As for the year 1996, others non-documented facilities were using only occasionally photoprocessing solutions and did not report a monthly consumption in their annual report.

In 2006, a total of 24 photoprocessing facilities were registered within the Palo Alto RWQCP service area, producing a total of 624,275 liters of silver-bearing solutions effluents for the year – with all of it officially reprocessed to collect over 99% of its silver content before discharge, either on site or in other remote reprocessing sites. See results in Table 28.

Table 28

2006 Palo Alto RWQCP Photoprocessing Facilities Census

	Hauling Non- documented	Hauling Documented	Permitted Non- documented	Permitted Documented	Total
Number of facilities (#)	9	5	2	8	24
Efluent volume (L)	NA	169,117	NA	455,158	624,275

Note. Original data from Palo Alto RWQCP Silver Permit Database. October 2010.

3.3.3. Comparison Between 1996 and 2006

The first conclusion that can be drawn from this data is that the number of permitted photoprocessing locations decreased by half between 1996 and 2006, in the City of Palo Alto RWQCP service area. This is a significant reduction in a relative short period of time, which confirms the major changes that transformed the retail photoprocessing industry during this time frame.

A more important consequence of the switch from film in 1996 to digital cameras in 2006 is the massive reduction in the self-declared total volume of photoprocessing silver-bearing solutions used within the City of Palo Alto RWQCP service area.

Data shows a decline from 2,324,984 liters for the year 1996 to only 624,275 liters for the year 2006. The methodology used to estimate is strictly identical for the two years considered; therefore, a reduction of 73% of the total volume of photoprocessing silver-bearing solutions is a reliable number to assess the change in activity of the local retail photoprocessing industry between the two years studied. The comparative results are shown in the Figure 16 below.

Figure 16. Palo Alto RWQCP Service Area Retail Photoprocessing Sites Census. Base 100 is applied to 1996 quantities (black bars).

3.4. Results Scaled to Santa Clara County

The impact related to retail photoprocessing activities for the entire County of Santa Clara estimated in this section follows the principles and assumptions described below.

Principles used to estimate the total volume of silver-bearing photoprocessing solutions used yearly in Santa Clara County: The volume of silver-bearing photoprocessing solutions used is calculated in Sections 3.3.1 and 3.3.2 for the five cities of the Palo Alto RWQCP service area for 1996 and 2006 ($V_{RWQCP\ 1996}$ and $V_{RWQCP\ 2006}$). In this section, volumes $V_{Santa\ Clara\ 1996}$ and $V_{Santa\ Clara\ 2006}$ of the same effluents are estimated according to a population ratio between the Palo Alto RWQCP service area and Santa Clara County.

Assumptions used to estimate the total volume of silver-bearing photoprocessing solutions used yearly in Santa Clara County: The basis for this calculation is that across the Santa Clara County, the number of retail photoprocessing facilities, per capita, is the same as the density of labs, per capita, documented in Palo Alto RWQCP service area. The calculations are based on population data from the 2000 Census. The population of Santa Clara County is about $P_{Santa\ Clara} = 1,682,585$ people; whereas, the population of the City of Palo Alto RWQCP service area is about $P_{RWQCP} = 226,000$. Therefore, the Palo Alto RWQCP service area represents about 13% of the total population of Santa Clara County (U.S. Census Bureau, 2000). In 1996, the total volume of silver-bearing photoprocessing solutions used yearly in Palo Alto RWQCP is equal to $V_{RWQCP\ 1996} =$

2,324,984 liters. In 2006, $V_{RWQCP\ 2006} = 624,275$ liters. Calculations follow the formula below and the results are summarized in Table 29.

$$V_{\text{Santa Clara}} (\text{liters}) = \frac{P_{\text{Santa Clara}} (\text{People})}{P_{RWQCP} (\text{People})} \times V_{RWQCP} (\text{liters})$$

Table 29

Volume of Silver-Bearing Photoprocessing Solutions Used Yearly in Santa Clara County for 1996 and 2006

	V_{RWQCP}	$P_{\text{Santa Clara}} / P_{RWQCP}$	$V_{\text{Santa Clara}}$
1996	2,324,984 liters	1,682,585 / 226,000	17,309,660 liters
2006	624,275 liters	1,682,585 / 226,000	4,647,769 liters

The total volume of silver-bearing photoprocessing solutions used in Santa Clara County by the retail photoprocessing industry is estimated to 17,309,660 liters in 1996 and 4,647,769 liters in 2006.

As previously established, the volume of silver-bearing photoprocessing solution used by photolabs is directly proportional to their production output expressed in F.U. (T). From the Lab #1 assessment in Section 3.1.2.3., it is possible to calculate the ratios: $S_{1996} = 0.097$ liter of silver-bearing solution per F.U., and $S_{2006} = 0.094$ liter of

silver-bearing solution per F.U. Table 30 presents calculations to establish the estimated retail photoprocessing total production from its annual volume of silver-bearing photoprocessing solution used within Santa Clara County.

Table 30

Total Retail Photoprocessing Production Output in Santa Clara County

	$V_{\text{Santa Clara}}$	S	$T = V / S$
1996	17,309,660 liters	0.097 liter per F.U.	1,784,501 F.U.
2006	4,647,769 liters	0.094 liter per F.U.	494,443 F.U.

Total retail photoprocessing production in Santa Clara County is estimated equal to 1,784,501 F.U. in 1996 and 494,443 F.U. in 2006.

Principles used to estimate the total electricity consumed, CO₂e emissions, silver discharge and water use by the retail photoprocessing industry in Santa Clara County: From the Lab #1 comparative assessment in Section 3.2.3. and the Lab #2 comparative assessment in Section 3.3.3., the impact per F.U. is estimated for two typical photolabs. These estimates are related to the total number of F.U. produced by similar photolabs within Santa Clara County.

Assumptions used to estimate the total electricity consumed, CO₂e emissions, silver discharge and water use by the retail photoprocessing industry in Santa Clara County: For each category, a low and high estimate is calculated using the different values per F.U. from the Lab #1 and Lab #2 assessments. Results are summarized in Table 31.

Table 31

County of Santa Clara Retail Photoprocessing Impact, Raw Results

	Source of Data per F.U.	Electricity Consumption Associated	CO ₂ e Emissions from Electricity	Silver Discharged in the Environment	Water Use
1996	Lab #1	(0.77 kWh/F.U.) 1,374,066 kWh	(0.094kg/F.U.) 167,743 kg	2.310 ⁻⁵ g/F.U. 41 g	0.82 L/F.U. 14.6 10 ⁵ L
	Lab #2	or (0.97 kWh/F.U.) 1,730,966 kWh	or (0.34 kg/F.U.) 606,730 kg	or 2.410 ⁻⁵ g/F.U. 43 g	or 0.96L/F.U. 17.1 10 ⁵ L
2006	Lab #1	(4.61 kWh/F.U.) 2,279,385 kWh	(0.177kg/F.U.) 87,516 kg	2.410 ⁻⁵ g/F.U. 12 g	1.07 L/F.U. 5.3 10 ⁵ L
	Lab #2	or (1.78 kWh/F.U.) 880,109 kWh	or (0.38 kg/F.U.) 188,100 kg	or 2.510 ⁻⁵ g/F.U. 12 g	or 0.93L/F.U. 4.6 10 ⁵ L

3.4.1. Study Questions 1 and 2 Analysis

Study question (1) is as follows:

(1) How much energy and water were consumed for two case study retail photoprocessing labs in Santa Clara County in 1996 versus 2006? What quantity of associated CO₂e emissions were generated? How much silver was discharged?

The information in Table 31 summarizes the energy and water consumption per F.U., as well as the amount of silver discharged per F.U. by Lab #1 and Lab #2 for the years 1996 and 2006, respectively. The impacts are estimated for Santa Clara County, based on the two sets of results from Lab #1 and Lab #2. The differences between the results based on Lab #1 and Lab #2 are commented in the replies to the study question (2).

Study question (2) is as follows:

(2) How much energy and water were consumed by the retail photoprocessing industry in Santa Clara County in 1996 versus 2006? What quantity of associated CO₂e emissions were generated? How much silver was discharged?

Principles to Estimate Electricity Consumption in 1996

Countywide electricity consumption is estimated between 13.7 10⁵ kWh (Lab #1) and 17.3 10⁵ kWh (Lab #2) using data from Lab #1 and Lab #2 respective assessments. The two numbers show a significant gap because Lab #2 assessment includes a slide film processor, while Lab #1 was not equipped with this type of processor. While it is unusual that retail photoprocessing facilities offer slide film or black and white film processing, the average between the two values is calculated without priority of one estimate over the

other. The retail photoprocessing total electricity consumption is estimated to be 15.5×10^5 kWh for Santa Clara County in 1996.

Principles to Estimate Electricity Consumption in 2006

Countywide electricity consumption is estimated to be 22.8×10^5 kWh and 8.8×10^5 kWh, using data from Lab #1 and Lab #2 respective assessments. The significant difference from the two estimates is because Lab #2 was equipped with a slide film processor, and that Lab #2 film processors were manually switched on only two hours per day, following the drop in demand for film processing. Other photolabs may have adopted this production method. To reflect in the calculation that half of the facilities closed between 1996 and 2006 the lower number (Lab #2 results) is the basis used to calculate the total electricity consumed in Santa Clara County in 2006. The retail photoprocessing total electricity consumption is estimated equal to be 8.8×10^5 kWh for Santa Clara County in 2006.

Principles to Average CO₂e Emissions in 1996

The CO₂e emissions estimates from Lab #2 are chosen to reflect the entire retail photoprocessing industry countywide since its provider, PG&E, is the leading electricity supplier in the county. The retail photoprocessing total CO₂e emissions related to electricity generation is estimated to be 6.1×10^5 kg in Santa Clara County in 1996.

Principles to Average CO₂e Emissions in 2006

The CO₂e emissions are estimated following PG&E power mix and CO₂e efficiency as documented in Section 3.3.2.2. using the total electricity consumption estimated for the

year 2006 in Santa Clara County, as equal to $8.8 \cdot 10^5$ kWh. The retail photoprocessing total CO₂e emissions related to electricity generation is estimated to be $1.9 \cdot 10^5$ kg for Santa Clara County in 2006.

Principles to Average Silver Discharge in 1996

Countywide silver discharge consumption is estimated between 41 g and 43 g using data from Lab #1 and Lab #2 respective assessments. The average is calculated without prioritizing one estimate over the other. The retail photoprocessing total silver discharge is estimated equal to 42 g for Santa Clara County in 1996.

Principles to Average Silver Discharge in 2006

Countywide silver discharge consumption is estimated to be 12 g, using data from the Lab #1 and Lab #2's respective assessments. The average is calculated without prioritizing one estimate over the other. The retail photoprocessing total silver discharge is estimated equal to 12 g for Santa Clara County in 2006.

Principles to Average Water Use in 1996

Countywide water consumption is estimated to be between $14.6 \cdot 10^5$ L and $17.1 \cdot 10^5$ L, using data from Lab #1 and Lab #2's respective assessments. The average is calculated without prioritizing one estimate over the other. The retail photoprocessing total water use is estimated to be $15.9 \cdot 10^5$ L for Santa Clara County in 1996.

Principles to Average Water Use in 2006

Countywide water consumption is estimated to be between $5.3 \cdot 10^5$ L and $4.6 \cdot 10^5$ L using data from Lab #1 and Lab #2's respective assessments. The average is calculated without

prioritizing one estimate over the other. The retail photoprocessing total water use is estimated to be $5 \cdot 10^5$ L for Santa Clara County in 2006. Table 32 summarizes final results to study question (2). Figure 17 compares the results between 1996 and 2006.

Table 32

County of Santa Clara Retail Photoprocessing Impact, Final results

	Yearly Production	Electricity Consumption	CO ₂ e Emissions	Silver Discharged	Water Use
1996	1,784,501 F.U.	$15.5 \cdot 10^5$ kWh	$6.1 \cdot 10^5$ kg	42 g	$15.9 \cdot 10^5$ L
2006	494,443 F.U.	$8.8 \cdot 10^5$ kWh	$1.9 \cdot 10^5$ kg	12 g	$5 \cdot 10^5$ L

Figure 17. Santa Clara County Retail Photoprocessing Industry Impact 1996 vs. 2006. Base 100 is applied to 1996 quantities (black bars).

3.4.2. Significance of Results of Study Question 3

Study question (3) is as follows:

(3) What are the implications of county-level findings for the retail photoprocessing industry nationally and the larger photo industry?

The use of electricity shows a cost of electricity per F.U. that is multiplied by four. This fact alone drastically changed the competitiveness of color film photography. It was difficult for any retail photoprocessing business that relied only on this specific

activity to remain profitable after the digital camera transition era. As a consequence, half of the retail photoprocessing locations were closed in Santa Clara County between 1996 and 2006. The market forced many other facilities to shut down their operations after 2006, as only eight retail photoprocessing locations remained documented by the Palo Alto RWQCP database in 2010. Nationwide, a similar proportion of retail photoprocessing businesses closed or had to reinvent their activities by moving from photoprocessing to other photography-related commercial activities (portrait, digital hardware, and accessory sales).

In 2006, estimates of the total electricity consumption from photoprocessing activities show a 43% reduction in energy consumption in Santa Clara County. Since 2006, the closure of retail photoprocessing facilities has accelerated. With a few of these conventional retail photoprocessing facilities still in operation as of 2010, the electricity consumption related to photoprocessing is becoming very low. The continued replacement of conventional processors by digital printers or drylabs (as presented in Section 2.5) is bringing substantial improvement to the electricity consumed per print. The benefit in terms of GHG emissions could be significant in the near future, but it will certainly be offset by the electricity consumption of the many visualization devices that digital photographers are increasingly using every day, such as digital cameras, cell-phones, computers, and digital photo frames. If the 1.7 million people from Santa Clara County were to spend 100 hours per year (approximately 15 minutes a day) watching digital photographs on a device consuming 0.010 kWh (the average weighted electricity consumption between a desktop computer and a smart phone), total electricity

consumption would be 17×10^5 kWh per year, already more than that consumed by the retail photoprocessing industry within the same zone in 1996. The future of electricity consumption related to consumer photography depends on the new methods used by digital photographers.

The change in terms of silver discharge is almost insignificant, since the remaining quantities that were discharged after the mandatory silver recovery were already negligible in 1996 for Santa Clara County (42 g), where a strict silver control plan was already in place. The local wetland environment will benefit from the reduction of silver discharge, but the recovery may be decades away due to the damage done prior to 1990 when a documented 4,000 kg of silver compound was discharged into San Francisco Bay each year.

The only local environmental benefit from the downturn of the retail photoprocessing industry—especially for Santa Clara County where fresh water supplies have to be closely managed in the future—is the amount of water that is spared annually by the retail photoprocessing industry. Comparing 1996 to 2006, the volume of unconsumed water equals 10^6 liters, totaling the annual consumption of 4 to 6 single-family homes in Santa Clara County, showing a 68% decrease in water consumption. As this study focuses exclusively on the retail photoprocessing industry, which represented only 20% to 30% of the total photoprocessing activity (see Section 1.2.3.), the local volume of unconsumed water related to the digital camera switch is expected to be four times greater.

Conclusions and Recommendations

The future of the electricity consumption related to consumer photography has yet to be studied in terms of digital imaging. On one side, the amount of electricity that was consumed by the photoprocessing industry is declining. On the other side, new ways to visualize, share and store pictures rely on regular use of digital devices, such as computers, TV screens and smartphones, which are consuming electricity and have the potential to increase the net amount. In order to keep GHG emissions related to the electricity consumed by photographers under control in a 100% digital world, it is critical that screen technologies that are less energy intensive be designed. Liquid Crystal Display (LCD) screens with Light-Emitting Diode (LED) backlighting are promising, but ultra low energy consumption screen technologies like electronic ink or Organic Light-Emitting Diode (OLED) must come to market to avoid an electricity consumption that will rise with digital imaging technologies thriving. Sustainable electricity generation from wind, sun and waves should also be a key priority to keep GHG emissions under control.

The retail photoprocessing silver discharge control plan that was in place in 1996 can be categorized as a typical societal response to a documented heavy metal environmental issue. Each species of heavy metal has a different environmental impact; however, the future heavy metal impact of consumer photography is expected to rise with digital imaging. Digital cameras and the batteries that power them, as well as all the aforementioned visualization devices will quickly become e-waste, carrying large amount of cadmium, lead, copper and gold, all heavy metals that could end-up in the local

environment. Global programs must hold the photo industry, as well as the electronic industry at large, accountable for the collection and recycling of the products manufactured.

With the downturn of the photoprocessing business, conventional processor and photopaper are expected to be phased-out within a few years. Drylabs and other digital printing technologies will replace silver-based photoprocessing. In January 2008, a PMA member chosen to test one of the early drylab asked for a complete analysis of the waste byproducts that the equipment produced. The results show that the used cartridges and the replacement ink collection pad were carrying large amount of copper particulates (see Appendix 3: Photo Printer Waste Stream Analytical Laboratory Report) and had to go through a specific recycling process. Unfortunately, mandatory legislation and proper recycling paths have yet to be organized in California for these new type of hazardous waste. As this first analysis shows, drylab and digital printing will bring new environmental issues that have yet to be properly managed. As conventional photoprocessors were forced to recover their silver emissions in the mid 1990s, digital photoprocessors and inkjet printer manufacturers have to be regulated and forced to recover and recycle the inkjet printer parts and used ink cartridges.

In the 1970s and 80s, when color photoprocessing was using running water as a final bath, the quantity of fresh water consumed by the industry was a real environmental concern. The new stabilization technology, coupled with low-rate replenishment photoprocessing solutions, brought a significant improvement to conventional photoprocessing, reducing by a factor 1000x the amount of fresh water use per roll of

film processed. Between 1996 and 2006, the downturn of the retail photoprocessing industry, as well as these technological improvements helped to save the equivalent of 4-6 single-family annual water consumptions in Santa Clara County. Water use attached to photography is no longer an issue at the local level. Globally, however, the large amount of fresh water necessary for the manufacturing of the electronic digital imaging devices is an issue that must be managed where the production centers are located, on a case-by-case analysis.

This study demonstrates a classic pattern of innovation and social interaction. Technological innovations are not environmentally driven, they are user driven. As a consequence, technological innovations do not solve environmental issues but rather displace them. Widespread environmental education and awareness are required to transform the users of the many technological innovations to come into consumer watchdogs.

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APPENDIXES

6.1. Appendix A: Palo Alto RWQCP Hauling Certification Form

Regional Water Quality Control Plant

Operated by the City of Palo Alto
for the East Palo Alto Sanitary District,
Los Altos, Los Altos Hills, Mountain View,
Palo Alto, and Stanford

REGIONAL WATER QUALITY CONTROL PLANT

HAULING CERTIFICATION

COMPANY NAME: _____

ADDRESS: _____

CITY: _____ Zip Code: _____

Contact Name: _____ Phone: _____

Photoprocessing Waste Hauler: _____

Anticipated Volume of "Spent Solutions" Hauled: _____/month

I declare that this facility will arrange to have all fix, bleach fix, stabilizer from washless systems, silver-bearing cleaning solutions and functionally similar solutions ("spent solutions") hauled away for appropriate, off-site silver recovery and/or disposal by fully licensed contractors. In addition, it is my understanding that no spent solutions will be discharged to the sanitary sewer system unless I first obtain a photoprocessing waste discharge permit from the Regional Water Quality Control Plant.

Signature

Date

FOR APPLICATION FORMS CALL 916/324-1781

Please print or type with ELITE type (12 characters per inch) in the unshaded areas only

Form Approved OMB No 2001-0001 EPA Form 10-1 (1-90)
GSA No. 754F-004-001

<p><small>*Please refer to the Instructions for Filing Notification before completing this form. The information requested here is required by law (Section 3010 of the Resource Conservation and Recovery Act).</small></p>	 Notification of Regulated Waste Activity United States Environmental Protection Agency	Date Received (For Official Use Only)
I. Installation's EPA ID Number (Mark 'X' in the appropriate box)		
☐ A. First Notification	☐ B. Subsequent Notification <small>(complete item C)</small>	C. Installation's EPA ID Number
II. Name of Installation (Include company and specific site name)		
YOUR COMPANY		
III. Location of Installation (Physical address not P.O. Box or Route Number)		
Street YOUR ADDRESS		
Street (continued)		
City or Town YOUR CITY	State CA	ZIP Code XXXXX-
County Code YOUR COUNTY		
IV. Installation Mailing Address (See Instructions)		
Street or P.O. Box MAILING ADDRESS		
City or Town	State	ZIP Code
V. Installation Contact (Person to be contacted regarding waste activities at site)		
Name (last) CONTACT PERSON	(first) JOE	
Job Title TITLE	Phone Number (area code and number) XXX-XXX-XXXX	
VI. Installation Contact Address (See Instructions)		
A. Contact Address Location Mailing	B. Street or P.O. Box ADDRESS	
City or Town YOUR CITY	State CA	ZIP Code
VII. Ownership (See Instructions)		
A. Name of Installation's Legal Owner LEGAL OWNER		
Street, P.O. Box, or Route Number ADDRESS		
City or Town CITY	State	
Phone Number (area code and number) XXX-XXX-XXXX	B. Land Type ☐	C. Owner Type ☐
D. Change of Owner Indicator Yes ☐ No ☐		(Date Changed) Month Day Year

EPA Form 8700-12 (01-90) Previous edition is obsolete

Continue on reverse

ID - For Official Use Only

VIII. Type of Regulated Waste Activity (Mark 'X' in the appropriate boxes. Refer to instructions.)

A. Hazardous Waste Activity		B. Used Oil Fuel Activities
<p>1. Generator (See Instructions)</p> <p>☐ a. Greater than 1000kg/mo (2,200 lbs.)</p> <p>☒ b. 100 to 1000 kg/mo (220 - 2,200 lbs.) 270-23,000 GALS</p> <p>☐ c. Less than 100 kg/mo (220 lbs.) (27 gals)</p> <p>2. Transporter (Indicate Mode in boxes 1-5 below)</p> <p>☐ a. For own waste only</p> <p>☐ b. For commercial purposes</p> <p>Mode of Transportation</p> <p>☐ 1. Air</p> <p>☐ 2. Rail</p> <p>☐ 3. Highway</p> <p>☐ 4. Water</p> <p>☐ 5. Other - specify </p>		<p>3. Treater, Storer, Disposer (at installation)</p> <p>Note: A permit is required for this activity; see instructions.</p> <p>4. Hazardous Waste Fuel</p> <p>☐ a. Generator Marketing to Burner</p> <p>☐ b. Other Marketers</p> <p>☐ c. Burner - indicate device(s) - Type of Combustion Device</p> <p>☐ 1. Utility Boiler</p> <p>☐ 2. Industrial Boiler</p> <p>☐ 3. Industrial Furnace</p> <p>☐ 5. Underground Injection Control</p>
		<p>1. Off-Specification Used Oil Fuel</p> <p>☐ a. Generator Marketing to Burner</p> <p>☐ b. Other Marketer</p> <p>☐ c. Burner - indicate device(s) - Type of Combustion Device</p> <p>☐ 1. Utility Boiler</p> <p>☐ 2. Industrial Boiler</p> <p>☐ 3. Industrial Furnace</p> <p>2. Specification Used Oil Fuel Marketer (or On-site Burner) Who First Claims the Oil Meets the Specification</p>

IX. Description of Regulated Wastes (Use additional sheets if necessary)

A. Characteristics of Nonlisted Hazardous Wastes. Mark 'X' in the boxes corresponding to the characteristics of nonlisted hazardous wastes your installation handles (See 40 CFR Parts 261.20 - 261.24)

1. Ignitable (D001)	2. Corrosive (D002)	3. Reactive (D003)	4. EP Toxic (D000)
☐	☐	☐	☒

(SILVER)

(List specific EPA hazardous waste number(s) for the EP Toxic contaminant(s))

D001

B. Listed Hazardous Wastes. (See 40 CFR 261.31 - 33. See instructions if you need to list more than 12 waste codes)

1	2	3	4	5	6
7	8	9	10	11	12

C. Other Wastes. (State or other wastes requiring an ID number. See instructions)

1	2	3	4	5	6

X. Certification

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this and all attached documents, and that based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment.

Signature	Name and Official Title (type or print)	Date Signed

XI. Comments

Note: Mail completed form to the appropriate EPA Regional or State Office. (See Section III of the booklet for addresses.)

Please print or type. (Form designed for use on elite (12 pitch typewriter).)

UNIFORM HAZARDOUS WASTE MANIFEST		1. Generator's US EPA ID No.	Manifest Document No.	2. Page 1 of	Information in the shaded areas is not required by Federal law
3. Generator's Name and Mailing Address				A. State Manifest Document Number 88459100	
4. Generator's Phone ()				B. State Generator's ID	
5. Transporter 1 Company Name		6. US EPA ID Number		C. State Transporter's ID	
7. Transporter 2 Company Name		8. US EPA ID Number		D. Transporter's Phone	
9. Designated Facility Name and Site Address		10. US EPA ID Number		E. State Transporter's ID	
				F. Transporter's Phone	
				G. State Facility's ID	
				H. Facility's Phone	
11. US DOT Description (Including Proper Shipping Name, Hazard Class, and ID Number)		12. Containers No.	Type	13. Total Quantity	14. Unit Wt./Vol.
a.					L. Waste No.
b.					State
c.					EPA/Other
d.					State
					EPA/Other
J. Additional Descriptions for Materials Listed Above				K. Handling Codes for Wastes Listed Above	
				a.	
				b.	
				c.	
				d.	
15. Special Handling Instructions and Additional Information					
16. GENERATOR'S CERTIFICATION: I hereby declare that the contents of this consignment are fully and accurately described above by proper shipping name and are classified, packed, marked, and labeled, and are in all respects in proper condition for transport by highway according to applicable international and national government regulations. If I am a large quantity generator, I certify that I have a program in place to reduce the volume and toxicity of waste generated to the degree I have determined to be economically practicable and that I have selected the practicable method of treatment, storage, or disposal currently available to me which minimizes the present and future threat to human health and the environment; OR, if I am a small quantity generator, I have made a good faith effort to minimize my waste generation and select the best waste management method that is available to me and that I can afford.					
Printed/Typed Name			Signature		
			Month Day Year		
17. Transporter 1 Acknowledgement of Receipt of Materials					
Printed/Typed Name			Signature		
			Month Day Year		
18. Transporter 2 Acknowledgement of Receipt of Materials					
Printed/Typed Name			Signature		
			Month Day Year		
19. Discrepancy Indication Space					
20. Facility Owner or Operator Certification of receipt of hazardous materials covered by this manifest except as noted in Item 19					
Printed/Typed Name			Signature		
			Month Day Year		

COMPLIANCE INFORMATION

The following items describe some of the requirements relating to the hauling option for compliance. For more detail please see the **Silver Source Control Information** sent to your facility or contact the agencies responsible for these requirements at the numbers listed below:

EPA ID Number:

In order to have your Spent Solutions waste hauled away for silver reclamation, you must first obtain a Hazardous Waste Generator's Identification number. The number must be entered on the hazardous waste shipping manifests each time waste is picked-up. For more information, please see the **Silver Source Control** materials that was sent to your office or call State Department of Health Services at 916-324-1781.

Hazardous Waste Storage:

"Spent Solutions" stored at your facility must be held in a sturdy container with sealable lid. Each container must have a hazardous waste label which identifies the contents and the date when the container was first filled. In addition, spent solutions should be stored in secondary containment (Secondary containment includes any tray, barrel or area which has the capacity to contain the entire volume of the storage container if it should break). Your waste hauler may provide labels, containers and manifest assistance for your facility. Please contact the hazardous Materials coordinator at your local fire department if you need more information about storage.

Record Keeping:

Records of all regulated solutions (fix and bleach fix) purchased and all spent solutions hauled away should be maintained on a log sheet (enclosed) and should be made available to any Fire, Regional Water Quality Control Plant or City inspector immediately upon their request. Contact Maree Doden with questions about record keeping, RWQCP, at 329-2495.

6.2. Appendix B: Palo Alto RWQCP Annual Report for Silver Treatment

Regional Water Quality Control Plant

Operated by the City of Palo Alto
for the East Palo Alto Sanitary District,
Los Altos, Los Altos Hills, Mountain View,
Palo Alto, and Stanford

Annual Report for Silver Treatment

This report covers the January 1-December 31, 2006 operating period. Please write in any corrections to the facility information below as necessary. Answer all questions and return the signed report to our office by March 20, 2007. Please submit any comments, questions or additional information with the report or call Margaret Zittle at 329-2514. Thank you for your time and cooperation.

Return completed forms to: Margaret Zittle, RWQCP
2501 Embarcadero Way, Palo Alto CA 94303

Permit Number:

Mailing Address:

Facility Address:

Same

Contact Person:

Phone Number:

Fax Number:

1. Transfer sampling results to the enclosed table and attach copies of all waste water analysis forms received from certified laboratories.
2. Estimate the volumes:

Chemistry	Monthly Volumes in Gallons		
	Average	Maximum	Minimum
Fix	2.4	33	8
Bleach-Fix	20	28	9
Stabilizer (Washless Systems)	58	73	36
Bleach	1.4	2	.78
Washwater	0	0	0

3. List the manufacturer and model number for all treatment equipment currently in use.

Equipment	Date Installed
HALLMARK BFX 1002 ELECTROLYTIC SYSTEM	6-15-94
HALLMARK PUMPING STATION # 202246	12-18-92
HALLMARK HOLDING TANK 70 GAL	6-2-97
HALLMARK MK9 RECOVERY COLUMNS	

4. Describe all improvements or changes made to the processing and treatment equipment during the reporting period.

MONTHLY MAINTENANCE OF SILVER RECOVERY UNIT. ROTATION OF AND REPLACEMENT OF MK9 COLUMNS AS REQUIRED TO OPTIMIZE SIZE.

Has your system been serviced at least once per year and all service been recorded in a log book?
 YES X NO

I have reviewed the information submitted in this report and believe it to be true, accurate and complete.

Name/Title of Responsible Person
 AL ILLIOTT

Signature
 AL ILLIOTT

Date
 1

Regional Water Quality Control Plant
Silver Source Control Program
Self Monitoring Results Form

Facility Name:

Permit Number:

Sampling Date	Sampling Location	Result (ppm)	Detection Limit	Discharge Rate (gpd)
1/18/06	DRAIN	0.57	0.01	4.2
2/27/06	DRAIN	0.02	0.01	2.8
3/23/06	DRAIN	0.25	0.01	2.8
4/20/06	DRAIN	0.07	0.01	4
5/19/06	DRAIN	0.12	0.01	2.8
6/23/06	DRAIN	0.61	0.01	3.8
7/21/06	DRAIN	0.04	0.01	2.4
8/17/06	DRAIN	0.7	0.01	4.1
9/26/06	DRAIN	0.22	0.01	4.1
10/18/06	DRAIN	0.41	0.01	4
11/21/06	DRAIN	0.18	0.01	3.6
12/19/06	DRAIN	0.14	0.01	2.4

Any violation of the 1.0 mg/L silver discharge limit must be reported to the Regional Water Quality Control Plant as soon as the violation is discovered.

2000												TOTAL 2 GAL	
8-3-01-9													
	Jan	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	
8	78	53	69	44	69	74	49	98	44	68	62	93	
94 Dev G	20	14	18	12	18	19	13	26	12	18	16		AVG/MO = 16
94 Beach FG	90	68	75	83	35	93	55	90	83	90	73	108	1 8 6
94 STAB G	24	18	20	22	9	19	14	24	22	24	19	28	AVG/MO = 20
92 Dev G	220	155	190	205	110	205	90	220	185	220	185	115	2 4 3
72 Black	58	41	50	54	29	54	24	58	49	58	49	30	AVG/MO = 46
72 STAB G	18	27	9	36	18	27	27	36	27	27	27	18	5 5 4
72 Black	5	7	2	9	5	7	7	9	7	7	7	5	7
72 STAB G	5	3	1	6	7	8	6	7	8	5	6	3	AVG/MO = 6
72 Black	1	78	24	15	2	2	16	2	2	13	16	78	1 7
72 STAB G	33	20	7	40	46	53	37	46	53	33	37	20	AVG/MO = 1-4
72 Black	9	5	2	10	12	14	10	12	14	9	10	5	1 1 2
72 STAB G	40	24	8	48	56	64	48	56	64	40	48	24	AVG/MO = 9
72 Black	10	6	2	13	15	17	13	15	17	10	13	6	AVG/MO = 11
72 STAB G	90	70	50	80	70	40	40	50	40	70	60	10	1 3 7
72 Black	24	18	13	21	18	10	10	13	10	18	16	3	AVG/MO = 15
72 STAB G	33	23	15	31	30	24	20	25	24	27	26	8	1 7 4
72 Black	68	47	52	67	44	71	37	73	66	68	62	36	AVG/MO = 24
72 STAB G	68	47	52	67	44	71	37	73	66	68	62	36	AVG/MO = 58
72 Black	68	47	52	67	44	71	37	73	66	68	62	36	6 9 1

6.3. Appendix C: Drylab Waste Stream Analytical Laboratory Report

26955
Thursday, January 17, 2008
Page 2 of 5

Analytical Laboratory Report								
Client Identification:	Photo Marketing Association	Sample Matrix:	Other (Solid)					
Fibertec Project Number:	26955	Sample Number:	26955-001					
Client Sample Information								
Project Identification:	Photo Printer Waste Streams	Client Sample Description:	Overspray Tray					
Project Number:	NA	Client Sample Number:	1					
Sample Date:	1/9/2008	Chain of Custody Number:	72787					
Comments:	ND = Not Detected at or above the reporting limit; RL = Reporting Limit; NA = Not Applicable/Not Available FF = Field Filtered; B = Analyte detected in blank; TIC = Tentatively Identified Compound; E = Estimated value; J = Analyte positively identified - estimated value X - Spike recovery distorted due to elevated sample target analyte concentration ($\geq 4X$ the amount spiked) Y - Spike unrecoverable due to sample dilution.							
Definitions:								
Analyte	Result	Units	Report Limit	Dilution Factor	Prep Batch	Prep Date/Time	Analysis Date/Time	Analyst
Michigan 10 Elements by ICP/MS (EPA 3050B/EPA 6020)								
Arsenic	ND	µg/kg	100	1	44801	1/14/2008	1/14/2008	EJA
Barium	1000	µg/kg	1000	1	44801	1/14/2008	1/14/2008	EJA
Cadmium	ND	µg/kg	50	1	44801	1/14/2008	1/14/2008	EJA
Chromium	2400	µg/kg	500	1	44801	1/14/2008	1/14/2008	EJA
Copper	1300000	µg/kg	1000	1	44801	1/14/2008	1/14/2008	EJA
Lead	ND	µg/kg	1000	1	44801	1/14/2008	1/14/2008	EJA
Selenium	460	µg/kg	200	1	44801	1/14/2008	1/14/2008	EJA
Silver	ND	µg/kg	100	1	44801	1/14/2008	1/14/2008	EJA
Zinc	1800	µg/kg	1000	1	44801	1/14/2008	1/14/2008	EJA
TCLP MI-10 Elements by ICP/MS (EPA 3010A/EPA 6020) (TCLP (1311) Extraction Date: 1/14/2008)								
Arsenic	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
Barium	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
Cadmium	ND	mg/L	0.20	1	44808	1/15/2008	1/15/2008	EJA
Chromium	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
Copper	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
Lead	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
Selenium	ND	mg/L	0.20	1	44808	1/15/2008	1/15/2008	EJA
Silver	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
Zinc	ND	mg/L	1.0	1	44808	1/15/2008	1/15/2008	EJA
1914 Holloway Drive 11766 E. Grand River 8660 S. Mackinaw Trail		Holt, MI 48842 Brighton, MI 48116 Cadillac, MI 49601		T: (517) 699-0345 T: (810) 220-3300 T: (231) 775-8368		F: (517) 699-0388 F: (810) 220-3311 F: (231) 775-8584		
lab@fibertec.us								