VIABLE ALTERNATIVES TO

PERCHLOROETHYLENE IN DRY CLEANING

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Disclaimer

Jacobs Engineering (Jacobs) prepared this document under contract to the City of Los Angeles Environmental Affairs Department (EAD). Much of the presented data is based on recent studies and reports issued by the South Coast Air Quality Management District (SCAQMD), the United States Environmental Protection Agency (USEPA) Design for the Environment (DfE) Program, and other reference sources as noted.

No dry cleaners were interviewed and no site visits were conducted to refine or validate the assembled data. Previous experience has shown that the level of resources needed to conduct a reliable, comprehensive, and accurate survey can be extensive. Given the dynamic changes occurring in the industry, the identification of a representative group of dry cleaners using each technology would be a major undertaking by itself. It was not the intent of the City to conduct extensive interviews or field surveys to confirm or refute the data that has been published to date.

Instead, collected data was reviewed for consistency and it was then used to prepare a standardized cost assessment for the alternatives of interest. Such standardization was necessary so as to fill in data gaps and to allow for a comparison of one alternative to another on an equal basis. This report, in addition to compiling all of the collected data and presenting the findings of the assessment, serves as the source document for an English language and Korean language "fact sheet" aimed at local dry cleaners.

While the information presented is believed to be derived from accurate and reliable sources, no claim is made as to the suitability of a given process or product for a specific facility. Compliance with all environmental and occupational health and safety laws is the responsibility of each individual business. Any person, entity, or third party relying upon the contents of this report does so at their own risk. The mention of commercial products, sources, or their use is not to be construed as either an actual or implied endorsement by Jacobs or the City of Los Angeles.

Table of Contents

1.0 Introduction.......... 1

1.1 Background.......... 1

1.2 Summary and Conclusions.......... 2

2.0 Basis of Concern.......... 4

2.1 Air Quality.......... 4

2.2 Air Toxics.......... 5

2.3 Cancer Risk.......... 5

2.4 Worker Health and Safety.......... 6

2.5 Other Impacts.......... 7

3.0 Regulatory OVERVIEW.......... 7

3.1 SCAQMD Rules 1421 and 1402.......... 7

3.1.1 Implementation Timeline.......... 8

3.1.2 Operational Requirements.......... 9

3.1.3 Solvent Usage Limits.......... 10

3.1.4 Financial Incentives.......... 11

3.2 Fire Permits.......... 11

3.3 Sewer Permits.......... 13

4.0 Industry Characteristics.......... 13

4.1 Support Operations.......... 13

4.2 Dry Cleaning System Evolution.......... 14

4.2.1 1st Generation 14

4.2.2 2nd Generation 16

4.2.3 3rd Generation 16

4.2.4 4th and 5th Generation 17

4.3 Basin Population 18

5.0 Alternative Technologies 18

5.1 New Perc-Based Systems 19

5.1.1 Solvent Availability; Use; Health & Safety 19

5.1.2 System Availability 19

5.1.3 Capital Cost and Equipment Life 20

5.1.4 Operating Costs and Cycle Time 20

5.1.5 Energy Use 21

5.1.6 Cleaning Performance 21

5.1.7 Permitting and Rule Compliance 22

5.1.8 Waste Generation 22

5.1.9 Grant Funding 23

5.1.10 Training Requirements 23

5.2 Solvent-Based Technologies 23

5.2.1 Solvent Availability; Use; Health and Safety 23

5.2.2 System Availability 28

5.2.3 Capital Cost and Equipment Life 29

5.2.4 Operating Cost and Cycle Time 30
5.2.5 Energy Use 30
5.2.6 Cleaning Performance 31
5.2.7 Permitting and Rule Compliance 31
5.2.8 Waste Generation 34
5.2.9 Grant Funding 34
5.2.10 Training Requirements 34
5.3 Professional Wet Cleaning 34
5.3.1 Detergent Availability; Use; Health & Safety 35
5.3.2 System Availability 36
5.3.3 Capital Cost and Equipment Life 36
5.3.4 Operating Cost and Cycle Time 37
5.3.5 Energy Use 38
5.3.6 Cleaning Performance 38
5.3.7 Permitting and Rule Compliance 39
5.3.8 Waste Generation 39
5.3.9 Grant Funding 39
5.3.10 Training Requirements 40
5.4 Carbon Dioxide (CO_2) Cleaning 40
5.4.1 Solvent Availability; Use; Health & Safety 41
5.4.2 System Availability 42

5.4.3 Capital Cost and Equipment Life 43
5.4.4 Operating Cost and Cycle Time 43
5.4.5 Energy Use 43
5.4.6 Cleaning Performance 43
5.4.7 Permitting and Rule Compliance 44
5.4.8 Waste Generation 44
5.4.9 Grant Funding 45
5.4.10 Training Requirements 45
6.0 ESTIMATE OF CLEANING COSTS 45
6.1 Cost Data & Assumptions 45
6.1.1 Work Load & Annual Revenue 46
6.1.2 Equipment & Installation Costs 46
6.1.3 Operating Labor 47
6.1.4 Solvent Mileage & Cost 48
6.1.5 Energy Costs 49
6.1.6 Supplies, Water, & Detergent 50
6.1.7 System Maintenance 51
6.1.8 Regulatory Compliance & Waste Disposal 52
6.1.9 Operator Training 52
6.2 Modeling Results 53
7.0 Sources of Information 54

List of Tables

Table 1 Comparison of Perc to Other Alternatives ... 3

Table 2 Summary of Cost Estimates ... 53

List of Appendices

Appendix A Estimate of Cleaning Cost Worksheets

List of Acronyms

ACGIH – American Conference of Government Industrial Hygienists

ASME – American Society of Mechanical Engineers

ACTM – Airborne Toxic Control Measure

ARCO – Atlantic Richfield Chemical Company

BoS – Bureau of Sanitation

CARB – California Air Resources Board

CCT – Cool Clean Technologies

CINET – International Committee for Textile Care

CO_2 – Carbon Dioxide

DCNA – Dry Cleaners of North America

DfE – Design for the Environment Program

Dow – Dow Chemical Company

DPTB – dipropylene glycol tertiary-butyl ether

EAD – Environmental Affairs Department (City of Los Angeles)

EBNS – Environmental Business & Neighborhood Services (City of Los Angeles)

ERMI – Environmental Risk Management Inc

HAP – Hazardous Air Pollutant

HCA – Hydrocarbon Cleaners Association

HFEs – Hydrofluoroethers

IARC – International Agency for Research on Cancer

IFI – International Fabricare Institute

KB – Kauri-Butanol value

KDLA – Korean Dry Cleaners and Laundry Association

LACSD – Los Angeles County Sanitation Districts

List of Acronyms (continued)

LAFD – Los Angeles Fire Department

LAMC – Los Angeles Municipal Code

LEL – Lower Explosive Limit

MATES – Multiple Air Toxics Exposure Study

NESHAP – National Emission Standards for Hazardous Air Pollutants

NIOSH – National Institute of Occupational Safety and Health

n-PB – n-propyl bromide

OEHHA – Office of Environmental Health Hazard Assessment

OSHA – Occupational Safety and Health Administration

PEL – permissible exposure limit

perc – perchloroethylene (also known as tetrachloroethylene)

PFCs – Perfluorocarbons

PPERC – Pollution Prevention Education and Research Center (Occidental College)

ppb – parts per billion

ppmv – parts per million by volume

psi – pounds per square inch

SCAQMD – South Coast Air Quality Management District

SCRD – State Coalition for the Remediation of Drycleaners

TAC – Toxic Air Contaminant

tric – Trichloroethylene

TSCA – Toxic Substances Control Act

TWA – Time Weighted Average

USEPA – United States Environmental Protection Agency

VOC – Volatile Organic Compound

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1.0 INTRODUCTION

The City of Los Angeles Environmental Affairs Department (EAD), Environmental Business & Neighborhood Services (EBNS) assists local businesses and neighborhood community groups with identifying and implementing best management practices that reduce or prevent the release of hazardous chemicals into the community. Concerns over the use and health effects of perchloroethylene (perc), a hazardous and toxic solvent, have led to national efforts to ban or restrict its use.

The purpose of this report is to explore and document the issues faced by dry cleaners in reducing and/or eliminating their reliance upon perc. Also presented is a standardized cost assessment that attempts to assess each alternative on an equal basis. The target audience for this information is the technical assistance community and those interested in providing technical support. Companion fact sheets summarizing the presented data and targeted towards the dry cleaning profession have also been prepared.

It is noted that the cost estimates presented in this report differ slightly from the values reported in the fact sheets. The fact sheets were based on previous calculations that used monthly energy factors that did not account for workload. Energy use varied by technology, but not by the amount of clothes cleaned. New energy factors that account for workload have been identified and the calculations revised. Other factors have also been revised so that the same estimation approach is used for each technology. The net effect of these changes was to increase the low-end cost estimates by 7 to 16 percent; the high-end estimates and the overall findings did not change.

1.1 Background

Perc is widely used for professional dry cleaning because of its excellent fire safety (it is non-flammable) and good cleaning performance. Equipment design has also improved over time so as to reduce the extent of worker exposure and release. However, air monitoring studies and risk assessments conducted by various agencies has shown the level of risk posed by the use of perc in dry cleaning to be unacceptable.

The use of perc places at risk the system operators, maintenance staff, and other shop employees. People working adjacent to or living near the dry cleaning shop may be at risk depending on the amount of perc used and emitted. A level of risk may also be associated with customers handling their dry-cleaned clothes, especially in an enclosed space such as a car or closet where fumes can collect. Some people recommend that customers remove the plastic from their clothes and drive home with the window open so as to minimize this risk.

In the Los Angeles area, recent rules and regulations enacted by the South Coast Air Quality Management District (SCAQMD) will prohibit the use of perc in dry cleaning by the end of 2020. New dry cleaning shops are not allowed to install a perc-based system and all existing shops must either limit their use to no more than one perc-based system of "low emission" design or install an alternative cleaning system. The decision as to which alternative approach is best is highly complex with final success often more dependent on the dedication and experience of the shop owner than it is on the specific technical approach.

1.2 Summary and Conclusions

Current SCAQMD regulations allow existing dry cleaners to continue using perc so long as the amount of perc used does not pose an unacceptable risk under Rule 1402. The continued use of perc may require the shop to adopt usage limits and all 3rd generation machines (1,449 in number) must be replaced by 1 November 2007. In addition, each shop is allowed to operate only one perc machine. Table 1 summarizes the findings presented in this report for perc, DF-2000, GreenEarth, wet cleaning, and liquid CO_2.

Shops faced with the need to replace their machines will find the capital cost of a DF-2000 system to be almost the same as a new perc system. This statement assumes that the shop receives $5,000 in available grant funding. The capital cost for a GreenEarth system will be slightly greater because grant funding is not available. Wet cleaning systems are least expensive, and they are substantially less in cost if one obtains the available $10,000 to $20,000 in grants and discounts. The capital cost for a liquid CO_2 system is about 50 percent greater than a new perc system even with $20,000 in available grant funding.

In terms of total annualized cost, wet cleaning demonstrates the lowest cost at $0.24 to $0.28 per pound followed by DF-2000 at $0.30 to $0.36; liquid CO_2 at $0.36 to $0.43; GreenEarth at $0.36 to $0.44; and perc at $0.40 to $0.45. These estimates assume

Table 1 Comparison of Perc to Other Alternatives

	Perc	DF-2000	GreenEarth	Wet Cleaning	CO_2 Cleaning
Solvent Availability?	Good, 3 major suppliers	Good, 1 major supplier with other major suppliers with similar products	Good, 1 Major Supplier	Good, Several Suppliers	Good, Several Major Suppliers
Equipment Availability?	Good, many suppliers	Good, many suppliers	Good, multiple suppliers	Good, multiple suppliers	Limited, few suppliers
Capital Cost, range for size & model	$32K - $64K	$38K - $72K	$38K - $72K plus $2,500 fee	$17K - $21K for washer/dryer; $20K - $32K for 2 tensioners	$80K - $90K
Installation Cost	$3K - $5K	$3K - $5K	$3K - $5K	$2K	$10K - $20K
Typical System Cost, Installed	$52K	$59K	$61K	$47K	$100K
System Life	8 - 14 yrs	8 - 14 yrs	8 - 14 yrs	15 yrs	15 yrs
Cleaning Performance	Best on oil-based stains, good for water-based stains. Good for rayon, acetate, silk, and wool, some trims are a problem.	Almost equal to perc, good for oil-based stains, easier to press, better finish	Not as effective as perc for all stains, good on water-soluble stains.	Very good on water-based stains, problem with special construction garments if tensioners are not used.	Good for all soils and all fabrics except acetate; less graying, reduced dye transfer
Cleaning Time, Minutes	45	45 - 60	45 - 60	30 - 45	30 - 40
Operating Labor	Baseline	Same as perc	Same as perc	Greater labor for finishing if old equipment is used and no training provided	Same as perc
Annualized Cost, $ Per Pound (a)	$0.40 - $0.45	$0.30 - $0.36	$0.36 - $0.44	$0.24 - $0.28	$0.36 - $0.43
Energy Demand	70 - 100 amp service; 15 kW peak; average use 1,100 kWh per month	70 - 100 amp service; 15 kW peak; same use as perc	70 - 100 amp service; 15 kW peak; greater avg use	70 - 100 amp service; 8 kW peak; avg use reduced 12 - 46 percent	100 - 150 amp service; 20 kW peak; greater avg use
Air Permits	Perc use may be limited; weekly leak test; clean coil/new gaskets every 2 years	Monthly system inspection & test per Rule 1102, record keeping	Exempt from VOC rules & regs except for record keeping	None	None

Table 1 (continued)

	Perc	DF-2000	GreenEarth	Wet Cleaning	CO_2 Cleaning
Fire Permits	Same, emergency vent system	1 hr fire-resistive separation with safeguards, if allowed by LAFD	1 hr fire-resistive separation with safeguards, if allowed by LAFD	None	Compressed gas storage
Worker Health and Safety	High Risk	Med Risk	Med Risk (under review)	Low Risk	Low Risk
Waste Generation	Hazardous still bottoms and spent filters	Hazardous still bottoms and spent filters	Still bottoms and spent filters, unknown status	Spent filters, solid waste	Spent filters, solid waste
Grant Funding, SCAQMD	None	$5K	Suspended due to potential health concerns	$10K; plus $2K grant & $7.5K in price discounts for demo sites through PPERC	$20K
Training	CARB approved certification and training required; vendor & trade organizations	Available from vendor & trade organizations	Available from vendor & user network	Available from vendor, demo sites, & outreach program	Available from vendor only

a) Assumes shop receives SCAQMD grant funding for DF-2000, wet cleaning, or liquid CO_2.

that the owner receives a SCAQMD grant for DF-2000, wet cleaning, or liquid CO_2 but that the shop does not file for a PPERC wet cleaning demonstration grant. Reported costs are based on a shop cleaning 50,000 to 85,000 pound of clothing per year.

2.0 BASIS OF CONCERN

The chlorinated solvent perchloroethylene (perc), also known as tetrachloroethylene, was once widely used for industrial metal cleaning and degreasing activities. The use of perc for dry cleaning dates back to the 1930’s when it was introduced as a safer and better alternative to the highly flammable and more toxic solvents then in use.

2.1 Air Quality

By the late 1960s, perc was the most widely used dry cleaning solvent in the United States; replacing Stoddard solvent and trichloroethylene (tric). Stoddard solvent is a distillation fraction of crude petroleum and tric is a chlorinated hydrocarbon. Issues of fire safety and photochemical reactivity drove the replacement of Stoddard while issues of toxicity and photochemical reactivity drove the replacement of tric. Solvents that are photo-chemically reactive contribute to the formation of ground level ozone and smog.

The United States Environmental Protection Agency (USEPA) excluded perc from the definition of volatile organic compound (VOC) on 26 January 1996 (FR, 1996). This exclusion was based upon studies that showed that perc contributes less to the ambient ozone problem than equal concentrations of ethane (a negligibly-reactive VOC that was previously exempted from control). On 2 December 1997, the SCAQMD amended their Rule 102 to list perc as a Group II exempt compound (SCAQMD, 2001). While perc is exempt from VOC control regulations, it is still subject to control as an air toxic.

2.2 Air Toxics

The USEPA lists perc as a hazardous air pollutant (HAP) and the State of California Air Resources Board (CARB) lists it as a toxic air contaminant (TAC). A TAC, as defined by law (section 39655 of the California Health and Safety Code), "means an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health." Emissions of perc are controlled under the SCAQMD air toxics control program.

Perc has been identified as one of six key TAC's in the South Coast air basin based on ambient air monitoring studies (SCAQMD, 2002c). While there has been a significant reduction in the mean ambient air concentration of perc, from around 0.5 parts per billion (ppb) in 1990 down to 0.25 ppb in 1997, concerns exist over its continued use because many dry cleaners are located near sensitive receptors such as schools, day-care centers, apartments, and nursing facilities. Dry cleaners are responsible for 60 percent of all perc emitted from stationary sources in the basin per a 1998 emission inventory (SCAQMD, 2002b).

2.3 Cancer Risk

Several international, federal, and state authoritative bodies classify perc as a possible or probable human carcinogen (NIOSH, 1997c). An increased incidence of some forms of cancer has been observed in various epidemiology studies of workers in the dry cleaning industry. Confounding factors may include smoking, alcohol consumption, diet, and exposure to other chemicals. Animal studies investigating the effects of exposure to perc have shown increases in liver cancer in mice, and renal cancer and mononuclear cell leukemia in rats. The relevance of these observations to humans is not clear due to differences between mice, rats, and humans in the way in which the liver responds.

The International Agency for Research on Cancer (IARC) has concluded there is sufficient evidence of carcinogenicity to experimental animals and limited evidence of carcinogenicity to humans. IARC classifies perc as a Group 2A substance (probably carcinogenic to humans). The National Toxicology Program (NTP) classifies perc as reasonably anticipated to be a human carcinogen. The State of California has listed perc under Proposition 65 as a chemical known to the state to cause cancer.

2.4 Worker Health and Safety

Acute health impacts due to perc exposure may occur to the eyes, central nervous system, and respiratory system, while chronic health impacts may occur to the kidneys and gastrointestinal system (CARB, 2002). Short-term exposure may result in irritation, burns, headache, dizziness, nausea, vomiting, fainting, and impaired judgment while long-term exposure can result in neurological defects, reproductive disorders, impaired liver and kidney function, and respiratory disease (CFCA, 2002).

Worker exposure occurs in three ways: inhalation, ingestion, and/or dermal contact. By far, inhalation is the most significant route of exposure because perc is readily absorbed into the blood stream via the lungs. Ingestion occurs from the eating or drinking of food or water contaminated with perc. Dermal absorption is possible via direct contact, which can happen if an operator fails to wear proper protective gloves while fixing a leak.

The permissible exposure limit (PEL) for perc set by the U.S. Occupational Safety and Health Administration (OSHA) is 100 parts per million by volume (ppmv) over an 8-hour time-weighted average (TWA). The acceptable ceiling concentration is 200 ppmv for 5 minutes in any 3-hour period, not to exceed a maximum peak of 300 ppmv. ACGIH, the American Conference of Government Industrial Hygienists, recommends a threshold limit value (TLV) of 25 ppmv and the State of California enforces a PEL of 25 ppmv.

2.5 Other Impacts

Both soil and groundwater contamination at some dry cleaning sites is a known problem and site cleanup is expensive. This has led some landlords to refuse lease renewal for dry cleaners who continue to use perc. In the state of New York, the Department of Environmental Conservation reported that one out of every five dry cleaning sites had contamination and that slightly more than 50 percent of these sites presented a threat to drinking water supplies.

3.0 REGULATORY OVERVIEW

Dry cleaners in the South Coast air basin were regulated under SCAQMD Rule 1102 for the use of solvents other than perc on 6 January 1978 and under Rule 1102.1 for the use of perc on 6 June 1980. Rule 1102.1 was repealed on 9 December 1994 following the adoption of Rule 1421. Rule 1421 controls perc emissions from dry cleaning under the SCAQMD's air toxics program. Dry cleaners using perc must also comply with Rule 1402 that limits the release of TAC's from existing sources.

Dry cleaners operating within the City must possess a SCAQMD permit for all emission sources, a City of Los Angeles Fire Department (LAFD) permit, an industrial wastewater discharge permit issued by the Bureau of Sanitation (BoS) or the Los Angeles County Sanitation District (LACSD) depending on site location, and a State of California EPA identification number for the management of hazardous waste.

3.1 SCAQMD Rules 1421 and 1402

Rule 1421 was adopted to reflect the requirements of the state Airborne Toxic Control Measure (ATCM) for emissions of perc from dry cleaning operations and the federal National Emission Standards for Hazardous Air Pollutants (NESHAP) for dry cleaning facilities. Rule 1421 was amended on 13 June 1997 to incorporate changes to NESHAP and was again amended on 6 December 2002 to implement part of the SCAQMD Air Toxics Control Plan. Control Measure AT-STA-02 calls for a 95 percent reduction in perc emissions from dry cleaners by the end of 2010.

Rule 1402 places limits on the amount of toxic air contaminant (TAC) released from an existing source so as not to create an unacceptable risk to sensitive receptors (Rule

1401 is similar but it applies to new sources). Since perc is a TAC, all dry cleaners using perc must comply with this rule. Compliance with Rule 1421 does not negate the need to comply with Rule 1402 and the SCAQMD can impose solvent usage limits as a permit condition to insure compliance.

3.1.1 Implementation Timeline

Rule 1421 gradually transitions dry cleaners away from perc. Transition occurs when a new business is opened and old systems are replaced. A sunset date of 31 December 2020 has been set for the phase-out of perc. Compliance dates are as follows:

- 9 June 1996 – Dry cleaners cannot install a converted dry cleaning machine (i.e., a vented machine with add-on controls). Dry cleaners cannot modify a vented machine to a converted machine.

- 1 October 1998 – Dry cleaners can no longer operate a vented machine or a wet transfer system (i.e., a separate washer and dryer). The operation of a machine designed for self-serve dry cleaning is prohibited.

- 6 December 2002 – An existing facility may continue to operate a perc system until the end of its useful life and the facility may operate no more than one perc system up until 31 December 2020 provided the system is equipped with primary and secondary emission controls. Any facility starting operation on or after this date is considered to be a new facility.

- 1 January 2003 – The use of dip tanks for dry cleaning is prohibited. A new dry cleaning facility cannot operate a perc system. An existing facility cannot install an additional perc system.

- 1 July 2003 – Existing facilities must submit an initial report to the SCAQMD detailing operating information, solvent usage, pounds of clothes cleaned, date of equipment purchase, and location of sensitive receptors.

- 1 July 2004 – The continued use of a converted machine is prohibited. The replacement machine must be a non-perc alternative technology or a new perc machine equipped with integrated primary and secondary controls.

- 1 January 2007 – New facilities must submit an initial report to the SCAQMD detailing operating information, solvent usage, pounds of clothes cleaned, date of equipment purchase, and location of sensitive receptors. Existing facilities must submit their quadrennial update (every four years).

- 1 November 2007 – The operation of a perc system without integrated secondary control is prohibited.

- 31 December 2020 – Use of any perc dry cleaning system in the South Coast air basin is prohibited.

Rule 1421 underwent many revisions during the hearing process. The amended rule, as issued, requires all dry cleaners to replace their systems by 1 November 2007 if they are not equipped with integrated secondary controls. The new replacement system may be a perc system provided the dry cleaner has no other perc system in use.

Systems equipped with integrated primary and secondary controls may be operated up until the end of their useful life or up to 31 December 2020, whichever occurs first. While the rule allows for the continued use of perc, owners should be aware of potential usage limits that can be imposed under Rule 1402 (see Section 3.1.3). The extent of this limit depends on the distance between the dry cleaning system and nearby receptors.

3.1.2 Operational Requirements

Rule 1421, which establishes a timeline for the replacement of all perc machines in the District, also imposes environmental training requirements and the need to follow good operating practices. The intent of these requirements is to ensure that emissions are controlled to the fullest extent practical. Specific requirements include:

- A trained operator, or designee, must operate and maintain the equipment in accordance with all rules and permit requirements. The trained operator, or designee, shall inspect the system at least once per week for liquid leaks and for vapor leaks using an approved detector.

- The trained operator shall be the owner, the operator, or other full-time employee who successfully completes the initial course of a CARB-authorized program to become a trained operator. The trained operator shall successfully complete a refresher course every three years.

- The refrigerated cooling coils must be removed and cleaned every two years by a qualified individual from a repair company licensed by the State of California to handle refrigerant. The main door, still door, button trap, and lint trap gaskets must be replaced every two years.

- The owner operator shall maintain records in accordance with the Rule 1421 Recordkeeping and Reporting form issued by the SCAQMD.

To help dry cleaners comply, the SCAQMD has prepared a self-inspection checklist that is available via their website (www.aqmd.gov) under the heading of business resources. A list of CARB-authorized dry cleaning environmental training instructors and classes is also posted. Training instruction and classes are available in English and Korean.

3.1.3 Solvent Usage Limits

Full compliance with Rule 1421 requires compliance with Rule 1402. This rule limits the lifetime cancer risk to the surrounding community due to the release of a TAC such as perc. The determination of risk is based on the amount of solvent released per year, the location of the facility, and distance to nearest sensitive receptor. Even with a new dry cleaning machine that incorporates both primary and secondary controls, some dry cleaners may be required to adopt an alternative system or limit their use of perc.

Screening level look-up tables prepared by the SCAQMD indicate that usage of more than 1 to 2 gallons per month of perc may pose an unacceptable risk to receptors that are located within 25 meters of the source. At 75 meters, the risk may be acceptable as long as the shop uses less than 6 to 9 gallons per month. At a usage of 8 gallons per month for a new perc system (see Section 4.2.4), a remote facility may not experience much impact due to imposed limits while a facility located near sensitive receptors may be severely restricted. The SCAQMD is currently conducting risk assessments for the dry cleaning facilities that submitted their initial reports.

3.1.4 Financial Incentives

To promote the adoption of dry cleaning alternatives, the SCAQMD established a $2 million financial incentives grant program following amendment of Rule 1421 (SCAQMD, 2002e). This program was later revised on 11 July 2003 to reflect changes in the grant status of certain alternative technologies. The grant amount for liquid carbon dioxide systems was increased and the grant for silicone-based systems such as GreenEarth was suspended. Grant amounts available for each of the alternative technologies is discussed later in this report.

As of 12 March 2004, one hundred eighty (180) applications amounting to $1,105,000 have been received by the SCAQMD. Most applications are for hydrocarbon-based systems (130), followed by professional wet cleaning (37), the silicone-based solvent system GreenEarth (11), and two for carbon dioxide (SCAQMD, 2004b). The State of California, since mid-2004, has imposed a $3 per gallon fee on the sale of perc used for dry cleaning. This fee will increase by $1 per year, up to a peak fee of $12 per gallon, and be used to fund additional conversion grants.

3.2 Fire Permits

Fire Code requirements for dry cleaning plants are found in Los Angeles Municipal Code (LAMC), Chapter V, Article 7, Division 79 (LAMC 57.79). This code specifies minimum fire protection requirements for dry cleaning plants in the City of Los Angeles. Other recommended requirements may be found in the Standard for Dry Cleaning Plants (NFPA 32, 2000 ed.) issued by the National Fire Protection Agency. A recognized testing laboratory must list any dry cleaning system used in the City of Los Angeles.

No person within the City may operate or maintain a dry cleaning plant unless issued a valid LAFD permit. The LAFD must also approve any construction or remodeling of a plant, a change in the class or quantity of solvent used, or a change in the cleaning method or equipment employed. No person may erect, install, relocate, or alter any appliance, device, or system, when such equipment is to be used in dry cleaning, unless a valid permit has been issued.

No flammable solvent may be used in the dry cleaning process. A flammable liquid is any liquid having a flash point below 100 °F and having a vapor pressure that does not exceed 40 pounds per square inch absolute at 100 °F. Flash point is defined as the temperature at which the liquid gives off vapor sufficient to form an ignitable mixture with air near the surface of the liquid. Flammable liquids are listed as Class I liquids and they are further classified as follows:

- Class IA liquids have a flash point below 73 °F and a boiling point below 100 °F. Examples of such liquids include liquefied butane, propane, and pentane.
- Class IB liquids have a flash point below 73 °F and a boiling point at or above 100 °F. Acetone and ethyl alcohol are common examples of Class IB liquids.
- Class IC liquids have a flash point at or above 73 °F and below 100 °F. Such liquids include butyl alcohol and turpentine.

A combustible liquid has a flash point at or above 100 °F. All of the hydrocarbon and petroleum-based solvents used in dry cleaning are classified as combustible liquids. Combustible liquids are further classified as follows:

- Class II liquids have a flash point at or above 100 °F and below 140 °F. Stoddard solvent, in its early days of use, was a Class II combustible liquid.
- Class IIIA liquids have a flash point at or above 140 °F and below 200 °F. For dry cleaners, refiners market a "safety" Stoddard or "high flash" naphtha with a flash point slightly above 140 °F. Other Class IIIA liquids used in dry cleaning include DF-2000 (147 °F) and GreenEarth (170 °F).
- Class IIIB liquids have a flash point at or above 200 °F. PureDry, with a flash point of 350 °F, is classified as a Class IIIB liquid.

Perc is a noncombustible liquid that is classified as a Class IV material. Only solvents approved for Class IV installations can be used in dry cleaning systems designed for such solvents. All solvent-handling equipment and components must be constructed to prevent leakage.

Class IV plants must also be provided with ventilation adequate to maintain an average solvent concentration anywhere within the plant of 100 ppmv or less. Manually operated emergency ventilation for spills or leaks must be installed to provide an air change every five minutes within 15 feet of Class IV equipment. The switch for this equipment must be readily accessible and clearly identified.

Exhaust ventilation ducts from the equipment must extend above the roof unless leading directly into a solvent recovery system. Exhaust systems must be installed per Chapter 9 of the LAMC (Mechanical Code), and they must be located no closer than 25 feet from any openings in other occupancies. Annual inspections are conducted by the LAFD to ensure compliance.

3.3 Sewer Permits

Dry cleaning facilities, depending on location, are required to possess either a Bureau of Sanitation (BoS) or a Los Angeles County Sanitation Districts (LACSD) permit for the discharge of industrial wastewater. Dry cleaners are required to certify annually that they do not dispose of their separator water by discharging it to the sanitary sewer.

Both agencies conduct periodic inspections and collect samples to confirm compliance with permit requirements. This practice is driven by the documented presence of perc in sanitary flows and by the prevalent use of perc by dry cleaners. To avoid the potential discharge of perc, many shops run the separator water through a carbon filter and then allow the perc-free water to evaporate. The filter is managed as hazardous waste.

4.0 INDUSTRY CHARACTERISTICS

Most dry cleaning facilities are owner-operated, with fewer than five employees and often run by family members. According to the Korean Dry Cleaners and Laundry Association (KDLA), about 50 percent of the shops in the South Coast air basin are Korean-owned (SCAQMD, 2002b). Total gross revenues vary, but often reflect a small profit margin. Annual revenues tend to average around $3 per pound of clothes cleaned with the shops operating 312 days per year (USEPA, 1998). The field is highly competitive and the market is saturated.

4.1 Support Operations

Prior to dry cleaning, the received clothes are checked to ensure compatibility with the solvent and are then tagged for customer identification. Clothing with visible stains is pretreated with various “spotting” chemicals prior to dry cleaning. Common chemicals include trichloroethylene, various ketones such as methyl isobutyl ketone, naphtha, oxalic acid, acetic acid, dilute hydrofluoric acid, hydrogen peroxide, and aqueous ammonia (NIOSH, 1997). While the overall volume of spotting chemicals used is small, worker exposure is a concern.

After dry cleaning, the clothes are removed from the machine and sent to the pressing department. A variety of specialized pressing equipment is used for this task. Common equipment includes utility presses, puff irons, pants toppers, finishers, electric irons, collar presses, cuff presses, yoke presses, and sleevers. After pressing, the garments are placed on an overhead rack and wrapped in plastic for customer pick-up.

4.2 Dry Cleaning System Evolution

Substantial evolution in the design of dry cleaning systems to control solvent loss has occurred over time. Early systems were very wasteful of solvent and they posed a very high risk of exposure to the system operator. Very high ventilation rates, both inside the machine and in the working area around the machine were mandated to maintain a safer working environment. Toxicity was the main concern for the use of perc while fire safety was the main concern for the use of petroleum solvents such as Stoddard.

In the discussion that follows, the dry cleaning systems are referred to as 1st through 5th generation. These designations are commonly used in the industry, although there are no fixed definitions and there are many interpretations as to what constitutes a specific “generation.” The description of system generation used in this report is in line with the definitions used by the SCAQMD during rule development.

4.2.1 1st Generation

A 1st generation “wet transfer” system designed for perc consists of a combined washer and extractor and a reclaiming tumbler. Cleaning begins by placing the clothes inside the washer/extractor, closing the lid, and charging the unit with perc along with a small amount of detergent and water. The purpose of adding detergent and water is to aid in the removal of water-soluble soils.

After agitating the clothes for a specified period of time, the perc is extracted by spinning the wash drum at high speed. A muck filter, followed by a water separator, is used to remove insoluble soil, lint, and spent detergent from the extracted perc. The perc is then sent to storage for reuse and the spent detergent is discharged directly to sewer (this practice is no longer allowed by law). The removal of soluble oils, fatty acids, and grease from used perc is achieved via periodic distillation with the still bottoms, along with the spent muck filters, being disposed of as hazardous waste.

After cleaning, the wet clothes are manually transferred from the washer/extractor to the reclaiming tumbler. Hot air is used to dry the clothes as they tumble. Perc is reclaimed from the exhaust by passing the air over a water-cooled coil or by venting into a water-filled bubbling tank. Hot air drying continues until there is a residual amount of perc left in the clothes and the concentration of perc in the exhaust starts to decline.

When the concentration of perc in the exhaust drops below its dew point, no further condensation occurs. At this point, the system switches to a once through mode with fresh air being used to cool the clothes and to remove additional perc. This exhaust commonly vents to atmosphere, though some shops employ a carbon adsorber to reclaim some of the vented perc.

Wet transfer systems emit a large amount of perc into the workspace when the wet clothes are manually transferred from one machine to another. This transfer step also represents the greatest risk to the operator in terms of exposure. Spillage of perc onto the shop floor is a likely source of site contamination.

Solvent mileage for a 1st generation wet transfer system without primary control ranges from 91 to 137 pounds of clothes cleaned per gallon of perc. The term “solvent mileage” refers to the amount of clothes cleaned in pounds to the amount of solvent used in gallons. These solvent mileage values are from a study of 2,000 dry cleaning shops conducted by the SCAQMD in the late 1960’s when the use of wet transfer systems was prevalent (USEPA, 1973). SCAQMD Rule 1421 prohibits the operation of a wet transfer system as of 1 October 1998.

4.2.2 2^{nd} Generation

Many perc wet transfer systems were replaced in the late 1960s with the introduction of "dry-to-dry" machines. These machines combine the washer/extractor and reclaiming tumbler into one unit, thus eliminating the need for wet transfer. Eliminating the wet transfer step substantially reduces worker exposure to perc and the potential for site contamination due to spills.

While worker exposure to perc is substantially reduced, solvent usage is still high due to system design. A 2^{nd} generation dry-to-dry system uses 50 percent less solvent than a wet transfer system but twice as much solvent as a 3^{rd} generation system. Some shops have tried to match the performance of a 3^{rd} generation system by installing an add-on control system.

The reported solvent mileage for a 2^{nd} generation "dry-to-dry" system without primary control was 182 to 278 pounds per gallon (USEPA, 1973). This mileage represents a 100 percent increase in the amount of clothes cleaned per gallon of perc or a 50 percent reduction in perc use. Operation of a 1^{st} or 2^{nd} generation system in the South Coast has been prohibited since 1 October 1998.

The addition of primary controls to a 2^{nd} generation system typically results in a further reduction in solvent use. While actual source test data has not been identified, it is fair to assume that the addition of primary controls reduces solvent use by 50 percent from the uncontrolled rate. This equates to a solvent mileage value of 364 to 556 pounds per gallon. Use of a 2^{nd} generation system with add-on controls, often called a "converted" machine, is prohibited in the South Coast as of 1 July 2004.

4.2.3 3^{rd} Generation

The introduction of 3^{rd} generation dry-to-dry, non-vented systems occurred in the late 1970s to early 1980s. In these systems, the water tank or water-cooled coil is replaced with a refrigerated condenser. The refrigerated condenser is capable of reducing the exhaust temperature down to 45°F or less. A temperature of 45°F tends to be standard because lower temperatures will result in icing of the coil by water vapor.

The equilibrium concentration of perc in air at 45°F is 8,600 parts per million by volume (ppmv) or slightly less than 1 percent by volume. Perc emissions are reduced because the refrigerated condenser is capable of achieving a lower exhaust temperature than the older cooling methods. The equilibrium concentration of perc in air following a water-cooled coil will range from 2 to 3 percent by volume. Thus, the refrigerated coil recovers 50 to 67 percent more perc per pass than the older methods.

Following the refrigerated coil, the cool exhaust is reheated and returned to the drum. The return of heated exhaust, along with the greater reduction in perc content provided by the refrigerated coil, helps in removing more of the residual perc from the clothes. Once the clothes are dry, the heater is turned off and the cold exhaust is used to aerate and cool the clothes. This step eliminates the need for introducing fresh air and it allows the system to operate in a non-vented mode.

Solvent mileage for a 3rd generation system is expected to be slightly better than the mileage reported for a 2nd generation system with add-on controls. If one assumes a 20 percent improvement in performance, then the resulting value would be in the range of 455 to 695 pounds per gallon. All perc systems operating in the South Coast must be of 3rd generation or better design as of 1 July 2004 with all 3rd generation systems removed from service by 1 November 2007.

4.2.4 4th and 5th Generation

A machine that incorporates an integrated refrigerated condenser with one or more carbon adsorber beds (i.e., primary and secondary control) is a 4th generation system. The carbon adsorber is used during the cool-down phase to reduce the concentration of perc in the recirculating exhaust to less than 300 ppmv. Perc captured by the carbon beds is returned to the solvent storage tank during bed regeneration. The frequency of regeneration is often based on a fixed number of cleaning cycles or loads.

Widely used overseas, but not as common in the United States, a 5th generation system adds drum monitoring and loading door interlocks to the 4th generation design. A drying sensor located inside the machine drum monitors the concentration of perc. Interlocks prevent the loading door from opening if the concentration exceeds 300 ppmv. This is the maximum peak concentration allowed by OSHA for worker exposure.

For systems of 4th or 5th generation design, average solvent mileage is reported to be 885 pounds per gallon (SCAQMD, 2002b). This average value is based on performance tests conducted by the SCAQMD at twenty sites with "dry-to-dry" systems that employ both primary and secondary controls. This represents a 546 to 873 percent increase in solvent mileage compared to a 1st generation system and a 27 to 99 percent increase compared to a 3rd generation system.

Typical solvent usage for the twenty shops tested by the SCAQMD was 8 gallons per month. This equates to a workload of approximately 7,000 pounds of clothes per month or 85,000 pounds per year. Fifty percent of the perc used is emitted to atmosphere with the rest present in spent filters and still bottom sludge. Another study reports the dry cleaning workload for a "model" shop to be less than 55,000 pounds per year (USEPA, 1998). A shop may operate one 4th or 5th generation system up until 31 December 2020 when the use of any perc-based dry cleaning system is prohibited.

4.3 Basin Population

Data reported by the SCAQMD indicates that there are 2,181 perc-based dry cleaning machines operating at 2,086 facilities in the South Coast air basin. Of these machines, about 33 percent (714) are estimated to be 4th or 5th generation design (i.e., dry-to-dry, closed-loop, and equipped with primary and secondary control). These machines are prohibited from operating after 31 December 2020.

The largest segment of the machines in use, about 66 percent (1,449), is estimated to be of 3rd generation design (i.e., dry-to-dry, closed-loop, and primary control only). A 3rd generation unit may be operated until 1 November 2007 when their continued use is prohibited. All of these machines will require replacement prior to this date.

5.0 ALTERNATIVE TECHNOLOGIES

Alternative dry cleaning technologies have been entering the market at an accelerated pace. Most of these technologies can be classified as solvent-based cleaning, carbon dioxide (CO_2) cleaning, and professional wet cleaning. For dry cleaning shops that were operating prior to 6 December 2002, the continued use of perc in a 4th or 5th generation system is an option. However, perc limits imposed by Rule 1402 may require the shop to install an alternative system so as to maintain full production capacity.

5.1 New Perc-Based Systems

The following sections discuss various issues related to the continued use of perc in dry cleaning systems of 4th or 5th generation design. The installation of a new perc system may be a viable choice for those shops that do not wish to implement an alternative technology at this time. This option is not available to new dry cleaning facilities. The same presentation format is followed for each discussion of alternative technologies to aid in the comparison.

5.1.1 Solvent Availability; Use; Health & Safety

The dry cleaning solvent perc is widely available from three major producers: Dow Chemical, PPG Industries, and Vulcan Materials. No reformulation of perc is required for use in these new machines. Solvent use by a "typical" shop operating a 4th or 5th generation system is 8 gallons per month based on the SCAQMD survey data for a shop cleaning 85,000 pounds of clothing per year. For this study, an average solvent mileage value of 800 pounds of clothes cleaned per gallon of perc is assumed.

Nationally, the cost of perc ranges from $7 to $8 per gallon. Starting in May 2004, the California Air Resources Board imposed a $3 per gallon fee on the sale of perc used for dry cleaning. This fee will increase each year in $1 increments until a maximum fee of $12 is reached. Funds collected from this fee will be used to provide grant assistance to dry cleaners who adopt an alternative technology.

New 4th and 5th generation machines can maintain worker exposures below PEL values set by OSHA (100 ppmv TWA and 300 ppmv peak) and the 25 ppmv PEL set by the State. Peak exposure values for a new 4th or 5th generation machine are 10 to 300 ppmv with a TWA value of less than 3 ppmv (NIOSH, 1997b). Peak values for a 3rd generation machine are reported by NIOSH to be in the 1,000 to 4,000-ppmv range with a TWA value of 15 to 20 ppmv.

5.1.2 System Availability

Most major dry cleaning equipment vendors who provide 3rd generation systems also offer systems of 4th or 5th generation design. Over 700 of these systems are permitted to operate in the South Coast air basin. For almost 1,500 shops faced with the need to replace their existing systems, it is not known how many will elect to install a new perc system instead of an alternative technology. Vendors offering 4th and 5th generation systems include Bowe Textile Cleaning, Columbia Drycleaning Machines, Firbimatic, GreenTech, Hoyt Corporation, Multimatic Corporation, Realstar USA, Renzacci SpA, Sail Star USA Inc, Sovrana, and UNION Drycleaning Products USA.

5.1.3 Capital Cost and Equipment Life

The capital cost for a new perc-based system is reported to be in the range of $32,000 to $64,000 with installation adding another $3,000 to $5,000 (SCAQMD, 2002d). The actual capital cost will vary depending on supplier, the materials of construction, system size, and number of features. The installation costs reported above are for replacement or retrofit applications where all required utilities are present.

A typical size unit has a maximum cleaning capacity of 35 to 40 pounds per load. The life of these systems can vary widely, with some vendors claiming an equipment life of 30 years or more. A more typical claim of expected life is in the range of 8 to 14 years. All vendors stress the importance of routine maintenance for ensuring maximum life.

5.1.4 Operating Costs and Cycle Time

Some equipment vendors claim that the cleaning cycle time for a 4th or 5th generation system is longer than the time required for a 3rd generation system due to the advanced emission controls. These controls prevent the opening of the access door for as long as the perc concentration inside the machine exceeds 300 ppmv. Other vendors claim that there is no reduction in cycle time with all systems requiring about 45 minutes per load. This time does not include the time required for subsequent pressing and finishing.

Operating costs derived from various references are difficult to compare because they do not provide the same level of analysis for each system of interest. The exclusion of certain costs when data is lacking can lead to erroneous conclusions. An attempt to derive a consistent level of cost analysis is presented in Section 6.

The annualized cost for owning and operating a new perc system is estimated to be $0.40 to $0.45 per pound of clothes cleaned depending on annual workload. Costs include the annualized cost of capital, solvent cost, electric power, process supplies including detergent, system maintenance, regulatory compliance including hazardous and solid waste management, and operator training. Labor, water, and natural gas costs have not been quantified but other references report these costs to be comparable for all of the alternatives considered.

5.1.5 Energy Use

The electricity required for the wash motor, extract motor, fan motor, pump motor, air exchange motor, and compressor, at maximum operating load, can be up to 15 kWh with the typical load averaging 2 to 3 kWh. Most dry cleaning systems except for liquid CO_2 require a 70 to 100-amp service.

Additional energy requirements at the shop include electricity for lighting, heating, and conveyor motors, along with natural gas for running the steam supply. The overall amount of electricity used by a shop running a new perc system is taken to be 1,100 kWh per month. This value is derived from a recent report discussing the conversion of a shop from perc to wet cleaning (PPERC, 2001b). Natural gas demand did not change markedly following the conversion so it has not been quantified. See Section 6.1.5 for additional information regarding energy costs.

5.1.6 Cleaning Performance

The aggressiveness of a hydrocarbon solvent with regard to its ability to dissolve oil and grease is often measured by its Kauri Butanol (KB) value. Benzene is assigned a KB value of 100. Perc has a KB value of 90 and is very effective at removing oil-based stains such as grease, wax, oils, and resins. To achieve a high level of performance for the removal of water-soluble stains, specially formulated detergents are used. Additives are also used to prevent some dyes from running or bleeding.

Some textiles are best dry cleaned with perc or hydrocarbon solvent. Notable examples include acetates, rayon, silk, and wool (Anonymous, 2003). However, other references state that silk and wool will do better in wet cleaning or liquid CO_2. Clothing made of acrylic, cotton, linen, polyester, or polyolefin may be either dry cleaned or washed depending on the attached care label instructions. Some synthetic materials that are used for trim and certain combinations of textiles can be damaged by dry cleaning.

5.1.7 Permitting and Rule Compliance

Existing LAFD and SCAQMD permits will require modification to reflect the change in equipment status. No change to the industrial wastewater discharge permit is expected for the replacement of a 3rd generation system with a 4th or 5th generation system. All three agencies will continue to conduct periodic inspections to ensure compliance.

Shops using perc in a new system must continue to comply with the operator training and equipment maintenance requirements of Rule 1421. Full compliance with this rule also requires compliance with Rule 1402. This rule limits the lifetime cancer risk to the surrounding community due to the release of a TAC such as perc. The determination of risk is based on the amount of solvent released per year, the location of the facility, and distance to nearest sensitive receptor.

Even with a new 4th or 5th generation dry cleaning system, some dry cleaners may be required to limit their use of perc. Screening level look-up tables prepared by the SCAQMD indicate that perc usage of more than 1 to 2 gallons per month may pose an unacceptable risk to sensitive receptors located within 25 meters of the release. Shops faced with severe limits may be forced to install an alternative system so as to maintain their level of business.

At 85,000 pounds per year of clothing, the annualized cost for installing and operating a new perc system is $0.40 per pound. This cost decreases to $0.35 per pound if the perc system is limited to 20,000 pounds per year and the shop elects to install a wet cleaning system to handle the bulk of the load. Since the cost of a wet cleaning system alone is $0.24 per pound, the shop pays an extra $0.11 per pound for this dual system capability. The dual system cost for the other technologies is either the same or more than the cost of owning and operating a single perc system.

5.1.8 Waste Generation

Waste generated by the use of perc in dry cleaning includes the hazardous still bottoms from solvent distillation and the spent cartridge filters used to remove lint and insoluble soil from the extracted perc. Cartridge filters are typically replaced every six months or less, depending on workload. A 60-pound load machine may have up to six filters while a 40-pound machine has three. Reusable spin disc filters are also in use, the removed lint and dirt requiring management as perc-contaminated hazardous waste.

5.1.9 Grant Funding

No SCAQMD grants are available for dry cleaning facilities seeking to install a new 4th or 5th generation perc system. Grants might be available to dry cleaners with perc systems that elect to install a second alternative system.

5.1.10 Training Requirements

An owner, operator, or other full-time employee who successfully completes the initial course of a CARB-authorized program must operate the system. The trained operator must also complete a refresher course every three years.

5.2 Solvent-Based Technologies

With restrictions placed on the use of perc, a return to hydrocarbon or petroleum-based solvent is underway. Engineered for safety (i.e., less flammable) and purity (i.e., little or no odor), these new solvents are safer to use than Stoddard. And unlike Stoddard, they do not contain toxic aromatic compounds such as benzene and they have a fairly high flash point that reduces, but does not eliminate, the risk of fire or explosion. Their lower vapor pressure also lowers the risk of worker exposure due to inhalation.

5.2.1 Solvent Availability; Use; Health and Safety

The two most common alternative dry cleaning solvents in use in the South Coast air basin are DF-2000, an aliphatic hydrocarbon produced by Exxon/Mobil, and GreenEarth, a silicone-based solvent produced by GE Silicones. As of 12 March 2004, 130 grant applications have been filed for DF-2000 and 11 have been filed for GreenEarth.

Other potential dry cleaning solvents include PureDry from Niran Technologies Inc., Rynex from ARCO, Impress from Lyondell Chemical Company, Resolve from R.R. Street & Co., and Comexsol from New York Machinery Tech, Inc. While limited use of these solvents is found in the available literature, the SCAQMD reports no use of these solvents as yet in the basin.

DF-2000

DF-2000, produced by Exxon/Mobil, is the most common hydrocarbon-based solvent used for dry cleaning in the South Coast. Similar solvents are available from most major refiners such as Shell Chemicals, Chevron/Texaco, and ConnocoPhillips but their use in the basin has not been reported.

Solvent mileage in a new system designed for DF-2000 is approximately the same as perc, about 800 pounds per gallon. However, some report that solvent mileage can be less due to potential problems with foaming. While no other data regarding this problem was identified in the literature, it is speculated that foaming indicates a problem with the maintenance of solvent quality due to poor handling practice.

The purchase price for DF-2000 is about $4 per gallon. The VOC content of DF-2000 is 6.4 pounds per gallon, its flash point is 147 °F, and its Kauri-Butanol (KB) value is 27. Straight-chain aliphatic hydrocarbons such as those found in DF-2000 have a relatively low KB value while aromatic or ringed-compounds tend to have a high value. Perc has a KB value of 90.

Based on KB value alone, perc would appear to be a better solvent for the removal of oil and grease. However, too aggressive a solvent may attack and damage the fabric. Dry cleaners using perc sometimes use a chemical additive to protect the fabric. Thus, a lower KB value is beneficial in that it is less damaging to the fabric being cleaned.

The aliphatic hydrocarbons that are present in the hydrocarbon-based solvents can act as asphyxiants and central nervous system depressants at high levels of concentration. Aliphatic hydrocarbons have different toxicological properties, often based upon the length of their carbon chain. Most will cause irritation of the skin while repeated and prolonged exposure may cause dermatitis. Aspiration of the solvent may cause diffuse chemical pneumonitis and pulmonary edema. Most agree, however, that the health risk posed by these solvents is much less than the risk posed by perc.

GreenEarth

The solvent GreenEarth, patented in 1998 and produced by GE Silicones, consists of cyclic methylated siloxane decamethylcyclopentasiloxane (D_5). Siloxanes are liquid silicones that are commonly used in cosmetics. They have no smell and they contain no

VOCs. Users are not required to obtain a Permit to Operate from the SCAQMD but they must comply with the recordkeeping requirements of Rule 1102.

The flash point for GreenEarth is 170 °F so it is classified as a Class IIIA combustible liquid. The purchase price for the GreenEarth solvent is $15 per gallon and shops using a GreenEarth dry cleaning system must pay an annual affiliation permit fee of $2,500. While the price of the solvent is almost 4 times greater than the price of DF-2000, solvent mileage is more at 1,000 to 1,600 pounds per gallon (IFI, Undated). The KB value of GreenEarth is less than 20, but its low surface tension aides in the removal of oil and dirt from the clothing.

Regarding issues of worker health and safety, toxicity tests recently submitted by Dow Corning to the USEPA TSCA Section 8(e) Coordinator have shown the solvent D_5 to increase the incidence of uterine endometrial tumors in female rats exposed for 12 to 24 months. This effect was noted only at highest exposure level of 160 ppmv. It is Dow's contention that this level greatly exceeds typical workplace or consumer exposure.

The USEPA has stated that these preliminary findings may indicate that there is a potential carcinogenic hazard associated with D_5 (USEPA, 2003). The USEPA also stated that they could not make a determination on potential risk to human health until final results from the study are available, appropriate exposure information is developed, and a quantitative risk assessment is conducted. Final study results from Dow Corning are not expected to be available until late 2004. In the meantime, the SCAQMD has suspended grant funding for this alternative while review is underway.

PureDry

Niran Technologies Inc produces the dry cleaning solvent PureDry. This solvent is a blend of DF-2000 and a chemical additive package produced by 3M. The additive is a blend of perfluorocarbons (PFCs) and hydrofluoroethers (HFEs) that increase flash point of the solvent from 147 °F up to 350 °F. This substantial increase in flash point markedly improves fire safety. The additive package also improves the cleaning ability of DF-2000 by increasing its KB value from 27 to almost 40. Given the expense of PFCs and HFEs, the price for Puredry is $15 to $17 per gallon compared to $4 per gallon for DF-2000.

The solvent PureDry was introduced to the United States dry cleaning market in 2001 as a viable replacement for perc. Testing at Walt Disney World Textile Services in Orlando Florida was very successful. The clothes were cleaned to exceptional standards and without residual solvent odor in the finished garments. Distillation of PureDry resulted in the recovery of a distillate free of odor. Cleaning mileage is expected to exceed 1,000 pounds of clothes cleaned per gallon of solvent (DCNA, 2002).

However, a number of concerns have been voiced over the use of this solvent and the SCAQMD has not reported its use in the basin. One concern is that PFCs and HFEs both demonstrate a significant potential for global warming. Future restrictions over the use or release of these compounds could occur.

A second concern has to do with the behavior of the additive package during solvent recovery and reprocessing. The reported tests were conducted in new dry cleaning machines specifically designed for PureDry. Controls are used to precisely maintain temperature because the additive package can be altered if the solvent temperature exceeds 80°F. Additive loss does not substantially reduce the ability of the solvent to clean but it does result in the critical lowering of flash point. This could create a serious fire or explosion hazard if PureDry is used in a conventional machine that relies upon the solvent's high flash point for fire safety.

Rynex and Impress

ARCO Chemical (now Lyondell Chemical Company) developed the solvent dipropylene glycol tertiary-butyl ether (DPTB) as an alternative to perc. DPTB is being marketed to dry cleaners under the Rynex label by Rynex Holdings. Lyondell Chemical Company, through Caled Chemical, is also marketing a propylene glycol ether-based solvent under the Impress label.

Propylene glycol ether-based solvents are effective cleaners with low volatility and high flash point (the flash point of Rynex is 200 °F). Since DPTB is less volatile than perc, it is easier to maintain a low level of exposure in the workplace and solvent losses to air are less. The KB value for Rynex, or Impress, is not available but is reported to be closer to perc than the other alternative solvents. The cost for Rynex is $13 per gallon.

To remove residual Rynex from the cleaned clothing after extraction, the cleaning drum is placed under vacuum so that the solvent volatilizes. The Rynex vapor is recovered as a liquid by compressing and cooling the exhaust. Failure to remove all Rynex from the clothes can leave a distinct menthol odor. Per SCAQMD reports, no permits for the use of Rynex or Impress have been filed in the South Coast air basin.

Resolve

The Resolve process was developed by R.R. Street & Co and it is now being introduced to the dry cleaning market. The process employs both dipropylene glycol normal-butyl ether (DPNB) and liquid CO_2 in a system similar to a conventional perc system. DPNB is similar to DPTB (i.e., Rynex) in that it is an effective cleaning solvent with low volatility and high flash point. The KB value for Resolve is not available.

After extracting the DPNB from the clothes, liquid CO_2 is introduced into the system to perform a second wash. This second wash removes any residual DPNB from the clothes and it allows the clothes to be dried without heat. Most of the liquid CO_2 used for extraction and drying is recovered with minimal loss during decompression.

According to R.R. Street, energy consumption is less than that of any other dry cleaning technology because the process cycle time is half of that of a conventional perc system and because the system does not use heat for drying. Other reported benefits include reduced time and labor for stain removal and finishing, lower solvent and additive costs, reduced or eliminated solvent taxes and license fees, and the avoidance of hazardous waste generation. It is not known if any SCAQMD permit applications for the installation of a Resolve system have been filed to date.

Comexsol

The solvent n-propyl bromide (n-PB) was reportedly being marketed in the state of New York for use in dry cleaning under the Comexsol label (SCAQMD, 2002b). This solvent is more expensive than perc but it reportedly provides better mileage and the cleaning and drying cycle times are shorter. The machines used for this solvent are very similar to 4th or 5th generation perc machines. Comexsol is likely to be an aggressive solvent based on a KB value of 125 for n-PB.

In July 2003, the California Department of Health Services Hazard Evaluation System and Information System (HESIS) issued a hazard alert regarding the use of n-PB in the workplace. This solvent is irritating to the eyes, nose, and throat, at exposure levels of about 30 ppm. Very high levels of exposure may harm the liver, but it is not known if there is any risk to the liver from levels likely to be found in the workplace.

High levels of exposure may also result in nerve and brain damage. Animal tests have found these effects with exposures as low as 400 ppm. Case reports show that similar effects can occur in humans. Damage to the reproductive systems in both male and female animals has been noted. While the reproductive toxicity of n-PB has not been studied in humans, the closely related chemical 2-bromopropane has been found to cause long-lasting ovarian failure and the absence of sperm in workers.

A permissible exposure limit (PEL) for n-PB has not yet been established. The HESIS alert recommends that workplace exposure be limited to about 1 ppm in order to protect against reproductive and nerve toxicity. Two producers of n-PB, Great Lakes Chemical and AtoFina, recommend exposure limits of 5 and 10 ppmv, respectively and neither company plans to market this solvent to the dry cleaning industry. The SCAQMD has not reported its use in the basin.

5.2.2 System Availability

Historically, hydrocarbon solvents were used for dry cleaning in wet transfer systems. The system consisted of three major items: a washer, extractor, and dryer. These systems emitted a large amount of solvent into the workspace when the wet clothes were manually transferred from one machine to another. Exhaust from the dryer was emitted directly to the atmosphere because the value of the solvent was low and recovery was difficult. A high ventilation rate through the dryer was used to guard against the formation of an explosive atmosphere inside the unit.

Modern alternative solvent-based systems have nothing in common with these earlier wet transfer systems but instead, are much closer in design to a 5th generation perc system. All new systems tend to incorporate a refrigerated condenser; a computerized temperature and cycle control system; and improved gasket materials to avoid leaks.

Temperature monitoring and control, while improving system performance, improves safety and insures compliance with fire code requirements. Most machines operate at a maximum temperature of 120 °F that is 27 °F below the flash point of DF-2000 and 50 °F below the flash point of GreenEarth.

Most major equipment manufacturers of perc-based systems also offer compatible or approved systems for DF-200 and GreenEarth. Manufacturers offering compatible systems for DF-2000 include AMA Universal, Bergparma of America, Bowe Textile Cleaning USA*, Columbia / ILSA Machines Corp.*, Firbimatic / EcoDry of America*, Fluormatic Midwest Ltd., Forenta LP, Hill Equipment Co., Hoyt Corp., Lindus West, Marvel Manufacturing*, Multitex*, Realstar USA*, Renzacci of America*, Sail Star USA*, Satec, Steiner-Atlantic Corp.*, Suprema Corp., and Union Drycleaning Products USA*. Those companies marked with an asterisk also offer equipment that has been field tested and approved for sale to a licensed GreenEarth affiliate.

5.2.3 Capital Cost and Equipment Life

The capital cost for most machines designed for DF-2000 or GreenEarth ranges from $38,000 to $72,000 (SCAQMD, 2002d) depending on size, materials of construction, and features. The cost of a new comparable perc machine was reported to be $32,000 to $64,000. This results in a price premium of $6,000 to $8,000. The equipment life for these systems is expected to be the same as for a new perc system.

It has been reported that conversion kits are available for modifying a 3rd generation, or later, perc machine to use the GreenEarth solvent (FutureClean, 2004). The conversion consists of adding a filtration system, temperature control sensors, pre-water separator filter, water separator, and electrical control panel to the unit. This lower-cost approach to conversion may be suitable for a shop with a relatively new perc system, but the shop must first obtain fire code approval prior to applying for a GreenEarth license.

The estimated cost for installation is in the $3,000 to $5,000 range. This cost assumes a retrofit application where all required utilities are already installed. In addition, this cost assumes that no building upgrades are required to meet Fire Code. Substantial costs could be incurred for such upgrades. The users of GreenEarth must also pay an annual license fee of $2,500 for the first machine installed at a given location.

Some solvent equipment vendors recommend upgrading one size when switching from perc to solvent. Other manufacturers claim that processing times are comparable so that such an increase in size is not required. However, the purchase of a slightly larger unit may be of benefit if the cycle time must be extended to achieve complete drying. A typical size unit has a maximum cleaning capacity of 40 to 45 pounds per load.

5.2.4 Operating Cost and Cycle Time

According to two local distributors of both solvent and perc machines, the cycle time for an old solvent machine was approximately 60 minutes versus 45 minutes for a perc machine. One reason for the longer cycle time was due to the longer wash cycle and drying cycle. Improvements in equipment design such as the addition of a vacuum system to speed drying, have reduced overall cycle times.

Derivation of operating costs for new systems employing DF-2000 and GreenEarth are presented in Section 6. The total annualized cost for owning and operating a new DF-2000 system is estimated to be $0.30 to $0.36 per pound of clothes cleaned for a shop cleaning 50,000 to 85,000 pounds of clothing per year. Total annualized costs for a shop using a GreenEarth system range from $0.36 to $0.44. Costs for DF-2000 include the $5,000 grant available through the SCAQMD.

Total annualized costs include capital, operator training, maintenance, electric power, cleaning solvent, process supplies, and regulatory compliance (including hazardous and solid waste disposal). Labor, water, and natural gas requirements are not included since these costs, while not quantified, have been reported in other sources to be comparable for all technologies considered.

5.2.5 Energy Use

Solvent machines are expected to use about the same amount of energy as a new perc machine. Therefore, the electricity required for the wash motor, extract motor, fan motor, pump motor, air exchange motor, and compressor, at maximum operating load, can be up to 15 kWh with the typical load averaging 2 to 3 kWh. However, one test report found the energy use of a GreenEarth machine to be 50 percent greater than a hydrocarbon solvent machine (see Section 6.1.5 for discussion). Natural gas demand is taken to be the same for all systems and has not been quantified.

5.2.6 Cleaning Performance

Solvents work best for stains that are oil-based such as grease, wax, oils and resins. To achieve a high level of performance, specially formulated detergents are required for use with DF-2000. Through the use of new additives and improved process conditions, the International Committee for Textile Care (CINET) believes that hydrocarbon solvents now have a cleaning effect that is almost equal to perc. This requirement for specially formulated detergents is common to all of the alternative technologies considered.

The SCAQMD, in conducting interviews, report that operators of hydrocarbon systems who switched from perc felt that the fabrics came out fresher with no odor and that they could clean a wide range of items. Some operators have complained of clothes feeling oily but equipment vendors counter that this may be due to improper drying. If oiliness occurs, the machine may be operating without a drying sensor and the operator may be removing the clothes too soon. Many users report the cleaned clothes to feel softer, be easier to press, and have a better finish than clothes cleaned in perc.

The GreenEarth process consists of the siloxane solvent used with specially formulated detergents from Proctor & Gamble. Testing conducted by the International Fabricare Institute (IFI) found that cleaning performance is not quite as effective as perc for all stains but is comparable when dealing with water-soluble stains. The solvent can handle a wide variety of specialty items, demonstrates affordable labor and operating costs, and the capital cost is reasonable.

5.2.7 Permitting and Rule Compliance

The major environmental and health and safety compliance issues faced by dry cleaners switching to alternative solvents such as DF-2000 or GreenEarth includes air quality, fire safety, and wastewater discharge.

Air Quality

Rule 1102, amended on 17 November 2000, applies to all persons owning or operating a dry cleaning facility that uses solvent other than perc. The replacement of perc with a hydrocarbon or petroleum-based solvent will require compliance with this rule. The dry cleaning solvent GreenEarth, a silicone-based fluid, is a Group II exempt compound and is exempt from all rule requirements except recordkeeping provided that the detergents and additives used contain less than 50 grams per liter of VOC.

For dry cleaners converting from perc to a hydrocarbon or petroleum-based solvent, the restrictions set on the use of wet transfer systems will have no impact. All new solvent machines that are being marketed are closed-loop. Rule 1102 does impose general equipment specifications and operating requirements that the owner or operator must follow. Specific equipment specifications and requirements include the following:

- A closed-loop machine shall not exhaust to the atmosphere or the workroom except when the vacuum pump exhausts to maintain continuous vacuum.
- For any closed-loop machine that is not equipped with a locking mechanism, the operator shall not open the door prior to the completion of the drying cycle.
- If the machine is equipped with a locking mechanism, the operator shall not inactivate the lock and open the door prior to the completion of the drying cycle.
- Equipment items where solvent may be exposed to the atmosphere (e.g., washer lint traps, button traps, access doors, etc.) shall be kept closed at all times except as required for proper operation and maintenance. Button and lint traps shall be cleaned each working day.
- All solvents and solvent-bearing wastes (e.g., still residue, used filtering material, spent solvent) shall be stored in closed containers. Cartridge filters shall be fully drained in a sealed filter housing for at least 24 hours before removal.
- No less frequently than monthly, the owner or operator shall inspect the dry cleaning system for liquid and vapor leaks. The detection of vapor leaks shall be via soap bubble technique, a non-halogenated hydrocarbon detector, or other District approved method.
- The owner or operator shall maintain a log listing date and pre-wash weight of clothes per load, solvent inventory for the reporting period, amount of solvent used, calculated mileage, date of leak inspections, and a leak repair log.

Compared to Rule 1421, Rule 1102 requirements are less restrictive and are less costly to adopt. Any owner or operator may perform inspection and testing since there is no requirement for operator training and certification. The inspection frequency for liquid and vapor leaks is also less, once per month compared to once per week. There is also no mandatory requirement to replace all gaskets and seals every two years.

Fire Code Requirements

Shops converting to flammable hydrocarbon solvents must comply with additional fire code requirements. Class IIIA dry cleaning shops and their associated operations must be separated from all other businesses by four-hour or more fire-resistive occupancy separations. A two-hour fire-resistive occupancy separation is allowed when the total quantity of Class IIIA liquid within the building does not exceed 1,320 gallons and the capacity of individual containers or tanks does not exceed 330 gallons.

Dry cleaning rooms that contain Class IIIA solvents must also be separated from other shop areas such as storage, offices, laundering, scouring, scrubbing, pressing, and ironing by not less than two-hour fire-resistive occupancy separations. If these total and individual storage quantities are exceeded, then the dry cleaning room must be provided with four-hour fire-resistive occupancy separations.

One of the largest machines sold, a seventy-seven pound load unit, holds about 150 gallons of solvent. Thus, a dry cleaner in the City of Los Angeles could install two units without having to install additional fire suppression (this assumes the shop currently meets the two-hour fire-resistive occupancy separation requirement).

The LAFD may also approve a permit based on an alternate method of compliance. For example, one-hour fire-resistive occupancy separations are acceptable when the shop is equipped with an automatic fire-protection sprinkler system or the cleaning equipment incorporates one or more appropriate safeguards to prevent fire. Safeguards include temperature sensors and operation at 30 °F below the flash point of the solvent, oxygen sensors and inerting to ensure than the oxygen content does not exceed 8 percent, and a combustible gas indicator to ensure that the vapor concentration is limited to less than 25 percent of the lower explosive limit (LEL). All new solvent machines incorporate one or more of these safeguards as standard design.

Wastewater Discharge

The alternative solvents used in the dry cleaning process tend to be biodegradable and/or of low toxicity so that their presence in wastewater discharge is not expected to be a problem. However, shops should continue the practice of filtering the separator water and then allowing the water to evaporate so as to avoid violating local wastewater discharge standards.

5.2.8 Waste Generation

No change in the type or amount of waste generated by the shop is expected from the switch to an alternative cleaning solvent. Both still bottoms and spent filters will require proper management and disposal.

5.2.9 Grant Funding

Effective 4 April 2003, the SCAQMD suspended funding for the silicone-based solvent systems (i.e., GreenEarth) in response to preliminary bioassay results that are currently under review. Funding may be restored at a later date pending review. A $5,000 grant is available for cleaners switching from perc to hydrocarbon solvent.

5.2.10 Training Requirements

Switching to an alternative dry cleaning solvent avoids the need for operator training imposed by SCAQMD Rule 1421. System operation is very similar to that of perc so that formal training is seldom required. Equipment vendors and trade organizations are available to assist in the conversion.

5.3 Professional Wet Cleaning

Professional wet cleaning is an alternative to dry cleaning for fabrics labeled “dry clean only.” It is different from commercial laundering in many aspects. In 1991, a German company introduced the technology. It consists of computer-controlled washers and dryers using detergents specifically formulated for the process. Finishing equipment includes pressing, tensioning, and stretcher machines.

5.3.1 Detergent Availability; Use; Health & Safety

Professional wet cleaning systems use non-toxic, pH-neutral, biodegradable detergents that are approved for disposal via the sanitary sewer. These detergents also include additives to maximize cleaning power while minimizing color change and shrinkage. Most suppliers offer more than one formulation, each tailored to a particular class of garment. Conditioners add smoothness and softness to garments, and they also coat fibers in a way that helps prevent shrinkage.

At least ten companies currently provide specially formulated detergents to the industry. Identified suppliers include Adco, Bufa, Sanitone, Stamford, Fiber Tech, Gurtler, Laidlaw, Kleerwite Chemicals, Pariser Industries Inc, and Seitz. Some suppliers also provide the dispensing equipment at a discount or for free depending on the amount of products purchased. Compared to the cost of perc, wet cleaning detergents tend to cost 50 to 100 percent more in terms of dollars per pound of clothes cleaned.

In addition to detergent, wet cleaning requires the use of water. A USEPA assessment reported process water demand to be 3.5 gallons per pound of clothes cleaned at a cost of $3 per 100 cubic feet (USEPA, 1998). This equates to 175,000 to 298,000 gallons of water per year at a cost of $700 to $1,200 per year or $0.01 to $0.02 per pound.

While some studies have reported higher water use for wet cleaning, others have found overall water demand to decrease following conversion. A reason for this reduction may be the elimination of the perc air emission control and recycling systems that use water for cooling. A recent study (PPERC, September 2004) found that shops that employ cooling towers may waste a substantial amount of water due to poor tower maintenance. Poor boiler and piping maintenance was also cited as a cause of high water use.

The major risk posed to shop workers by the use of these new detergents is expected to be skin or eye irritation. This risk is mitigated by avoiding contact with the concentrated detergents and by wearing proper personnel protective gloves and safety glasses when servicing the equipment. Compared to perc, the formulated detergents are expected to be much safer and shops in a wet cleaning demonstration project did note a reduction in worker complaints due to headaches and dizziness.

5.3.2 System Availability

All professional wet cleaning is performed in a special washer and dryer. The core technology of the washer is the use of a frequency-controlled motor. Controlling rotation of the wash drum provides smooth acceleration and deceleration, resulting in an ultra-gentle wash action. An ordinary washer can damage garments by excessive agitation during the wash and spin cycles. The wash program software determines the best combination of wash drum water level, washing time, degree of agitation, temperature, chemical injection, and extraction cycle for a given batch of clothing.

After washing, the wet cleaned garments must be carefully dried prior to finishing. The wet cleaning cycle generally takes about 45 minutes from washer through dryer, not including finishing. As with aggressive wash drum agitation, prolonged tumbling can cause shrinkage. Excessive drying also causes shrinkage, which accelerates when the final 6 to 10 percent of remaining moisture is removed. Thus, the dryer is computer controlled to provide gentle tumbling, minimized drying time, and to avoid the removal of too much moisture from the garments.

Six manufacturers provide wet cleaning machines to the industry: Aqua Clean, Bowe Permac, Ipso, Miele, Milnor, and UniMac. Aqua Clean, Bowe Permac, and Miele also offer dryers designed for the wet cleaning process. Tensioning equipment is available from Bruske, Clean Concepts, Forenta, Hi-Steam, Hoffman/New Yorker, Itsumi, Sankosha, Trevil, Unipress, and Veit.

5.3.3 Capital Cost and Equipment Life

The cost of a wet cleaning system ranges from $17,000 to $21,000 for the washer and dryer plus $10,000 to $16,000 per tensioning press as reported by the SCAQMD. Data from the Pollution Prevention Education and Research Center (PPERC) at Occidental College reports the capital cost for a 30 pound load washer and dryer to be $17,000 to $30,000. In addition, two or more tensioning presses are required for a viable system at a cost of $9,000 to $13,000 per press.

Therefore, the capital cost for a complete professional wet cleaning system consisting of washer, dryer, and two tensioning presses is expected to be in the range of $35,000 to

$56,000 with installation adding another $2,000. Installation can often be performed over a weekend, thereby minimizing downtime and loss of revenue.

Equipment life for these systems varies as a function of workload, usage, installation, operation, and equipment design. The manufacturer of the Aqua Clean fixed-mount system estimates a minimum life of 15 years (PPERC 2004). To obtain maximum life from a fixed-mount system, a solid and secure foundation is required and care must be taken to ensure that the cleaning load is balanced.

Miele equipment uses a soft-mount system and they report an expected operating life of 30,000 hours. Depending on workload and usage, 30,000 hours equates to a lifetime of 11 to 17 years. Soft-mount systems are less prone to vibration and load imbalance but the springs and dampeners represent added components that can break and wear out. Most wet cleaners in the South Coast use the Aqua Clean system (PPERC 2004).

5.3.4 Operating Cost and Cycle Time

The total time from start to finish (dry to dry) for the wet cleaning process is reported to be on the order of 45 minutes. This time is equivalent to the time required for cleaning a load in a new perc system. However, wet cleaning can actually process more loads in a given period of time because the system consists of a separate washer and dryer. A second load of clothes may begin washing while the first load is drying.

Performance tests have shown that dimensional change (shrinking and stretching) of the garments can be a problem if the cleaner uses conventional pressing equipment. The use of conventional pressing equipment also results in a slowdown in production and a common complaint that wet cleaning is more labor intensive. Use of proper tensioning equipment and thorough training of the operator can maintain a level of productivity equivalent to a shop using perc.

The annualized operating cost for a new wet cleaning system is estimated to be $0.24 to $0.28 per pound of clothes cleaned depending on workload. This cost estimate includes capital, operator training, maintenance, electric power, process supplies and detergent, and regulatory compliance (including solid waste disposal). Labor, water, and natural gas requirements have not been quantified since other sources have reported these costs to be equivalent for the alternatives considered. Overall, the wet cleaning process demonstrates the lowest annualized cost of ownership and operation.

5.3.5 Energy Use

Tests conducted by PPERC at the San Clemente Natural Cleaning Center before and after their switch from perc to wet cleaning found a 46 percent reduction in electricity use and a 4 percent reduction in natural gas use. Energy use while operating a perc system was 800 to 1,500 kilowatt-hours (kWh) per month. Usage was approximately 600 kWh per month following conversion. Peak demand for wet cleaning was 6 to 8 kW.

Business levels remained constant before and after the conversion so the change was not related to any reduction in load. The range of reduction in energy use among five PPERC facilities was 12 to 46 percent for electricity and 1 to 36 percent for natural gas. Water use ranged from a reduction of 1 percent to an increase of 17 percent. See Section 6.1.5 for additional information regarding energy use.

5.3.6 Cleaning Performance

Wet cleaning is more effective than perc at removing water-based stains such as salts, sugars, body fluids, starch, milk and many foods and drinks. The removal of oil-based stains such as grease and oil requires the use of pre-spotting chemicals that have been specifically designed for the wet cleaning process.

Wet cleaning may also be of help in keeping white garments white. White garments can sometimes be dulled when using recycled perc or other solvents. Garments made of wool, silk, and rayon may present problems for wet cleaning because of possible fiber shrinkage or bleeding of dye. Problem garments include suit jackets with front fixing construction, coats, items with shoulder pads, and ornate clothing. Special sizing equipment may be able to restore the original size and shape to some of these items.

At all facilities that participated in the PPERC project, more than 62 percent of the garments carried a dry clean label and greater than 96 percent of all garments were successfully wet cleaned. Four of the five cleaners reported a success rate of 99 percent or better. No cleaner reported a negative response from customers.

Many dry cleaners worry about the potential liability associated with wet cleaning a garment labeled “dry clean” only. A cleaner is liable for damage caused to a garment that is not cleaned according to the garment manufacturers recommendation. Efforts are underway at the international level to increase the use of “wet clean” labels. Some shops have elected to install both a hydrocarbon-based solvent and wet cleaning system to address this concern.

5.3.7 Permitting and Rule Compliance

A wet cleaning system does not require a Permit to Operate from the SCAQMD and it is not subject to Rules 1421, 1102, 1401 or 1402. A wet cleaning shop is mostly exempt from fire code requirements except for any flammable or combustible chemicals kept in stock for spotting. An industrial wastewater discharge permit is required to discharge water from the wet cleaning system to sewer. Since many shops also operate laundry equipment, the need for a discharge permit is not a new requirement.

5.3.8 Waste Generation

The detergents used in the process are intended for discharge via the sanitary sewer. While some of the compounds used in the detergents may pose a risk to aquatic life, all are readily biodegradable and should be readily removed at the local treatment plant. Spent filters will still be generated, but these filters are expected to require management as a solid waste rather than hazardous waste.

5.3.9 Grant Funding

There are currently 15 facilities in the South Coast air basin that are dedicated to wet cleaning with a similar number operating both wet cleaning and solvent-based systems (PPERC, 2004). A total of 37 facilities have applied for SCAQMD grants to install wet cleaning systems. The SCAQMD offers a $10,000 grant for dry cleaners seeking to install a complete wet cleaning system that consists of computerized washer, dryer, tensioning form finisher, and tensioning pants finisher. A $5,000 grant is available for facilities that do not need to purchase new tensioning equipment.

A primary goal of the Professional Wet Cleaning Commercialization Project that is being conducted by the PPERC is to establish a support infrastructure for the industry. Based on their experience, no dry cleaner has switched to wet cleaning without first visiting a demonstration site to see the system in use. To encourage site participation, PPERC offers grants to dry cleaners to serve as wet cleaning demonstration sites.

Each grantee receives $12,500 towards the purchase of new equipment (this includes the $10,000 grant from the SCAQMD), $7,500 in guaranteed discounts from system manufacturers, and free technical training. In return, the shop must be willing to allow other dry cleaners to witness the operation of the system and to serve as a resource in helping others to network and resolve operational problems. In addition to the current sites, the program seeks to fund an additional 14 sites over the next two years.

5.3.10 Training Requirements

Dry cleaners switching to wet cleaning report favorable results with most reporting no increase in customer complaints. Encountered cleaning problems have been related to improper installation and programming of the equipment. Most problems have been successfully corrected via additional operator training.

Based on PPERC experience, the two most important keys to success include ready access to a support network and operator training. Such training includes load sorting, spotting, garment measurement, and drying strategies. The operating cost estimate presented in Section 5.3.4 assumes that an operator will require two days of training at an off-site facility. The cost for this training is taken to be $800, including operator time. Cleaners who have gone through the conversion and training have been able to avoid a loss in revenue due to downtime by conducting the conversion and training over a 3-day holiday weekend when the workload is light.

5.4 Carbon Dioxide (CO_2) Cleaning

Another alternative to perc is the use of supercritical or liquid carbon dioxide (CO_2) as a cleaning solvent. This technology originally used CO_2 in supercritical condition, a state that begins at 88°F and 1,070 pounds per square inch (psi). Most supercritical CO_2 systems are designed to operate in a temperature range of 90 to 120°F and a pressure range of 1,070 to 3,500 psi.

To safely maintain the required pressures at these conditions, the equipment must be extremely heavy and is therefore expensive. This has limited the use of supercritical

CO_2 to high dollar value activity such as the precision cleaning of military components, the extraction of essential oils from plants, and the removal of caffeine from coffee.

Research in this field also led to the investigation of the solvent properties of liquid carbon dioxide. While not as effective as supercritical CO_2, the liquid is capable of dissolving oils and grease to the same extent as some petroleum solvents. In addition, maintaining the gas as a liquid requires a lower pressure of several hundred psi which can be achieved with less expensive equipment.

Los Alamos National Lab explored the use of liquid CO_2 as an alternative dry cleaning solvent in 1994. An alpha prototype machine, developed by Raytheon and Global Technologies appeared at the Las Vegas Clean show in 1997. A beta commercial unit first appeared in Forest Lake, Minnesota in 1999. Since then, the technology known as the DryWash Cleaning Process has been sublicensed to a team of manufacturers and systems have been installed in fourteen states. There are at least two systems in the South Coast air basin.

5.4.1 Solvent Availability; Use; Health & Safety

The CO_2 used in this process does not contribute to global warming, as it is an industrial by-product from other industrial operations. This CO_2 is also used in other applications such as carbonating soft drinks. The bulk delivery of liquid carbon dioxide to fast food restaurants for use in carbonating water is common practice. The delivered price for liquid CO_2 is about $0.20 per pound or $2.50 per gallon. Some suppliers of liquid CO_2, most notably ICI and Linde under their Washpoint label, offer the liquid pre-blended with detergent for use in cleaning.

Solvent mileage is very dependent on the size of the system and the allotted cycle time. One system designed for a maximum load of 55 pounds (50 pounds typical) is reported to use 10 to 15 pounds of CO_2 per load. This equates to a solvent mileage value of 34 to 63 pounds of clothes per gallon of solvent. Machines can be adjusted to reclaim more CO_2 by regulating the release pressure at the end of the cycle but this practice is offset by an increase in cycle time.

The major worker health and safety concern for this technology involves potential skin and eye irritation due to exposure to detergents. Wearing proper protective gloves and goggles when handling these products can mitigate this risk. A lesser risk is the release of CO_2 from the system. Exposure to liquid CO_2 can cause severe frostbite or cryogenic burns. The liquid can also vaporize rapidly, displacing air, resulting in asphyxiation. High-pressure gas leaks due to pinholes in flexible lines can also result in worker injury. To mitigate these risks, systems are designed and built to high standards and only vendor-approved parts should be used for their repair.

5.4.2 System Availability

The DryWash cleaning process from Global Technologies operates in a closed-loop mode, with washing, extraction, and drying performed in the same cleaning chamber. The machine includes a high-pressure cleaning chamber, a cryogenic storage tank for the liquid CO_2, a filtration and distillation unit for the removal of soil from the recovered liquid, a lint trap, computer controls, and safety interlocks.

Cleaning begins by loading the chamber with clothes, sealing the door, and then filling the system with liquid CO_2 and detergent. Next, the liquid is circulated and returned to the chamber via fluid jets. These fluid jets are located inside the chamber and they are arranged so that they impact the clothes, causing rotation. This design avoids the need for motor, shaft, and seal to rotate the chamber as is common in other dry cleaning and wet cleaning systems. The jets also aid in the removal of soil locked in the fibers.

Following the cleaning cycle, the fluid is filtered, the CO_2 separated from the dissolved oils and detergent, and returned to storage for reuse. The pressure inside the cleaning chamber is gradually reduced, resulting in the cooling and drying of the clothes as the liquid evaporates. This cooling avoids the heat-set of wrinkles and the shrinkage that may occur with conventional hot air drying. The vented gas is recompressed and cooled so as to recover about 98 percent of the vented CO_2 as liquid.

In addition to Global Technologies, several other companies offer these systems. Micell Technologies, through their Hanger Cleaners franchises, was an initial competitor to the Drywash system. The Hanger Cleaners brand and the Micell technology were then acquired by a spin-off of Chart Industries, Cool Clean Technologies. Other companies include Alliance, Electrolux, and Sail Star.

5.4.3 Capital Cost and Equipment Life

Cost data presented by the SCAQMD shows the cost of a CO_2 dry cleaning machine to be $80,000 to $90,000 with a total system price of $100,000. The additional $10,000 to $20,000 for a complete system covers the cost of other necessary equipment along with shipping, distributor commission, and installation. Expected equipment life has been reported by one supplier to be as great as 40 years but a more conservative estimate of 15 years is expected. This is based on the view that the fewer number of moving parts in these systems should result in a longer life compared to alternative systems.

5.4.4 Operating Cost and Cycle Time

The total cycle time from start to finish for the cleaning process is reported to be on the order of 35 to 40 minutes. This time is slightly less than the 45 minutes required by a perc system. One factor that helps to achieve a reduction in cycle time is the elimination of heat from the drying process. The other technologies require longer drying cycles to avoid the heat-set of wrinkles. The cycle time for this technology may be extended, if desired, to achieve a greater degree of solvent recovery. The operating cost for a liquid CO_2 cleaning system is estimated to be $0.36 to $0.43 per pound of clothes cleaned depending on overall workload.

5.4.5 Energy Use

A typical liquid CO_2 system requires a 70 to 150-amp service to operate the refrigeration system necessary to maintain the CO_2 in a liquid state. Peak load for the pumps and compressor could be up to 20 kWh. This is the highest peak load reported and it could result in increased peak load demand charges and a higher rate. See Section 6.1.5 for additional information regarding energy use.

5.4.6 Cleaning Performance

Liquid carbon dioxide has a KB value similar to that of petroleum-based solvents (i.e., between 27 to 45). While one might assume that liquid CO_2 would not be as effective as perc with a KB value of 90, testing performed by Los Alamos National Laboratory found the performance of this technology to be better in terms of soil redeposition and potential dye transfer (GT, 2003). Equivalent performance was noted for the removal of oily soil, collar dirt, particulate soil, stain removal, and water-soluble soils.

Cleaned fabrics included both natural (leather, cotton, silk, wool, and linen) and synthetic (rayon, polyester, poly/cotton, and diacetate) materials. Dimensional changes for all of the fabrics except diacetate were within the same range as that noted for perc. Users of this process have also noted problems associated with the cleaning of acetate materials. Buttons (metallic, shell and bone, and synthetic) have been processed without damage but the high pressure may crush hollow buttons.

5.4.7 Permitting and Rule Compliance

Like professional wet cleaning, dry cleaners using liquid CO_2 systems are not subject to SCAQMD Rule 1102, 1401, 1402, or 1421 requirements provided the detergents and additives used in the process contain less than 50 grams per liter of VOC. Additionally, these machines do not require a SCAQMD Permit to Operate.

The storage of liquefied gas, as well as the continued use of flammable or combustible spotting chemicals will require a permit from the LAFD. The liquid CO_2 storage tank and the cleaning chamber are pressure vessels and they must carry an American Society of Mechanical Engineers (ASME) stamp. The operation of these pressure vessels requires the shop to obtain a pressure vessel permit from the State of California.

An industrial wastewater discharge permit may be required depending on how much spent detergent waste is generated per day and how it is managed. Hauling the spent detergent offsite as a solid waste would avoid the need for a discharge permit. Spent filters will also require management as solid waste.

5.4.8 Waste Generation

The two wastes generated by this process are the spent filters used to remove insoluble dirt and the spent detergent that contains the soluble oils and grease. Both of these wastes should be manageable as solid wastes provided no hazardous chemicals have been introduced. The use of such chemicals would be associated with spotting. In terms of volume, this process is expected to generate the least amount of waste compared to perc or the other alternative technologies.

5.4.9 Grant Funding

The SCAQMD has increased the level of funding for these systems to $20,000 (up from $10,000) to better offset their high capital cost.

5.4.10 Training Requirements

As with wet cleaning, training is a key requirement for the success of this technology. Training issues include load sorting, selection of appropriate detergent formulations, and the programming of system cycle times. Given the small user base in the South Coast basin, shop operators should contact their equipment manufacturer for assistance.

6.0 ESTIMATE OF CLEANING COSTS

Many of the reference documents do not account for all cost variables on a consistent basis. Certain costs are often omitted when data is not available. While this approach is useful for developing an estimate based solely on known data, it can result in serious error when comparing the result of different studies. The extent of this error depends on the specific omissions and their magnitude.

To conduct an equivalent comparison of the competing alternatives, an attempt has been made to quantify all of the major cost variables associated with perc, DF-2000, GreenEarth, professional wet cleaning, and liquid CO_2. Section 6.1 presents the cost data and the assumptions used to estimate annualized costs. Section 6.2 presents the results of this effort. Cost estimation worksheets are presented in Appendix A.

6.1 Cost Data & Assumptions

Cost data and the assumptions used in preparing these estimates are derived from the studies referenced elsewhere in the report. Major variables include workload and annual revenue, capital equipment cost (including installation), operating labor, solvent cost, electric power, process supplies, system maintenance, regulatory compliance and waste disposal, and operator training. Costs that have not been quantified, but are taken to be equivalent for all of the alternatives are so noted.

6.1.1 Work Load & Annual Revenue

The derived cost for each technology in terms of dollars per pound of clothes cleaned is very sensitive to workload. Data from a SCAQMD survey of 20 dry cleaning shops using 4^{th} or 5^{th} generation perc systems reported an annual workload of 85,000 pounds. Other USEPA studies place the typical annual workload closer to 50,000 pounds. Both values are used in this assessment to set the range of expected costs.

For an existing dry cleaner who adopts a new perc system, it is possible that they will need to curtail production in order to maintain compliance with SCAQMD Rule 1402. Such curtailment will trigger the need for a second alternative dry cleaning system so as to maintain production. A dual-system scenario in compliance with Rule 1402 has been included in this assessment.

Annual revenue taken in by the shop is taken to be $3 per pound of clothes cleaned regardless of the technology employed. It is assumed that the shop operates 6 days per week, 52 weeks per year, for a total of 312 days. Annual revenue for the typical dry cleaning shop therefore ranges from $150,000 to $255,000 depending on workload.

6.1.2 Equipment & Installation Costs

Equipment costs are taken as the mid-point of the capital cost range reported in Table 1. Other capital equipment costs include two new tensioning presses for the wet cleaning system and equipment installation for all systems. Installation costs assume a retrofit application where all required utilities are present in the shop. The installation cost for the DF-2000 system assumes that no building improvements are required to meet Fire Code. Available grants, which offset the overall capital cost, are handled as a separate calculation following the determination of total annualized cost.

Reported equipment life varies widely with some references stating 8 to 14 years for a 4^{th} and 5^{th} generation system and some suppliers claiming up to 30 years or more depending on maintenance. The same can be said for wet cleaning systems. For this estimate, 12 years is taken as a typical life for the perc and solvent systems and 15 years is taken for the wet cleaning and liquid CO_2 systems.

To determine the annual cost of equipment purchase and installation, all one-time costs are annualized over the life of the equipment at an interest rate of 7 percent. Costs are annualized by use of the Capital Recovery Factor (CRF) equation:

CRF = $i \times (1 + i)^{n} / ((1 + i)^{n} - 1)$

where:

i = annual interest rate as a fraction

n = life of the equipment in years

For a system life of 12 years and a 7 percent interest rate:

CRF = $0.07 \times (1 + 0.07)^{12} / ((1 + 0.07)^{12} – 1)$

= $0.07 \times 2.252 / 1.252$

= 0.1259

Annual Cost = CRF x One-Time Capital Cost

6.1.3 Operating Labor

All dry cleaning systems are reported to be relatively comparable in terms of the amount of labor required for the cleaning process. Some references report that the wet cleaning process requires more labor for pressing and finishing, but others contend that this is not the case when new tensioning equipment is used and proper operator training provided. Since new finishing equipment and operator training has been included for wet cleaning, operating labor for all systems is assumed to be the same.

Since operating labor for each system is assumed to be the same, labor cost has not been quantified and is excluded from the estimate. Differences in labor requirements might be a concern if system operators are hired on a part-time basis or if the difference in labor requires the hiring of additional staff or the curtailment of business. Based on available data, no shop adopting an alternative system has had to hire additional staff or curtail business due to the change.

6.1.4 Solvent Mileage & Cost

Solvent mileage for a 4th or 5th generation machine using perc or DF-2000 is taken to be 800 pounds per gallon. This mileage figure is much greater than the 300 pounds per gallon used in the USEPA assessment, but it is much closer to the results obtained from the SCAQMD survey. Solvent mileage for GreenEarth is taken to be 1,300 pounds per gallon (the mid-point of the reported range).

The price of alternative solvent is taken to be $4 per gallon for DF-2000 and $15 per gallon for GreenEarth. The price of perc has been in the $7 to $8 range, but this price will see substantial increase due to the fees imposed by CARB. These fees start at $3 per gallon and will increase up to $12 per gallon in $1 annual increments. Assuming the new perc system was purchased in mid 2004 when the fee went into effect, and that the base price for perc remains constant at $8 per gallon over the 12-year life of the system, the average price per gallon will be:

Perc Price = [($8+$3) + ($8+$4) + ($8+$5) + ($8+$6) + ($8+$7) + ($8+$8) + ($8+$9) + ($8+$10) + ($8+$11) + ($8+$12) + ($8+$12) + ($8+$12)]/12 yrs

= $16 per gal

Knowing the annual workload, solvent mileage, and the cost per gallon of solvent, the annual solvent cost may be calculated as follows:

Annual Cost = $/gal x lbs of clothes cleaned per yr / lbs cleaned per gal

Perc Cost = $16 x 50,000 / 800

= $1,000 per yr

Vendor literature for the Cool Clean system indicates a solvent loss of 10 to 15 pounds per load or 0.8 to 1.2 gallons of liquid CO_2 per load based on a density of 12.6 pounds per gallon. Since typical loads range between 40 to 50 pounds, solvent mileage can range from a low of 34 pounds per gallon to a high of 63 pounds per gallon. A mid-point value of 45 pounds per gallon is used for the assessment.

The delivery cost for liquid CO_2 is taken to be $0.20 per pound or $2.50 per gallon given a liquid density of 12.6 pounds per gallon. Following the conversion of solvent mileage to a pound per gallon basis and the conversion of solvent price to dollars per gallon, the calculation of annual cost employs the equation shown above for perc.

6.1.5 Energy Costs

The annual energy cost reported in the USEPA assessment for a 3rd generation perc system was $186. This cost is very low and is suspect based on other reported data. Energy usage monitored during a professional wet cleaning conversion study by the PPERC reported monthly energy use of 600 kWh following conversion and a 46 percent reduction from the pre-conversion use of a perc system. This data implies that a shop operating a perc system uses 1,100 kWh per month. For comparison, the USEPA cost of $186 per year equates to 194 kWh per month based on $0.08 per kWh.

A recent study collected energy usage data from shops employing most of the systems of interest (PPERC, September 2004). This study was sponsored by the Los Angeles Department of Water and Power and was conducted to evaluate the potential for an electricity rebate program for professional wet cleaners. Electric power demand was monitored over several cleaning loads and the reported results are as follows:

3rd Generation Perc	30.1 kWh per 100 lbs cleaned
DF-2000	23.8 kWh per 100 lbs cleaned
GreenEarth	34.7 kWh per 100 lbs cleaned
Wet Cleaning	12.0 kWh per 100 lbs cleaned
Liquid CO_2	29.0 kWh per 100 lbs cleaned

Additional work is planned by the PPERC to increase the number of shops included in the database. While the above factors are based on single system measurements, they represent the most complete set of factors identified. These factors agree with the previous PPERC study since monthly energy use for cleaning 50,000 pounds of clothing per year would be 1,254 kWh for perc and 500 kWh for wet cleaning.

For this assessment, the energy usage for a new 4th or 5th generation perc system is taken to be the same as for a DF-2000 system. This represents a 20 percent reduction from a 3rd generation perc system. At an energy cost of $0.08 per kWh, the annual cost for energy is calculated as follows:

Annual Cost = $ per kWh x kWh per 100 lbs cleaned x lbs cleaned per yr / 100

Perc Cost = $0.08 x 23.8 x 50,000 / 100

= $952 per yr

Natural gas usage is assumed to be the same for all of the systems and has not been quantified. The recent PPERC study did collect natural gas usage data but a number of problems with the data were noted. Natural gas usage varied from shop to shop, but overall usage appeared to be a strong function of boiler system condition and operator experience. A poorly maintained boiler system can have a larger effect on natural gas usage than the actual cleaning system employed.

6.1.6 Supplies, Water, & Detergent

The cost for filters and other cleaning supplies such as detergents and spotting agents is derived from the USEPA assessment report. Reported costs were $1,913 for perc, $1,551 for a solvent system, and $3,162 for a wet cleaning system. These costs were reported in 1997 dollars for a shop cleaning 53,333 pounds of clothes per year. The adjustment of these values for use in this assessment was as follows:

Cost Factor = USEPA Factor (1997) x Consumer Price Index Ratio for 1997 to 2004 x 100 lbs per 100 lbs / lbs of clothes cleaned per yr

Perc Factor = $1,913 x 1.183 x 100 / 53,333

= $4.24 per 100 lbs

Perc Cost = Perc Factor x lbs of clothes cleaned per yr / 100 lbs per 100 lbs

= $4.24 x 50,000 / 100

= $2,120

No data was provided for a liquid CO_2 system but it is taken to be equivalent to wet cleaning since available references indicate that the process supply costs for a CO_2 system are more than a perc system.

Some studies have reported higher water use for wet cleaning while other studies have found water use to be the same compared to perc. The reason for this equivalent use is likely due to the use of cooling water for the perc emission control equipment. Cooling water may also be required for the compressor associated with a CO_2 system. Water demand for each system has not been quantified and it is noted that many shops do not pay for water since this cost is covered in their rent (PPERC, September 2004).

6.1.7 System Maintenance

The USEPA assessment reported the annual cost of maintenance for a perc system to be in the range of 1.3 to 3.3 percent of total revenue. These values are assumed to be low since they do not account for SCAQMD Rule 1421 requirements such as periodic coil cleaning and gasket replacement. To account for these requirements, a value of 3.5 percent of annual revenue is assumed for new perc systems. The maintenance cost for a perc system is calculated as follows:

Maintenance = % of annual revenue x $ revenue per lb of clothes cleaned x lbs of clothes cleaned per yr / 100

Perc Cost = 3.5 x $3.00 x 50,000 / 100

= $5,250 per yr

The overall maintenance cost for the alternative systems is expected to be less than the cost of maintaining a perc system. For the two solvent systems, a near mid-range value of 2.5 percent is assumed. Demonstrations at shops adopting wet cleaning have shown a four to one reduction in maintenance costs. This would yield a cost range of 0.3 to 0.8 percent. Maintenance costs for a CO_2 system are claimed by the vendor to be low since these systems contain few moving parts. To be conservative, a low-end range value of 1.5 percent is taken for both wet cleaning and liquid CO_2.

6.1.8 Regulatory Compliance & Waste Disposal

The cost of regulatory compliance for a perc system per the USEPA assessment report was in the range of 2.3 to 4.5 percent of total annual revenue. Compliance costs include registration and permit fees for pollution control systems, the charges for hazardous waste disposal, reporting duties for compliance with USEPA and OSHA requirements, local water pollution control discharge fees, and other local, state, and federal fees.

Given the increase in local compliance requirements for the continued use of perc, the high-end value of 4.5 percent is taken for perc and a less than mid-range value of 3.0 percent is taken for DF-2000 and GreenEarth. This lower value reflects the lesser level of regulatory oversight required for compliance and the lower waste disposal fees. The compliance and waste disposal cost for a perc system is calculated as follows:

Compliance = % of annual revenue x $ revenue per lb of clothes cleaned x lbs of clothes cleaned per yr / 100

Perc Cost = 4.5 x $3.00 x 50,000 / 100

= $6,750 per yr

No specific data is available regarding regulatory compliance and waste disposal costs for the wet cleaning and liquid CO_2 systems. While both systems avoid the generation of hazardous waste and air emissions, they are not free of compliance requirements. Both generate solid waste and sanitary sewer discharges increase with wet cleaning. To be conservative, a compliance cost of 2.0 percent of annual revenue is assumed.

6.1.9 Operator Training

Few references provide reliable data on training costs. It is assumed that the operators of a new perc system will require one-half day of on-site training and the operators of solvent and liquid CO_2 systems will require one day of on-site training. This training is typically provided by the equipment supplier and is included in the equipment cost.

For the wet cleaning process, proper operator training is reported to be essential to the success of the process. It is assumed that the operator will attend a two-day training course offered off-site but in the local area. The cost for this course is taken to be $800, including the time for the operator. The need for annual training is assumed so as to be conservative. PPERC offers free on-site training and they can conduct this training over the weekend so as to avoid any downtime.

6.2 Modeling Results

Table 2 presents the estimated cleaning costs for the technologies of interest based on the cost data and assumptions discussed above. Costs are presented for two levels of production (50,000 and 85,000 pounds per year) as well as a case where the shop has Rule 1402 limits imposed on their use of perc. In this case, it is assumed that the shop will clean 20,000 pounds per year of clothing in a new perc system and 65,000 pounds per year in one of the other systems. Worksheets used to prepare these estimates are presented in Appendix A.

For production levels of 50,000 to 85,000 pounds per year, wet cleaning demonstrates the lowest cost at \$0.24 to \$0.28 per pound followed by DF-2000 (\$0.30 to \$0.36), liquid CO_2 (\$0.36 to \$0.43), GreenEarth (\$0.36 to \$0.44), and then perc (\$0.40 to \$0.45). The costs reported for wet cleaning, DF-2000, and liquid CO_2 assume that the shop will file for and receive a SCAQMD grant (the PPERC grant for wet cleaning demonstration sites is not included in these estimates). The SCAQMD grant provides savings of \$0.01 to \$0.04 per pound depending on workload and system.

Table 2 Summary of Cost Estimates

Dry Cleaning System	Annualized Cleaning Cost (\$/lb) for a Given Workload		
	50,000 lbs	85,000 lbs	20,000/65,000 lbs
Perc	\$0.45	\$0.40	---
GreenEarth	\$0.44	\$0.36	\$0.45
Liquid CO_2	\$0.43	\$0.36	\$0.45
DF-2000	\$0.36	\$0.30	\$0.40
Wet Cleaning	\$0.28	\$0.24	\$0.35

The last column of Table 2 indicates the annualized cost for a shop cleaning 85,000 pounds of clothing but limited to 20,000 pounds with perc. This production equates to a

SCAQMD Rule 1402 limit of 2 gallons of perc per month; a limit that may be imposed on shops located within close proximity to sensitive receptors. These shops will be required to purchase two new systems (one perc and one alternative) if they desire to use perc and not limit their business.

The lowest cost system combination is perc with wet cleaning at a combined cost of $0.35 per pound. This is followed by DF-2000 at $0.40 and a tie between GreenEarth and liquid CO_2 at $0.45. All of these costs are higher than the cost of operating a single dedicated system. Actual costs for a dual system operation may be substantially greater if the shop requires extensive modification due to space limitations.

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Appendix A

Estimated Cleaning Cost Worksheets

Table A-1 Estimated Cleaning Costs for 50,000 Pounds Per Year

	Perc	DF2000	Green Earth	Wet Cleaning	CO2
Pounds of clothes per year	50,000	50,000	50,000	50,000	50,000
Days per year of operation	312	312	312	312	312
Pounds of clothes per day	160	160	160	160	160
Revenue per pound of clothes	$3.00	$3.00	$3.00	$3.00	$3.00
Total annual revenue for the shop	$150,000	$150,000	$150,000	$150,000	$150,000
Size of cleaning machine, lbs	35	40	40	35	55
Typical max. load, lbs	32	36	36	28	50
Number of loads per day	6	5	5	6	4
Cycle time per load, min	45	50	50	45	35
Operating hours per day	4.5	4.2	4.2	4.5	2.3
Capital Cost, Cleaning System	$48,000	$55,000	$55,000	$19,000	$85,000
Capital Cost, Pressing System	$0	$0	$0	$26,000	$0
Installation Cost, Retrofit	$4,000	$4,000	$4,000	$2,000	$15,000
Total Installed Capital Cost	$52,000	$59,000	$59,000	$47,000	$100,000
Interest rate	7.00	7.00	7.00	7.00	7.00
Equipment life	12	12	12	15	15
Capital recovery factor	0.1259	0.1259	0.1259	0.1098	0.1098
Solvent cost, $/gal of solvent	$16.00	$4.00	$15.00	(a)	$2.50
Solvent mileage, lbs cleaned/gal	800	800	1,300	---	45
Energy use, kWh/100 lbs cleaned	23.8	23.8	34.7	12.0	29.0
Supplies & Detergent, $/100 lbs cleaned	$4.24	$3.44	$3.44	$7.01	$7.01
Maintenance, % of revenue	3.5	2.5	2.5	1.5	1.5
Reg. compliance, % of revenue (b)	4.5	3.0	3.0	2.0	2.0
Days of training	0.5	1.0	1.0	2.0	1.0
Annualized Capital Cost	$6,547	$7,428	$7,428	$5,160	$10,979
Annual License Fee	$0	$0	$2,500	$0	$0
Operating Labor	---	---	---	---	---
Solvent Cost	$1,000	$250	$577	(a)	$2,778
Energy Cost (d)	$952	$952	$1,388	$480	$1,160
Supplies & Detergent	$2,120	$1,720	$1,720	$3,505	$3,505
Maintenance Cost	$5,250	$3,750	$3,750	$2,250	$2,250
Reg. Compliance & Waste Disposal	$6,750	$4,500	$4,500	$3,000	$3,000
Operator Training (c)	$0	$0	$0	$800	$0
Total Annualized Cost	$22,619	$18,600	$21,863	$15,195	$23,672
Annualized Cost, $ per lb (no grant)	**$0.45**	**$0.37**	**$0.44**	**$0.30**	**$0.47**

SCAQMD Grant Funding	$0	$5,000	$0	$10,000	$20,000
Annualized Grant, $ per lb	$0.00	$0.01	$0.00	$0.02	$0.04
Annualized Cost, $ per lb (with grant)	**$0.45**	**$0.36**	**$0.44**	**$0.28**	**$0.43**

(a) Detergent costs are included under process supplies.
(b) Includes hazardous waste and solid waste disposal.
(c) Training included in equipment purchase price except for wet cleaning.
(d) Excludes natural gas, cost of electricity taken to be $0.08 per kWh.

Table A-2 Estimated Cleaning Costs for 85,000 Pounds Per Year

	Perc	DF2000	Green Earth	Wet Cleaning	CO2
Pounds of clothes per year	85,000	85,000	85,000	85,000	85,000
Days per year of operation	312	312	312	312	312
Pounds of clothes per day	272	272	272	272	272
Revenue per pound of clothes	$3.00	$3.00	$3.00	$3.00	$3.00
Total annual revenue for the shop	$255,000	$255,000	$255,000	$255,000	$255,000
Size of cleaning machine, lbs	35	40	40	35	55
Typical max. load, lbs	32	36	36	28	50
Number of loads per day	9	8	8	10	6
Cycle time per load, min	45	50	50	45	35
Operating hours per day	6.8	6.7	6.7	7.5	3.5
Capital Cost, Cleaning System	$48,000	$55,000	$55,000	$19,000	$85,000
Capital Cost, Pressing System	$0	$0	$0	$26,000	$0
Installation Cost, Retrofit	$4,000	$4,000	$4,000	$2,000	$15,000
Total Installed Capital Cost	$52,000	$59,000	$59,000	$47,000	$100,000
Interest rate	7.00	7.00	7.00	7.00	7.00
Equipment life	12	12	12	15	15
Capital recovery factor	0.1259	0.1259	0.1259	0.1098	0.1098
Solvent cost, $/gal of solvent	$16.00	$4.00	$15.00	(a)	$2.50
Solvent mileage, lbs cleaned/gal	800	800	1,300	---	45
Energy use, kWh/100 lbs cleaned	23.8	23.8	34.7	12.0	29.0
Supplies & Detergent, $/100 lbs cleaned	$4.24	$3.44	$3.44	$7.01	$7.01
Maintenance, % of revenue	3.5	2.5	2.5	1.5	1.5
Reg. compliance, % of revenue (b)	4.5	3.0	3.0	2.0	2.0
Days of training	0.5	1.0	1.0	2.0	1.0
Annualized Capital	$6,547	$7,428	$7,428	$5,160	$10,979
Annual License Fee	$0	$0	$2,500	$0	$0
Operating Labor	---	---	---	---	---
Solvent Cost	$1,700	$425	$981	(a)	$4,722
Energy Cost (d)	$1,618	$1,618	$2,360	$816	$1,972
Supplies & Detergent	$3,604	$2,924	$2,924	$5,959	$5,959
Maintenance Cost	$8,925	$6,375	$6,375	$3,825	$3,825
Reg. Compliance & Waste Disposal	$11,475	$7,650	$7,650	$5,100	$5,100
Operator Training (c)	$0	$0	$0	$800	$0
Total Annualized Cost	$33,869	$26,421	$30,218	$21,660	$32,557
Annualized Cost, $ per lb (no grant)	**$0.40**	**$0.31**	**$0.36**	**$0.25**	**$0.38**

SCAQMD Grant Funding	$0	$5,000	$0	$10,000	$20,000
Annualized Grant, $ per lb	$0.00	$0.01	$0.00	$0.01	$0.03
Annualized Cost, $ per lb (with grant)	**$0.40**	**$0.30**	**$0.36**	**$0.24**	**$0.36**

(a) Detergent costs are included under process supplies.
(b) Includes hazardous waste and solid waste disposal.
(c) Training included in equipment purchase price except for wet cleaning.
(d) Excludes natural gas, cost of electricity taken to be $0.08 per kWh.

Table A-3 Estimated Cleaning Costs for 85,000 Pounds Per Year with SCAQMD Rule 1402 Limits

	Perc	DF2000	Green Earth	Wet Cleaning	CO2
Pounds of clothes per year	20,000	65,000	65,000	65,000	65,000
Days per year of operation	312	312	312	312	312
Pounds of clothes per day	64	208	208	208	208
Revenue per pound of clothes	$3.00	$3.00	$3.00	$3.00	$3.00
Total annual revenue for the shop	$60,000	$195,000	$195,000	$195,000	$195,000
Size of cleaning machine, lbs	35	40	40	35	55
Typical max. load, lbs	32	36	36	28	50
Number of loads per day	3	6	6	8	5
Cycle time per load, min	45	50	50	45	35
Operating hours per day	2.3	5.0	5.0	6.0	2.9
Capital Cost, Cleaning System	$48,000	$55,000	$55,000	$19,000	$85,000
Capital Cost, Pressing System	$0	$0	$0	$26,000	$0
Installation Cost, Retrofit	$4,000	$4,000	$4,000	$2,000	$15,000
Total Installed Capital Cost	$52,000	$59,000	$59,000	$47,000	$100,000
Interest rate	7.00	7.00	7.00	7.00	7.00
Equipment life	12	12	12	15	15
Capital recovery factor	0.1259	0.1259	0.1259	0.1098	0.1098
Solvent cost, $/gal of solvent	$16.00	$4.00	$15.00	(a)	$2.50
Solvent mileage, lbs cleaned/gal	800	800	1,300	---	45
Energy use, kWh/100 lbs cleaned	23.8	23.8	34.7	12.0	29.0
Supplies & Detergent, $/100 lbs cleaned	$4.24	$3.44	$3.44	$7.01	$7.01
Maintenance, % of revenue	3.5	2.5	2.5	1.5	1.5
Reg. compliance, % of revenue (b)	4.5	3.0	3.0	2.0	2.0
Days of training	0.5	1.0	1.0	2.0	1.0
Annualized Capital	$6,547	$7,428	$7,428	$5,160	$10,979
Annual License Fee	$0	$0	$2,500	$0	$0
Operating Labor	---	---	---	---	---
Solvent Cost	$400	$325	$750	(a)	$3,611
Energy Cost (d)	$381	$1,238	$1,804	$624	$1,508
Supplies & Detergent	$848	$2,236	$2,236	$4,557	$4,557
Maintenance Cost	$2,100	$4,875	$4,875	$2,925	$2,925
Reg. Compliance & Waste Disposal	$2,700	$5,850	$5,850	$3,900	$3,900
Operator Training (c)	$0	$0	$0	$800	$0
Total Annualized Cost	$12,976	$21,952	$25,444	$17,966	$27,480
Annualized Cost, $ per lb (no grant)	**$0.65**	**$0.34**	**$0.39**	**$0.28**	**$0.42**

SCAQMD Grant Funding	$0	$5,000	$0	$10,000	$20,000
Annualized Grant, $ per lb	$0.00	$0.01	$0.00	$0.02	$0.03
Annualized Cost, $ per lb (with grant)	$0.65	$0.33	$0.39	$0.26	$0.39
Annualized Cost, $ per lb (2 systems)	**---**	**$0.40**	**$0.45**	**$0.35**	**$0.45**

(a) Detergent costs are included under process supplies.
(b) Includes hazardous waste and solid waste disposal.
(c) Training included in equipment purchase price except for wet cleaning.
(d) Excludes natural gas, cost of electricity taken to be $0.08 per kWh.