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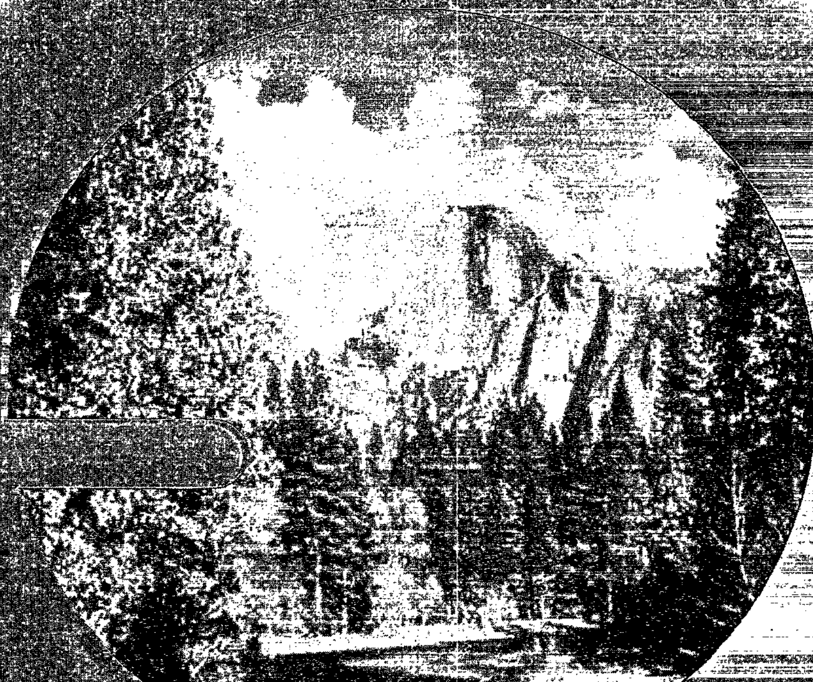
June 1998

Design for the Environment
U.S. EPA

Cleaner Technologies Substitutes Assessment for Professional Fabricare Processes: SUMMARY



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Design for the Environment Program
U.S. Environmental Protection Agency
Office of Pollution Prevention and Toxics
Economics, Exposure and Technology Division (7406)
401 M Street SW
Washington, DC 20460

Disclaimer

The information in this document is based entirely upon the full technical report titled *Cleaner Technologies Substitutes Assessment for Professional Fabricare Processes (EPA 744-B-98-001, June 1998).* That document has been subject to U.S. Environmental Protection Agency (EPA) internal review and external technical peer review and has been approved for publication. Mention of trade names, products, or services does not convey, and should not be interpreted as conveying, official EPA approval, endorsement, or recommendation.

Information on sales, costs, performance, and product usage was provided by individual product vendors, or by EPA Garment and Textile Care Program stakeholders, and was not independently corroborated by EPA.

Discussion of selected federal environmental statutes is intended for information purposes only; this is not an official regulatory guidance document and should not be relied upon by companies to determine applicable regulations.

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Lynne received excellent support from the EPA/OPPT Technical Workgroup:

Lynne Blake-Hedges, Workgroup Chair
Andrea Blaschka
Lois Dicker, Ph.D.
Elizabeth Margosches, Ph.D.
Fred Metz, Ph.D.
Ossi Meyn, Ph.D.
Mary Katherine Powers
Scott Prothero

Management support and other general assistance was provided by:

David Lai, Ph.D.
Robert E. Lee, Ph.D.
Cindy Stroup
Mary Ellen Weber, Ph.D.
Vanessa Vu, Ph.D.

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To obtain a copy of this or other EPA/Design for the Environment Program publications, contact:

EPA's Pollution Prevention Information Cleaninghouse (PPIC)
401 M. Street, SW (3404)
Washington, DC 20460
202-260-1023
fax: 202-260-4659

Any questions or comments regarding this document should be addressed to:

Lynne Blake-Hedges
Economics, Exposure and Technology Division (7406)
U.S. EPA/OPPT
401 M. Street, SW
Washington, DC 20460

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Introduction

Background

Chemical solvents have been used for cleaning clothes since the mid-19th century, and perchloroethylene (perc) has been the solvent of choice for drycleaners since the 1960s. Although the volume of perc used by drycleaners has declined significantly over the past decade, a variety of health and safety issues and increased regulation of the chemical have compelled the U.S. Environmental Protection Agency (EPA), industry, and environmental groups to address concerns about perc emissions. As part of an effort to explore opportunities for pollution prevention and reduce exposures to traditional drycleaning chemicals, the EPA's Design for the Environment Garment and Textile Care Program developed the *Cleaner Technologies Substitutes Assessment for Professional Fabricare Processes* (CTSA) which was published in June 1998. The current report is a summary version of that document.

The CTSA is a compilation of information on the relative risks, costs, and performance of clothes cleaning operations. It is based upon readily available information and uses simplifying assumptions and conventional models to provide general conclusions about various cleaning technologies. It is not a rigorous risk assessment of chemicals used in the fabricare industry and should not be used to describe the absolute level of risk associated with a particular clothes cleaning operation to specific populations or individuals. Assumptions used to develop the information are presented in the CTSA to assist users in determining the applicability of the information to various clothes cleaning operations. Because of these assumptions and the limitations of available data, it is reasonable to expect that actual risks, costs, and performance may vary for specific clothes cleaning operations.

The fabricare industry is characterized by small companies that rarely have the time or resources needed to do the type of complex technical analysis in the CTSA. EPA's goal in undertaking this assessment was to provide cleaners with information that can be used to inform business decisions and to encourage their consideration of environmental issues along with cost and performance factors. In addition to professional cleaners, the audience for the fabricare CTSA includes technically informed individuals such as environmental health and safety personnel, owners, equipment manufacturers, and other decision makers.

The Design for the Environment Garment and Textile Care Program

"Design for the Environment" means building in pollution prevention aspects when industry is developing or making changes to a product or process. The EPA Design for the Environment (DfE) Program harnesses EPA's expertise and leadership to facilitate information exchange and research on risk reduction and pollution prevention efforts. DfE works with businesses on a voluntary basis, and its wide-ranging projects include:

- Encouraging businesses to incorporate environmental concerns into decision-making processes in their general business practices.

- Working with specific industries to evaluate the risks, performance, and costs of alternative chemicals, processes, and technologies.

- Helping individual businesses undertake environmental design efforts through the application of specific tools and methods.

Drycleaning was selected as the first DfE project in response to concerns raised at a May 1992 International Roundtable on Pollution Prevention and Control in the Drycleaning Industry. Researchers, industry representatives, and government officials met to exchange information on exposure reduction, regulation, and information dissemination. Numerous other topics were also discussed, such as potential health and environmental considerations related to exposures to drycleaning solvents. Key stakeholders were committed to exploring ways to prevent pollution, choose safer substitutes, and reduce exposures to traditional drycleaning chemicals and included the Neighborhood Cleaners Association-International (NCAI), International Fabricare Institute (IFI), Federation of Korean Drycleaners Associations (FKDA), Greenpeace, New York State Departments of Health and Environmental Conservation, Fabricare Legislative and Regulatory Education Organization, EcoClean, The Dow Chemical Company, Center for Emissions Control (now the Halogenated Solvents Industries Alliance), American Clothing and Textiles Workers Union (now the Union of Needletrades, Industrial, and Textile Employees), Center for Neighborhood Technologies (CNT), and the Toxic Use Reduction Institute at the University of Massachusetts.

The DfE Garment and Textile Care Program's (GTCP) mission is to assist in providing professional garment and textile cleaners with a wider range of environmentally friendly technology options that they can offer to their customers, while maintaining or increasing economic viability. Much progress has been made as evidenced by both dramatic reductions in perc use by the drycleaning industry as well as the growing commercialization of several new cleaning technologies. The CTSA is intended to further that progress by providing extensive detailed technical information to inform business decisions.

In recent years, the GTCP focus has expanded with the recognition that drycleaning is at the terminal end of an elaborate chain of industries in the garment and textile industry sectors, and that decisions made by these "upstream" industries can directly affect the cleanability of garments in new cleaner processes. As a result, the GTCP has adopted a "systems" or industrial ecology approach to pollution prevention and is soliciting participation from a wider group of stakeholders than was involved in the development of the fabricare CTSA. The objective is to promote not only cleaner production in the design and manufacture of garments and textiles, but also to promote production of garments and textiles that will facilitate the use of clean technologies by the professional fabricare provider.

Road Map to Document

Recognizing that not all professional cleaners have the time to read the full fabricare CTSA, EPA prepared this summary document which was abstracted directly from the June 1998 publication. Information that has become available since June 1998 is not included in this summary and will be made available through fact sheets and case studies.

In this summary report, the reader is first introduced to the clothes cleaning industry and provided an overview of professional fabricare technologies. New and emerging technologies are also covered including liquid carbon dioxide (CO_2), ultrasonics, and solvents based on chemicals such as glycol ethers, although there is much less information available on these systems. Summary information is presented on release, exposure, health and environmental relative risk, selected federal regulations, costs, performance, process trade-offs, environmental improvement approaches, and industry trends. A complete list of references is included.

The Professional Clothes Cleaning Industry

The professional clothes cleaning industry, includes approximately 36,000 facilities that generate a total revenue of $7.2 billion annually (Seitz, 1997; Faig, 1998; Wong, 1998). Clothes cleaning volume for these facilities is estimated to be 871 million kilograms (1.9 billion pounds) of clothes per year (Faig, 1998; Wolf, 1998). More than 90 percent of the 36,000 commercial facilities in the U.S. are small neighborhood stores that consist of a small storefront operation with customer pickup and delivery in the front, and cleaning and finishing in the back.

Although there are numerous fabricare cleaning processes under development, drycleaning and wetcleaning are the primary clothes cleaning processes that are commercially available at this time. Drycleaning uses organic solvents to clean soils from clothing. Commonly-used solvents are perchloroethylene (perc) and hydrocarbon solvents. Perc drycleaning solvents are used by approximately 30,600 (85%) fabricare facilities in the U.S., while hydrocarbon solvents are used by approximately 5,400 (15%) facilities. Hydrocarbon solvents are a by-product of the distillation of petroleum and are often sold as either Stoddard solvent or 140° F solvent, in reference to the flashpoint. In 1994, Exxon introduced a synthetic hydrocarbon solvent, called DF-2000, with a flashpoint above 140° F. Since then, several other firms have either introduced or are testing synthetic petroleum solvents for the drycleaning market (DeSanto, 1998). Figure 1 provides details of solvent usage in the commercial sector of the drycleaning industry.

Professional wetcleaning is a relatively new process that uses water as the primary solvent to clean fabrics. It has been in commercial use since 1994 and is more often used in combination with other cleaning methods, although there are a small number of 100 percent wetcleaning shops. Equipment sales data and anecdotal information indicate that the use of wetcleaning is steadily increasing.

Although perc holds the largest market share of the clothes cleaning industry, between 1981 and 1996, there was a 72 percent decrease in perc use by the fabricare industry (Risotto, 1997). There were a number of reasons for this decline including regulatory pressure, the growth in the production of wash-and-wear fabrics by the garment industry (Levine, 1997), and concerns regarding the human health and environmental hazards associated with perc. Until recent years, the drycleaning industry had focused on designing new perc-using equipment with more effective solvent recovery and recycling systems, as well as developing safer solvents. There is growing interest in alternatives to perc in order to reduce exposures from perc use.

Figure 1: Solvent Usage in the Commercial Sector of the Drycleaning Industry

Fabricare Solvent Type	Perchloroethylene	Hydrocarbon Solvents	Wetcleaning
Number of Facilities	30,600[a]	5,400[a]	38[b]
Drycleaning Volume (kg/yr)	741,818,181[c]	130,909,091[c]	NA
Solvent Consumption (MM kg/yr)	45[d]	8.3 to 34[e]	NA

NA = Not available.

[a] Estimate based on 85% perc and 15% hydrocarbon use; data provided by the California Air Resources Board (Wong, 1998).
[b] There are 38 facilities using wetcleaning methods exclusively (Star, 1998). By the end of 1997, 3,000 wetcleaning machines had been sold in the U.S.; however, it is not known how many facilities combine wetcleaning with other methods (EPA, 1998).
[c] Estimated from revenue (Falg, 1998; Seitz, 1997), and based on 85% perc and 15% hydrocarbon use.
[d] Estimate based on Textile Care Allied Trade Association survey, adjusted for brokered import volume (Risotto, 1997).
[e] Estimated from the range of mileages presented with the hydrocarbon solvent options presented on pages 15-17.

Overview of Professional Fabricare Technologies

Perchloroethylene Processes and Equipment

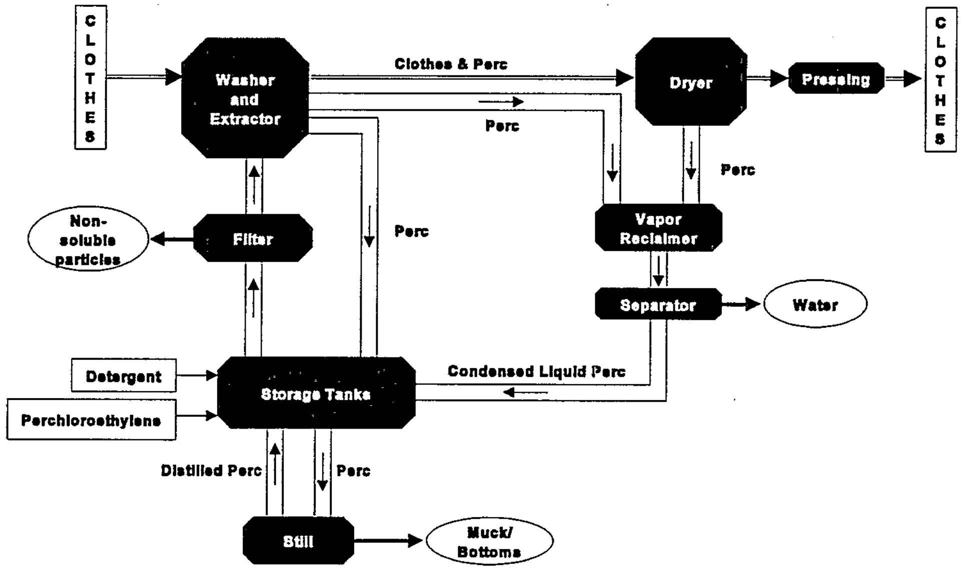
Perc use in drycleaning became prevalent in the 1960s, and several of perc's desirable characteristics have helped it become the most common drycleaning solvent in the United States. As the use of perc in drycleaning has proliferated, a combination of financial factors, regulations, and environmental concerns has given drycleaners incentives to reduce perc releases. As a result, perc drycleaning equipment has evolved considerably. This summary report describes the equipment through use of the most common terminology.

Equipment and Process Terminology

Machines used to clean garments and other articles may be classified into two types: *transfer* and *dry-to-dry*. Figures 2a and 2b illustrate how perc transfer and dry-to-dry configurations work. Like home clothes washing equipment, transfer machines have a unit for washing/extracting and another unit for drying. Following perc extraction, articles that had been immersed in perc are transferred by a worker from the washer/extractor to the dryer, sometimes called a reclaimer. Dry-to-dry machines wash, extract, and dry the articles in the same cylinder in a single machine, so the articles enter and exit the machine dry. Transfer machines are sometimes called "first generation" machines. Dry-to-dry machines may be called "second," "third," "fourth," or "fifth generation," and each machine's designation depends upon its internal perc vapor recovery machinery.

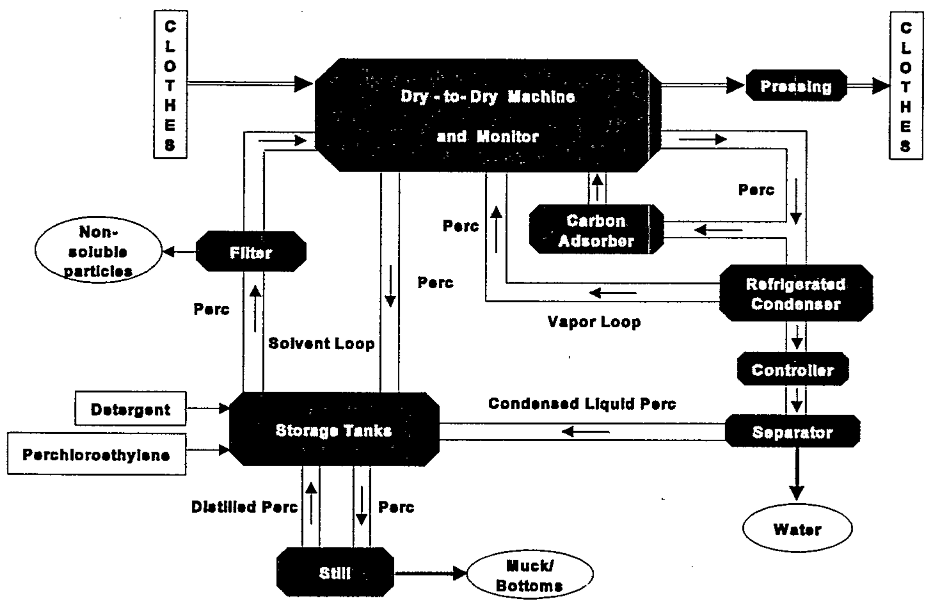
The following are terms that describe the primary equipment used to clean garments for the technologies covered in this document. The reader should note that some of the terms listed below also apply to hydrocarbon and emerging technologies configurations as well as perc configurations.

Figure 2a
Simplified Process Flow Diagram for Perc Transfer Machinery ("First Generation")



Source: Adapted from USEPA, 1991b, for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics.
With consultation from Hill, 1998.

Figure 2b: Simplified Process Flow Diagram for Perc Dry-to-Dry Closed Loop Machinery with Integral CarbonAdsorber("Fifth Generation")



Source: Adapted from NIOSH, 1997.
With consultation from Hill, 1998.

These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations that are not represented on these diagrams.

- *Primary controls* are devices that can either recover perc from vented aeration air or eliminate the aeration step from first and second generation machines (CEPA, 1993).

- *Carbon adsorbers* are the most commonly used primary controls along with refrigerated condensers. Once the carbon adsorber reaches its capacity for adsorbing perc from the aeration stream on a daily basis, the perc is usually removed (desorbed) from the carbon adsorber by passing steam through the carbon adsorber. Steam containing perc exits from the carbon adsorber and is routed to a condenser, which liquefies the perc and water vapors. The liquid perc and water mixture from the condenser is routed to the water separator. The carbon adsorber must dry thoroughly before it is ready for reuse (CEPA, 1993).

- *Spin disk filters* consist of fine-mesh disks in a tube. During filtration, perc contaminated with insolubles passes into the tube, depositing the insolubles on the outside of the disk. When the pressure across the disk increases to a certain level, filtration ends and the filter is spun. The insolubles (and powder, if used) spin off the disks and into the perc, which is then sent to distillation. Powderless disk filters may require a finishing or polishing filter to remove extremely small insolubles such as dyes that pass through these filters (CEPA, 1993).

- *Tubular filters* are cylindrical screens on the outside of which diatomaceous earth and carbon are coated. During filtration, perc contaminated with insolubles passes through the screen, depositing the insolubles on the outside of the screen (CEPA, 1993).

- *Bump-style* filters are modified tubular filters that are "regenerated" after each load of clothes (CEPA, 1993).

- *Cartridge filters*, unlike other filter types that are reusable, are used and discarded. Perc containing insoluble impurities passes through the cartridge filter's perforated outer shell, through paper, carbon, and a fine mesh that collectively remove the insolubles from the perc, which then exits the filter. Usually, the spent filters are then removed from the facility as hazardous waste (CEPA, 1993).

- *Still bottoms* are the concentrated waste material (usually 20% to 80% perc) resulting from distillation. Most drycleaners use distillation to keep the solvent clean enough to avoid odors and the darkening of articles. Without distillation, oils, soils, dyes, detergents, and other perc-soluble impurities would build up in the solvent (CEPA, 1993).

- *Muck cookers* are a special type of still that is used with machines that use powder filters (usually spin, tubular, and bump-style filters). Muck cookers have several features that stills do not: a special intake opening and valve from the air filter; an agitator with a universal joint; a sight glass; and a large bottom clean out door. Muck cookers use a distillation step, then a "cook down" step, and a final air or steam sweeping step, which results in a "dry" powder muck. The "dry" muck, which contains used filter powder and other soluble and insoluble impurities from the perc, is then removed from the cooker (IFI, 1994).

- *Water separators* are devices that receive perc and water mixtures from many sources and separates them. The mixtures enter the separator and are separated into perc and water layers, with the heavier perc settling to the bottom. The water phase is usually drained from the top of the separator into a container for later evaporation or disposal as a hazardous waste. The perc is usually drained from the bottom of the separator to either the perc storage tank or the machine cylinder (CEPA, 1993).

Machine Types

Perc machines can have various configurations. Some of these configurations are described below:

- *Perc-A1: Transfer with No Carbon Adsorption or Refrigerated Condenser:* Washing and extraction in one machine, drying in a second machine (i.e., first generation equipment). At the end of the drying cycle, aeration air leaving the drying tumbler vents to atmosphere.

- *Perc-A2: Transfer with Carbon Adsorber Vent Control:* Washing and extraction in one machine, drying in a second machine (i.e., first generation equipment). At the end of the drying cycle, aeration air leaving the drying tumbler vents to a carbon bed, which may remove much of the perc before emitting the air stream.

- *Perc-A3: Transfer with Refrigerated Condenser Control:* Washing and extraction in one machine, drying in a second machine (i.e., first generation equipment). By the end of the drying cycle, the refrigerated condenser will have removed more of the perc from the drying air stream, resulting in lower emissions than would occur from a machine with a non-refrigerated condenser.

- *Perc-B1: Dry-to-Dry with No Carbon Adsorption or Refrigerated Condenser:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment). At the end of the drying cycle, aeration air vents to atmosphere after leaving the tumbler.

- *Perc-B2: Dry-to-Dry with Carbon Adsorber Vent Control:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment). At the end of the drying cycle, aeration air leaving the tumbler vents to a carbon bed which may remove much of the perc before emitting the air stream.

- *Perc-B3: Dry-to-Dry Converted to Closed-Loop:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment converted to third generation). Two common conversions are an internal conversion or an add-on. Internal conversion includes converting the internal condenser from an air- or water-cooled condenser to a refrigerated condenser and ducting the exhaust back to the machine as input air. The add-on includes ducting the vent to an add-on refrigerated condenser, which supplements the original condenser, and ducting the exhaust from the condenser back to the machine as input air.

- *Perc-C: Dry-to-Dry Closed-Loop with No Carbon Adsorber or with Door Fan and Small Carbon Adsorber:* Washing, extraction, and drying operations all in one cylinder/one machine. Built-in internal refrigerated condenser which exhausts drying air back to the machine as input air in a "closed-loop" cycle (i.e., third generation equipment). Some of these machines have a fan intended to reduce exposures; when the machine door is opened after the drying cycle, the fan draws air through an exhaust and sometimes to a small carbon adsorber. These small adsorbers, sometimes known as "OSHA fans," are not believed to have much effect on emissions.

- *Perc-D: Dry-to-Dry Closed-Loop with Unvented Integral Secondary Carbon Control:* Washing, extraction, and drying operations all in one cylinder/one machine. Built-in internal refrigerated condenser that exhausts back to the machine as input air. After the drying cycle ends and while the door is closed, air from the drum circulates to a large carbon adsorber (40- to 60-pound carbon capacity for a 50-pound clothing capacity machine), which may remove most of the perc before the door is opened (i.e., fourth generation equipment). Some machines may have an integral perc sensor, which will not allow the door to be opened until the perc level has fallen to a maximum allowable level (i.e., fifth generation machine).

Perc Equipment for Spill Containment

Spill containment is a control that reduces perc losses and ground contamination due to spills. Two options for spill containment are safety troughs and floor coatings. Safety troughs are shallow rectangular tanks in which all drycleaning equipment and auxiliaries that contain solvent reside. These tanks are designed to allow for containment of the entire volume of the largest storage tank. The tank generally contains a drain that can be connected to a pump for removal of spilled solvent, or, for smaller spills, rags may be used to absorb the spill and later cleaned in the drycleaning equipment. Floor coatings in conjunction with a diked area or containment lip can function similarly to a trough, although the effectiveness of these coatings has yet to be determined (CEPA, 1993).

Perc Equipment for Fugitive Emissions Control

A variety of fugitive emissions recovery, ventilation, and containment systems have been employed to reduce emissions and/or exposure to perc vapor in the facility. The "OSHA fans" described earlier under *Machine Types* (pg. 7) are one of these systems. Other local and general exhaust systems may be used to remove and sometimes recover perc vapor from air in the facility. Floor vents can be effective at removing and recovering perc, especially in the event of spills. In some of these systems, air containing perc can be directed to carbon adsorbers to recover some of the perc vapor.

Perc emissions and migration within and from drycleaning facilities can also be reduced through the use of enclosures sometimes called vapor barriers. Vapor barriers can contain some or all drycleaning equipment that uses perc and can be used to achieve minimum ventilation rates or other requirements. The walls and ceiling are made of materials that are impermeable to perc. The enclosures have negative air pressure relative to the facility to prevent perc migration. The air collected from the vapor barrier may be exhausted outside the facility or to a control device such as a carbon adsorber to recover some of the perc vapor (CEPA, 1993). Similarly, particular coatings and wallpapers used as perc diffusion barriers in Germany appear to have achieved some effectiveness, although significant numbers of defective applications have been found (Hohenstein, 1994).

In facilities with transfer machines, the transfer of clothing from the washer/extractor to the dryer may result in a significant fugitive emission that does not occur in facilities with only dry-to-dry machines. Under the National Emissions Standards for Hazardous Air Pollutants (NESHAP), a dry-to-dry machine used in conjunction with a dryer/reclaimer is considered to be a transfer machine. Articles are damp with perc when they are physically transferred from the washing machine to the dryer, and some evaporation occurs during this transfer. The NESHAP identified three control technology options for reducing transfer losses: hamper enclosures, room enclosures (a particular variation of the vapor barriers described above), and replacement with dry-to-dry machines.

The most effective alternative for reducing fugitive emissions associated with clothing transfer is to replace the transfer machine with a dry-to-dry unit. By definition, this eliminates transfer losses, since the transfer process is eliminated. The new dry-to-dry machine would likely include process controls providing additional reductions in total perc emissions relative to the older transfer machine. Another alternative to reduce transfer emissions is to enclose the space surrounding washing and drying machines with a vapor barrier (described above) and to vent air from the enclosure to a control device, usually a carbon adsorber. This alternative is sometimes called a "room enclosure." The least effective of these alternatives is a hamper enclosure, which consists of a hood or canopy that encloses the transfer basket and doors of the washer and dryer during loading and unloading and covers the hamper during movement from the washer to the dryer. The operator reaches into slits in the hamper enclosure to load and unload the perc-damp articles. A fan can draw room air into the enclosure, and air and perc vapor are routed to a control device, usually a carbon adsorber, attached to the hamper enclosure.

Hydrocarbon (petroleum-based) Processes and Equipment

Prior to perc, hydrocarbons dominated the drycleaning industry in the United States. The most commonly used hydrocarbons are two petroleum solvents: Stoddard solvent and 140°F solvent (IFI, 1994). However, synthetic hydrocarbon and other alternatives to petroleum solvents are being marketed. Regarding the process equipment, hydrocarbon equipment has not undergone the evolution which perc machinery has, so fewer variations and options exist in hydrocarbon equipment. Also, hydrocarbon processes and equipment seem to have received little attention, as indicated by scant coverage in the literature. Therefore, information presented in this document is based on aging literature sources and some more recent personal contacts.

Like perc machines, machines used to clean garments and other articles may be classified into two types: *transfer* and *dry-to-dry*. Like home clothes washing equipment, transfer machines have a unit for washing/extracting and another unit for drying. Following hydrocarbon extraction, articles that had been immersed in hydrocarbon are transferred by a worker from the washer/extractor to the dryer, sometimes called a reclaimer. Dry-to-dry machines wash, extract, and dry the articles in the same cylinder in a single machine, so the articles enter and exit the machine dry.

Three hydrocarbon machine configurations utilizing emission control technologies follow some of the same perc configurations. They are described below:

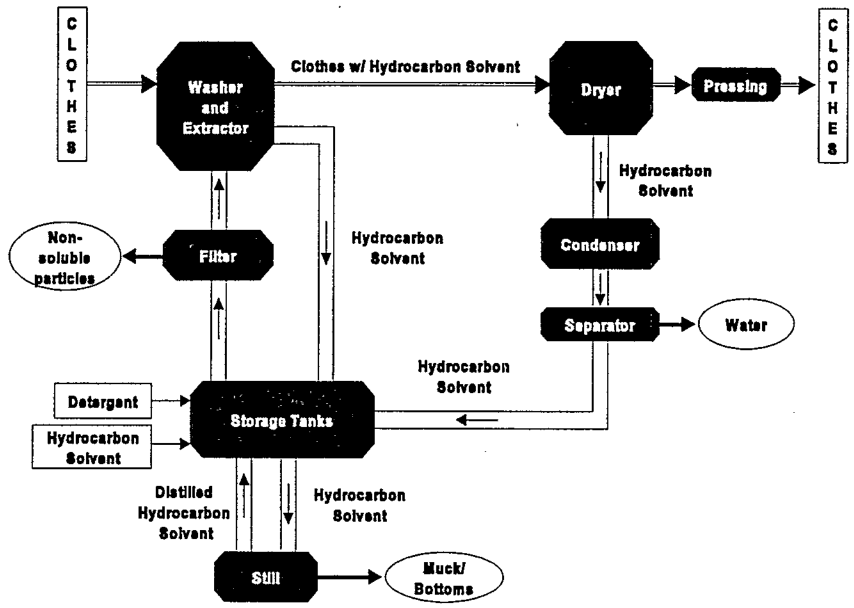
- *H.C.-A1: Transfer with Standard Dryer (with No Condenser):* Washing and extraction in one machine, drying in a second machine. Throughout the entire drying cycle, fresh air is drawn into the tumbler, removes hydrocarbon from the wet clothes, and exits the drying tumbler directly to the atmosphere. (All hydrocarbon that is not extracted from the clothes is emitted to air.)

- *H.C.-A2: Transfer with Recovery Dryer (with Condenser):* Washing and extraction in one machine, drying in a second machine. During the drying cycle, drying air leaving the tumbler passes through a condenser. The condenser cools the air and recovers some of the hydrocarbon from the drying air stream, which is reheated and returned to the tumbler. At the end of the drying cycle, aeration air vents to atmosphere after leaving the tumbler.

- *H.C.-B: Dry-to-Dry Closed-Loop with Condenser:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment). During the drying cycle, drying air leaving the tumbler passes through a condenser, which cools the air and recovers some of the hydrocarbon from the drying air stream, which is reheated and returned to the tumbler. At the end of the drying cycle, aeration air vents to atmosphere after leaving the tumbler.

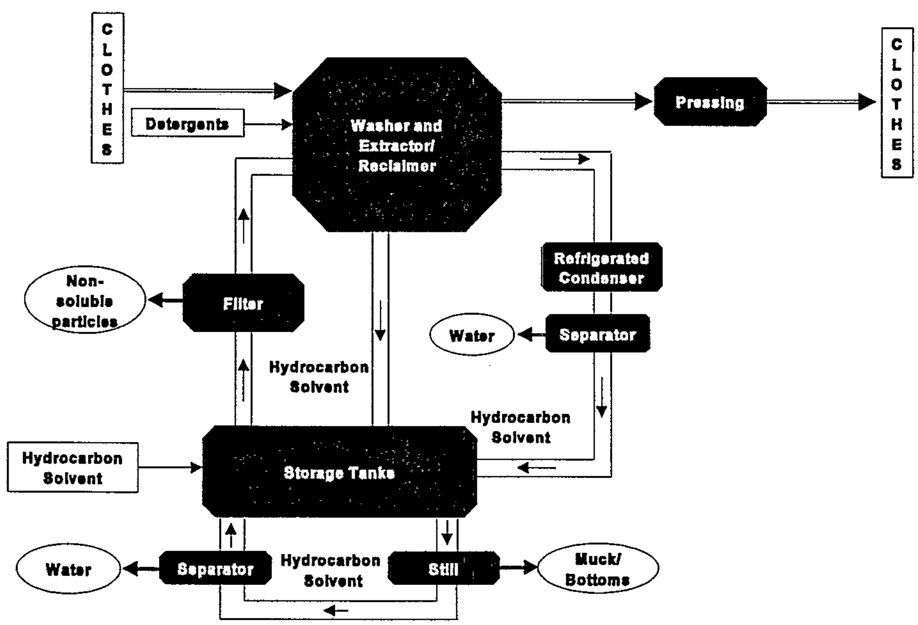
Figures 3a and 3b illustrate how two hydrocarbon configurations work.

Figure 3a: Simplified Process Flow Diagram for Hydrocarbon Transfer Solvent Machinery



Source: Adapted from USEPA, 1991b, for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics.
With consultation from Hill, 1998.

Figure 3b: Simplified Process Flow Diagram for Hydrocarbon Dry-to-Dry Solvent Machinery



Sources: Adapted from OTEC, Swiss Clean Hydrocarbon Drycleaning Instruction Handbook.

These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations that are not represented on these diagrams.

Hydrocarbon Flammability Hazards

A major hazard identified with the hydrocarbon solvents is their potential flammability. The National Fire Protection Association (NFPA) ranks chemicals on a scale of 0 to 4 for flammability. NFPA gives hydrocarbon solvents a grading of "2," indicating that they must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. For comparison, perc receives a grade of "0" for flammability, which indicates that it will not burn.

Of the hydrocarbon chemicals examined, DF-2000 has the highest flashpoint, followed by 140°F solvent and Stoddard solvent. Two dry-to-dry equipment variations have been developed to reduce the likelihood of explosion by reducing the oxygen concentration in the machine. These variations are nitrogen injection and oxygen vacuum systems. No information has been found in the published literature for these systems. The following descriptions are based upon limited personal contacts and assumptions. The nitrogen injection and oxygen vacuum is expected to be used only during the drying cycle when air containing hydrocarbon vapor is heated.

Drycleaning equipment with nitrogen injection injects nitrogen into the cleaning chamber in combination with hydrocarbon. The addition of nitrogen lowers the concentration of oxygen, reducing the chance of explosion (Abt, 1994). Drycleaning equipment with oxygen vacuum lowers the pressure in the cleaning chamber. The partial vacuum resulting from the reduced pressure reduces the concentration of oxygen, which greatly lowers the flashpoint of the solvent and reduces the chance of explosion (Abt, 1994).

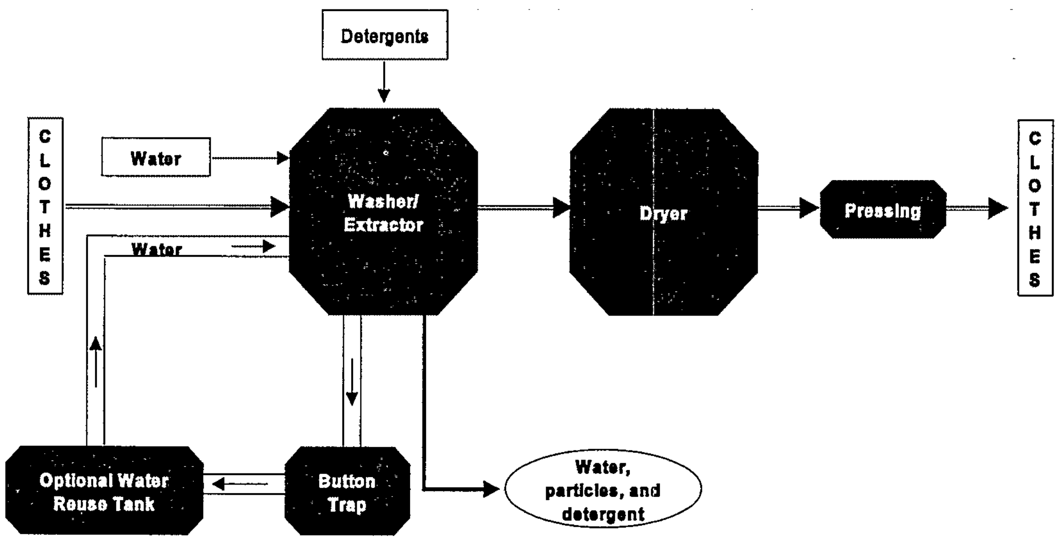
Professional Wetcleaning Processes and Equipment

During the 1990s, several aqueous-based processes were explored as substitutes for drycleaning of some garments. One of these processes, previously called "multiprocess wetcleaning," relied heavily on hand labor to remove soil from garments. This process used a variety of different techniques depending on the individual characteristics of the garment. These techniques included steaming, immersion and gentle hand washing in soapy water, hand scrubbing, tumble drying, and air drying. This process also used spotting and pressing as in any of the fabricare technologies. The spotter-cleaner determined which technique was most appropriate for each garment, given the fabric, construction, and degree of soiling. A number of different techniques may have been used on any one garment (Abt, 1994). Multiprocess wetcleaning has not gained acceptance as a commercially viable cleaning method. However, some of its techniques have been used to supplement the second, more widely-accepted aqueous process, which is called wetcleaning (Environment Canada, 1995).

The currently-employed wetcleaning process differs from multiprocess wetcleaning by using machinery instead of hand labor in the washing process. The basic difference in the machinery from traditional laundering units is that the agitation applied to the clothes is reduced (Abt, 1994). The following example of wetcleaning process equipment is particular to a Miele/Kreussler system, one of the earliest systems developed for this process. Although the equipment specifics mentioned in this section are particular to this example system, the process equipment functions for this system are expected to be generally applicable to other wetcleaning systems.

The example system consists of a washer/extractor and a separate dryer, which both control mechanical action and temperature (Patton et al., 1996). The principle of the system is that "spinning" clothes during both water-based washing and drying can thoroughly clean and dry the clothes without incurring the damage to delicate fabrics caused by agitation and tumbling. The washer/extractor developed for the example system has holes in its drum to provide optimum protection for the garment being washed and to facilitate chemical flow and active cleaning. The temperature and the water level are each monitored and controlled. The washing/extracting process is fully automated, and a liquid detergent is dispensed by two pumps at a predetermined time. After the garment washing step, the wash water containing soils, oils, and detergents is extracted and discharged to the sewer. After the garment rinsing step, rinse water may be discharged to the sewer or may be recovered and reused using storage and filtrating systems (Patton et al., 1996). The dryer in the example system monitors the moisture of items in the drum, and air passes horizontally through the drum. A fraction of drying air is recycled, and automatic drum reversal is intended to dry the load evenly and help prevent creasing. Figure 4 below illustrates the process for wetcleaning.

Figure 4: Simplified Process Flow Diagram for Machine Wetcleaning



Sources: Adapted from EPA, 1997, for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics. Training Curriculum for Alternative Clothes Cleaning.
With consultation from Star, 1998.

Emerging Technologies

There are several new technologies under development. Some involve substituting solvents coupled with modifications to existing machinery, while others involve the use of newer machinery. This document briefly describes liquid carbon dioxide (CO_2), aqueous ultrasonic fabricare technologies, and new solvents in development. There may be others, but these are the only ones for which EPA had information in June of 1998, at the time the CTSA was published. These technologies are in various stages of commercial development, therefore, information is limited and may be speculative.

Carbon dioxide (CO_2) processes that use CO_2 in a liquid state have been developed for fabric cleaning. Since the publication of the CTSA, at least one liquid CO_2 process has become commercially available. [EPA has developed a case study summarizing available information on this new technology.] Ongoing studies should eventually present a clear determination of the actual capabilities of drycleaning with liquid CO_2 (Williams et al., undated).

Extensive information on CO2 processes is not yet available. However, initial information indicates that the closed-loop machine configuration significantly reduces CO_2 emissions by recovering and recycling the solvent in which the garments are washed (Chao, 1994; Micell, 1997). In addition, research has shown that liquid CO_2 processing had no deleterious effects on test fabrics, had acceptable shrinkage, and removed more soil than standard perc drycleaning. Because the liquid CO_2 technologies under development are proprietary, complete process operating parameters are not available.

Aqueous-based ultrasonic washing processes have been used in industrial cleaning applications for many years. They are now being researched for garment cleaning. Ultrasonic cleaning uses a high-intensity sound wave in a fluid medium to create mechanical forces that dissolve and displace contaminants on clothing. Detailed descriptions of ultrasonic process equipment are not available.

Surfactants, detergents, and/or ozone theoretically may be used in an ultrasonic aqueous solution to clean stationary garments. Free-floating items tend to reduce ultrasonic energy in solutions, and this reduction would not allow for the sound wave energy needed to create mechanical agitation. A combination of blended detergents and ultrasonics may allow polar and non-polar contaminants to be removed at temperatures between 90°F and 122°F (32°C to 50°C) without damage (Abt, 1994). If developed, a machine that could accomplish cleaning in this way would be an alternative to the washer in the wetcleaning system, and extraction and drying would need to be incorporated into this system.

Other new solvents are being developed. One, based on glycol ethers, has been in development for some time. It is intended to be a drop-in substitute for perc in modified perc equipment. There are other solvents in development. EPA has no independent data on any of these processes other than manufacturers' claims.

Release and Exposure

Releases occur when chemicals are no longer contained within the process or are no longer under the control of the facility using those chemicals. The assessment of releases involves the estimation of magnitude, frequency, and medium (e.g., to air, to water, or in solid waste for off-site disposal to landfill, incineration, or recovery processes) of releases.

Perc and Hydrocarbon Releases

Because perc is defined as a hazardous air pollutant by the Clean Air Act (CAA) and a hazardous waste by the Resource Conservation and Recovery Act (RCRA), releases from perc-based systems are a significant concern. Drycleaners can release perc and hydrocarbons to the air, as both vented and fugitive emissions, and to water mainly as separator wastewater. In addition, certain perc and hydrocarbon waste waters can be discharged to sewers and may leak to ground water before reaching a publicly owned treatment works (POTW) for treatment (Wolf, 1992). Some facilities also dispose of separator water as hazardous waste. Facilities generating more than 220 pounds per month of hazardous waste are required to dispose of such waste through a RCRA-approved waste handler. Hydrocarbon solvent wastes generated from certain cleaning processes are also defined as a hazardous waste.

Both processes also create chemicals that are discarded by drycleaners in the form of solid wastes, such as distillation still bottoms and used cartridge filters. Amounts of these releases vary widely between individual facilities and may be affected by equipment differences, such as cleaning machine capacity, vapor recovery devices, operating temperatures, separator size, filter type, number of cleaning machines, and still type. In addition, differences in operating conditions, such as number of articles cleaned per load, number of loads per day, drying time, residence time in water separator, and differences in maintenance and general housekeeping, all affect releases. Both perc and hydrocarbon processes have a multitude of machine configurations for which EPA has developed release estimates. Figure 5 and Figure 6 outline some of the major configurations and their release estimates.

Wetcleaning Releases

Clothes cleaners using the wetcleaning process are expected to release detergents, finishes, water softeners, and other cleaning and processing aids primarily to water during the wash and rinse cycles of the machines. Most chemical constituents in the various wetcleaning formulations are likely to be non-volatile. Releases of chemical constituents such as fragrances to air and chemicals from the formulations in solid wastes would also be expected to be relatively small.

Because wetcleaning technologies are relatively new to commercial cleaning, no actual environmental release data are available for these processes. However, two existing studies contain enough information to calculate formulation use rates (Environment Canada, 1995; Gottlieb et al., 1997). In these studies, modeling was used to estimate releases of detergents from

Figure 5: Estimated Releases from Perc Model Facilities with Various Machine Types and Emission Controls

Machine Type and Control Technology	Releases					
	Perc			Total Volume		
	To Air[a] (gal/yr)	To Water[b] (gal/yr)	In Hazardous Waste[c] (gal/yr)	Total Perc Loss (gal/yr)	Total Wastewater Volume[b] (gal/yr)	Total Hazardous Waste Volume[c] (gal/yr)
Transfer						
No RC or CA - Option Perc-A1	501	0.007	127	627	75	658
With CA - Option Perc-A2	342	0.100	127	469	1,500	667
With RC - Option Perc-A3	290	0.014	127	417	150	658
Dry-to-Dry						
No RC or CA - Option Perc-B1	434	0.007	127	561	75	658
With CA - Option Perc-B2	228	0.100	127	355	1,500	667
Converted to Closed-Loop - Option Perc-B3	176	0.014	127	303	150	658
Closed-Loop with no CA or with Door Fan and Small CA - Option Perc-C	83	0.014	127	210	150	662
Closed-Loop with Unvented Integral Secondary CA - Option Perc-D	51[d]	0.014	127	178	150	662

RC = refrigerated condenser; CA = carbon adsorber; see text for further explanation of equipment.

[a] Based on Table 4 of CEPA, 1993, assuming that the transfer and vented dry-to-dry emission estimates would be representative of CA-controlled machines. Total air emissions are the sum of vented emissions and fugitive emissions. For transfer machines with no CA or RC, vented emissions were assumed to be 50% of fugitive emissions; for dry-to-dry machines with no CA or RC, vented emissions were assumed to be equal to fugitive emissions. Vent control efficiencies were assumed to be 95% for CA. The difference in emissions between transfer with CA and transfer with RC was assumed to be the same as the difference between dry-to-dry with CA and dry-to-dry converted to closed-loop. Average "model" and California facilities are estimated to clean 53,333 and 51,460 lbs/yr clothes, respectively, and CEPA emissions data were scaled proportionally from California throughput to "model" facility throughput.

[b] Based on 150 gal/year for RCs (EPA, 1997) and 1,500 gal/year for CAs (EPA, 1993), and assuming water-cooled condenser generates 50% of volume generated by RC; also, based on 150 ppm perc average in wastewater and 3.78 kg/gal water and 6.1 kg/gal perc.

[c] Based on the International Fabricare Institute estimate of 3.2 lb of perc is lost in hazardous wastes from filters and distillation residues per 100 lb clothes cleaned (CEPA, 1991) plus CA waste, as applicable, of less than 10 lb perc annually, based on an average 275 lb carbon bed (EPA, 1991b), spent carbon is 10% perc by weight (assumed based on CEC, 1992), and a carbon change-out frequency of 5 years for CAs used without RCs and 10 years for CAs used as integral secondary controls. Hazardous waste is assumed to average 40% perc by weight (based on Safety Kleen, 1986, and PEI, 1985) and to average 2.94 kg/gal (assuming that the non-perc portion has the density of diatomaceous earth, 0.834 kg/gal).

[d] CEPA, 1993, estimates that secondary control reduces emissions for a closed-loop machine by almost 40% (drum levels of 300 ppm for secondary control vs. 8,600 ppm for no secondary control is equivalent to 96.5% removal; emissions from drum are 40% of total facility emissions).

Figure 6: Estimated Releases from Hydrocarbon Model Facilities with Various Machine Types and Emission Controls

Machine Type and Control Technology	Releases: Hydrocarbon Solvent: To Air[a] (gal/yr)	To Water[b] (gal/yr)	In Solid Waste[c] (gal/yr)	Total Volume: Total Hydro-carbon Loss (gal/yr)	Total Waste Water Volume[b] (gal/yr)	Total Solid Waste Volume[c] (gal/yr)
Transfer						
w/ Standard Dryer - Option Hydrocarbon-A1	1,839	< 0.0001	320	2,159	415	1,415
w/ Recovery Dryer - Option Hydrocarbon-A2	678	0.0001	320	998	829	1,415
Dry-to-Dry						
Closed-Loop w/ Condenser - Option Hydrocarbon-B	194	0.0001	320	514	829	1,415

[a] Based on emission factors in EPA, 1982. Total air emissions are the sum of vented emissions and fugitive emissions. The CTSA's "model facility" throughput of 53,333 lb/yr clothes was used to estimate these releases. Air release from dry-to-dry closed-loop is based on air release from transfer with recovery dryer multiplied by the ratio of perc dry-to-dry closed-loop to perc transfer with refrigerated condenser.

[b] Based on 3.4 lb water recovered per 100 lb clothes for a system with a recovery dryer, and the same recovery assumed for dry-to-dry; hydrocarbon losses based on 0.036 ppm hydrocarbon average in waste water, 3.78 kg/gal water and 3.0 kg/gal hydrocarbon, and 10% of total water volume recovered from a system with no condenser relative to recovery from a system with a condenser.

[c] Based on emission factors in EPA, 1982. Total solid waste loss includes spent cartridge filters and vacuum still bottoms. Hazardous waste is assumed to average 40% hydrocarbon by weight (EPA, 1982) and to average 1.71 kg/gal (assuming that the non-hydrocarbon portion has the density of diatomaceous earth, 0.834 kg/gal).

two model facilities. It was assumed that all detergents were released to water. Only one primary factor affecting release quantities was found, that is, the percentage of clothes cleaned by immersion in water. The Environment Canada study estimated a detergent release of 29.5 gallons per year from a model facility that machine washes less than 100 percent of the clothes cleaned. The study by Gottlieb et al. estimated a detergent release of 95.4 gallons per year from a model facility that machine washes 100 percent of the clothes cleaned. It is not known whether the estimated releases are representative of the universe of wetcleaning processes. As is similar to perc and hydrocarbon processes, the modeling indicates that wetcleaning releases will vary between individual facilities.

Exposure

Exposure is defined by EPA as contact between a chemical and the skin, nose, or mouth of a person over a given period of time. The assessment of exposure is the estimation of the magnitude, frequency, duration, and route of exposure. The exposure assessment describes who comes into contact with the chemicals used in the various cleaning processes and, thus, who may experience the effects related to the chemicals.

Figure 7: Exposure Scenarios Evaluated for Human Health Effects

Population Exposed to the Chemical	Exposure Routes and Pathways					
	Inhalation Exposure		Ingestion Exposure		Dermal Exposure	
	Residence	Workplace	Nursing (Infants)	Drinking Water	Bathing	Workplace
Perchloroethylene						
Workers		✓				✓
Co-located Adults	✓			✓	✓	
Co-located Elderly, Infants, and Children	✓		✓			
General Population - Adults	✓			✓	✓	
General Population - Elderly, Infants, and Children	✓					
Hydrocarbon						
Workers		✓				✓
General Population - Adults	✓			✓		
General Population - Elderly, Infants and Children	✓			✓		
Wetcleaning Chemicals						
Workers						✓

✓ Indicates that the pathway-population combination is considered by EPA in the *Cleaner Technologies Substitutes Assessment*.

Populations exposed to clothes cleaning chemicals include workers, co-located residents, and the general public. People who have the highest rate of exposure include workers in an establishment that uses a solvent, such as perc, and children and other people who live in the same building or adjacent ("co-located") to an establishment that uses a solvent such as perc. The general population is also thought to come into contact with clothes cleaning chemicals to a lesser degree. Environmental exposures for the general population are not generally high, therefore, this document emphasizes human health concerns for workers and co-located populations.

Health and Environmental Risk

The full CTSA provides a review of the relative human health, environmental, and other (e.g., flammability) hazards or effects of various fabricare technologies, and provides a basic description of those potential effects. In short, adverse outcomes can include the ability of a chemical to cause cancer, developmental and/or neurological effects, respiratory illness, or injury such as repetitive stress syndrome. Effects can also be environmental in nature, such as the ability of a chemical to cause harm to aquatic organisms.

The CTSA does not contain estimates of the absolute level of risk for various technologies. Relative risk assessments for the various cleaning technologies were conducted at a "screening level" of review, using readily available information and standard analyses for comparison purposes only. The risk assessments and characterizations present an idea of the **relative** risks to human health and the environment, offer a basis for comparison, and give a rough idea of the potential risks associated with each of the processes. Careful interpretation is necessary given that the extent and type of hazard, exposure data, and uncertainties associated with each process differ widely. Also, the absence of information on a technology does not mean that it has no risks.

Risk Assessments

This summary organizes information on the relative health, environmental, and property risks of clothes cleaning processes so that they can be compared. Characterizing these risks involves gathering a variety of information. A risk assessment is an interactive process that generally includes the following components of analysis:

- Hazard assessment and characterization to determine if exposure to a chemical can cause adverse health effects in humans and the environment.

- Dose-response assessment and characterization to define the relationship between the dose of a chemical and the incidence and severity of adverse health effects in the exposed population. From the quantitative dose-response relationship, toxicity comparison values are derived and are used in the risk characterization step to estimate the likelihood that adverse effects will occur in humans at a variety of anticipated exposure levels.

- Exposure assessment and characterization to identify populations exposed to a chemical, describe their composition and size, and present the types, magnitudes, frequencies, and durations of exposure to the chemical.

- Risk characterization to integrate hazard, exposure, and dose-response information into qualitative expressions of risk. A risk characterization includes a description of the major assumptions and key issues, scientific judgments, strengths and weaknesses of data and analyses, and the uncertainties embodied in the assessment.

Perchloroethylene Solvent

Human data indicate that perc is absorbed into the body via inhalation, from the gastrointestinal tract following ingestion, and through the skin. There is human evidence that perc can cause neurotoxicity and kidney effects. Perc has been shown to cause other effects, including cancer, developmental toxicity, and liver effects in laboratory animals.

The results of a number of monitoring studies indicate that the concentrations of perc in indoor air can be elevated in dwellings located in the same building as drycleaners, but are not as high as concentrations found in drycleaning workplaces (BAAQMD, 1993; NYSDOH, 1993; Schreiber et al., 1993; Wallace et al., 1995). The excess cancer risk over a lifetime is estimated to be higher than 1 in 1 million for residents living in co-location with drycleaning establishments, particularly if they live in such dwellings for more than a few years. Risks appear to be higher for residents living above transfer machines and poorly maintained dry-to-dry machines than for the general population. Children, infants, and the elderly who spend most of their day within the residence are thought to be at a slightly greater risk for both cancer and non-cancer effects due to increased exposure duration relative to adults in general. The cancer risk analysis approach used to derive these conclusions is tied to an upper bound lifetime excess cancer risk estimate, and there is the possibility that the lifetime excess cancer risk is as low as zero.

Co-located residents are also at risk through a variety of perc exposures that the general public experiences, in addition to their exposures related to co-location with drycleaning facilities. Risks potentially experienced by the general population, such as drinking perc-contaminated water, would be added to the risks due to co-location.

There is a reasonable basis for concluding that there could be a health risk for cancer and some non-cancer effects to workers from the relatively high perc exposures observed on average in the drycleaning industry. This conclusion is based on monitored worker inhalation exposure data from several sources, from information about the circumstances of dermal exposures in the workplace and the absorption potential of perc through the skin, combined with evidence from animal studies. The risk analysis approach used to derive these conclusions is tied to an upper bound lifetime excess cancer risk estimate, and there is the possibility that the lower bound is as low as zero.

In a recent study conducted by the National Institute for Occupational Safety and Health (NIOSH), researchers found that operator/cleaners generally have higher exposures relative to most non-operators (e.g., pressers, spotters). NIOSH observed a general decreasing trend in exposure levels and permissible exposure limit (PEL) excursions over time. In the study, operators in facilities with transfer machines tended to have higher exposures than workers in facilities with dry-to-dry machines. Closed-loop machines with integral carbon adsorbers resulted in significantly lower worker exposures than all other machine configurations currently available (NIOSH, 1997). The researchers found that as the number of machines increased, exposure levels also increased.

Although no studies or data are available that quantify dermal exposures to perc for drycleaning workers, models have been developed to estimate dermal exposure. Results of these models suggest that dermal exposure is not a significant source of perc exposure for drycleaning workers. Workers are usually exposed during routine activities that include, but are not limited to, transferring wet articles from the washer to the dryer and cleaning the bottom trap and still (or muck cooker) (EPA, 1991b).

Several EPA studies have suggested that the general public's exposure to perc (via inhalation and ingestion) presents low risks for cancer and non-cancer toxicity. The risk analysis approach used to derive these conclusions is tied to an upper bound lifetime excess cancer risk estimate, and there is the possibility that the lower bound is as low as zero.

Risks to aquatic organisms are expected to be low if drycleaning wastewater effluents are sent to publicly-owned treatment works (POTWs). This is expected to be the case for most drycleaning establishments. If wastewater effluent is not sent to a POTW, there would be health risks to aquatic organisms from high perc concentrations in surface waters.

Hydrocarbon Solvents

In the full CTSA, the health risks for hydrocarbon solvents are based upon findings for Stoddard solvent. There are no data suitable for drawing conclusions concerning carcinogenic potential. [Since the June 1998 publication of the full CTSA, EPA has attempted to obtain carcinogenic testing information for newer hydrocarbon solvents, and it appears that no such testing has been conducted.]

Hydrocarbon solvents are used much less often than perc in commercial drycleaning, and less information is available for them. According to a NIOSH study, the number of workers exposed to hydrocarbon solvents in facilities that dryclean clothes is estimated to be between 21,000 and 49,000. The most significant route of exposure for workers is expected to be inhalation, although they may also be exposed through dermal (skin) absorption (NIOSH, 1980; OCIS, 1994, 1998).

There is evidence indicating that Stoddard solvent is absorbed into the body via inhalation, the gastrointestinal tract, and the skin. Some human data indicate that this chemical can cause neurotoxic effects and is an irritant to the eyes, mucous membranes, and skin. Kidney toxicity has also been reported in animal studies (ATSDR, 1995).

Weighing this information, there is a reasonable basis for concluding that there is a health risk for non-cancer toxicity in workers due to the relatively high hydrocarbon solvent exposures observed in the drycleaning industry. This conclusion is based on monitored workers' inhalation exposure data from several sources, information about the circumstances for dermal exposures in the workplace, the potential for Stoddard solvent to be absorbed through the skin, and evidence that Stoddard solvent can be toxic in laboratory rodents.

Chronic health risks to the general population from estimated inhalation exposures to hydrocarbon solvents are considered low. Risks from ingesting drinking water contaminated with hydrocarbon solvents are also considered low, given the very low projected releases of hydrocarbon solvents to surface waters. These conclusions are based on modeled exposure scenarios, combined with evidence indicating that Stoddard solvent can cause toxicity in laboratory animals. However, conclusions about these risks are hampered by the lack of actual exposure data.

It is possible that co-located residents have ambient air exposures to hydrocarbon solvents, and therefore would have health risks, although no data are available for this exposure scenario.

As is the case with perc, the data available do not indicate whether health risks due to hydrocarbon solvent exposures differ significantly between special sub-populations (such as infants, children, and the elderly) and average adults. Therefore, risks to special sub-populations due to hydrocarbon solvent exposures should be treated the same as those for other adults.

There is a potential flammability hazard associated with hydrocarbon solvents. The *Fire Protection Guide to Hazardous Materials* of the National Fire Protection Association (NFPA) ranks chemicals on a scale of 0 through 4 for flammability. Materials ranked 0 will not burn, and those ranked 4 include flammable gases, pyrophoric liquids, and flammable liquids. All of the hydrocarbon solvents discussed here are ranked 2, meaning that they have a low flashpoint (that is, they must be moderately heated before ignition will occur) and that they give off ignitable vapors. Stoddard solvent is also considered ignitable based upon the standard outlined in EPA regulations (Protection of Environment, RCRA, Identification and Listing of Hazardous Waste, Characteristic of Ignitability). Under this standard, a chemical is considered ignitable if it "is a liquid, other than an aqueous solution containing less than 24 percent alcohol by volume and has a flash point less than 60°C." DF-2000 and 140°F solvent are considered to have a non-ignitable ranking.

Although fire potential is a commonly recognized hazard of hydrocarbon solvents, data are not available to assess the potential for the hydrocarbon solvents to ignite and cause a fire (Ahrens, 1998).

The potential risk to the environment from hydrocarbon solvents is estimated to be low. The projected releases of hydrocarbon solvents to surface water are very small. The resulting concentration of hydrocarbon solvents in surface water is also small and is not expected to exceed the toxicity concern concentrations for aquatic organisms. Thus, there is a low risk of toxicity to aquatic species.

Wetcleaning Detergent

Very little toxicity data are available on the chemical constituents of the formulations (detergent) used in most wetcleaning processes. Workers are expected to be the population most highly exposed to wetcleaning detergent formulations. Dermal exposures are expected, but currently there are no data on actual worker dermal exposures. Inhalation exposure of workers is not expected because of the low volatilities of the component chemicals and because the chemicals are in an aqueous solution. Dermal exposures to wetcleaning formulations can be modeled, and the results suggest that dermal exposures are relatively low for wetcleaning workers. However, there could be possible risks to workers of eye and skin irritation from wet process formulations based upon findings associated with the example detergents.

In general, several characteristics of surfactants may affect the likelihood of human health and environmental effects. These chemicals can differ in inherent toxicity, persistence, and bioaccumulation potential, any of which can be a concern. Surfactants that minimize these characteristics are presumed to be more desirable. A desirable property of surfactants is that they can be easily destroyed, either through conventional treatment processes or through biodegradation. Those that are easily destroyed are less likely to persist in the environment.

Selected Federal Regulatory Requirements

Professional clothes cleaners may be subject to numerous Federal requirements, including the following Federal air, water, waste management, and occupational health and safety regulations: Clean Air Act (CAA); Clean Water Act (CWA); Safe Drinking Water Act – Underground Injection Control Regulations (SPWA-UICR); Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); Occupational Safety and Health Act (OSH); and the Federal Trade Commission's Care Labeling Rule. Compliance with these requirements will affect operational costs. Owners and operators of drycleaning facilities are encouraged to consult EPA's *Plain English Guide for Perc Drycleaners: A Step by Step Approach to Understanding Federal Environmental Regulations and Multimedia Inspection Guidance for Drycleaning Facilities* for a more detailed discussion of perc drycleaning regulations.

In addition, cities and municipalities have enacted zoning restrictions that may affect all types of fabricare operations, and many localities have adopted some, or all, of the National Fire Protection Association's standards for drycleaning equipment and operations (NFPA-32). These restrictions and requirements may affect costs and liabilities.

The chart below lists Federal regulations that may affect clothes cleaning operations covered in the CTSA for Professional Fabricare Processes. The two most prevalent technologies, perc cleaning and hydrocarbon (petroleum) cleaning are most affected by Federal regulations. Wetcleaning currently has fewer requirements that are directly applicable. There currently are few Federal regulations governing the use of the emerging cleaning technologies (e.g., liquid CO_2 and ultrasonic cleaning). It is unclear how requirements may change as industry use of these technologies changes.

Figure 8: Summary of Regulations Related to Fabricare Technologies[a]

Fabricare Option	CAA	CWA	RCRA	CERCLA	OSH	Care Labeling Rule	Other
Perc Cleaning	✓	✓	✓	✓	✓	✓	NFPA-32
Hydrocarbon Cleaning	✓	✓	✓	✓	✓	✓	NFPA-32
Wetcleaning	NA	✓	NA	NA	NA	✓	NA

✓ Indicates that a technology is regulated specifically by the statute.

NA Indicates that although the statute applies to the technology, there are no specific regulatory requirements.

[a]The list of regulations covered in this booklet should not be considered exhaustive and may not cover all regulated aspects of the fabricare industry.

The **Clean Air Act (CAA)** and subsequent amendments are a regulatory framework established to protect and improve ambient air quality in the United States. The CAA was passed in 1970 and amended with significant provisions in 1977 and 1990. Section 111 of the CAA established new source performance standards and best achievable technology standards for sources of specific volatile organic chemical compounds (i.e., fabricare establishments). These standards require establishments that emit volatile chemicals to establish and maintain records, make reports, install/use/maintain monitoring equipment, sample locations, and provide this information to applicable regulatory agencies.

The **Clean Water Act (CWA)** is the Federal law designed to protect the chemical, physical, and biological quality of surface waters in the United States. The original statute and subsequent amendments evolved from the Federal Water Pollution Control Act of 1972 (PL 92-500). The CWA regulates both waste water discharges directly into surface waters via the National Pollutant Discharge Elimination System (NPDES) and discharges into municipal sewer systems. The CWA designates and regulates pollutants in waste water effluent according to the following three categories:

- *Priority Pollutants* - 126 toxic chemicals;
- *Conventional Pollutants* - include biological oxygen demand, total suspended solids, fecal coliform bacteria, fats/oils/greases, and pH; and
- *Non-conventional Pollutants* - any pollutant not identified as priority or conventional.

The **Safe Drinking Water Act (SDWA)** prohibits the injection of contaminants through wells that will cause a public water supply system to violate a national drinking water standard or otherwise endanger public health or the environment. This statute requires EPA to set maximum levels for contaminants in water delivered to users of public water systems. Such standards are health-based for drinking water and require water supply system operators to come as close as possible to meeting these standards by using the best available technology that is economically and technologically "feasible." Primary enforcement responsibility may be delegated to states that request it, if they adopt drinking water regulations no less stringent than the national standards and implement adequate monitoring and enforcement procedures.

Passed in 1976, the **Resource Conservation and Recovery Act (RCRA)** is the primary waste management statute in the United States. RCRA regulates the management and disposal of hazardous (Subtitle C) and solid (Subtitle D) wastes. It establishes a "cradle to grave" system for tracking the production, management, and disposal of hazardous waste. Detailed definitions are provided for both hazardous and solid wastes, as well as specific requirements related to waste generation, management, storage, and disposal. The Hazardous and Solid Waste Amendments of 1984 strengthened RCRA's waste management provisions and added Subtitle I, governing the management of underground storage tanks.

The **Comprehensive Environmental Response, Compensation and Liability Act (CERCLA),** known more commonly as Superfund, is the Federal statute that established a variety of mechanisms to clean up sites contaminated with improperly discarded chemical wastes. This 1980 statute authorizes EPA to respond to releases, or threatened releases, of hazardous substances that may endanger public health, welfare, or the environment. CERCLA also enables EPA to force responsible parties to clean up environmental contamination or reimburse EPA's Superfund for emergency response costs. The Superfund Amendments and Reauthorization Act (SARA) of 1986 revised various sections of CERCLA, extending the taxing authority for the Superfund and creating an additional free-standing Federal law (SARA Title III - Emergency Planning and Community Right to Know Act).

The Occupational Safety and Health Administration (OSHA) was established in 1970 under the U.S. Department of Labor to reduce occupational fatalities, injuries, and illnesses and to develop health and safety standards and training programs for the protection of workers in the United States. Section 6 (a) of the **Occupational Safety and Health Act (OSH)** enabled OSHA to promulgate existing Federal and national consensus standards as OSHA standards. Under the authority of this provision, the Health Standards program of OSHA established exposure limits for general industry air contaminants (29 CFR 1910.1000 Subpart Z).

The **Care Labeling Rule (16 CFR 423)** was promulgated by the Federal Trade Commission in order to establish uniform care instructions for textile garments and accessories. This rule requires clothing manufacturers to label garments with an acceptable cleaning method, supported by a "reasonable basis." The reasonable basis for labeling a garment with a particular cleaning method can be based upon either the historical success with a particular cleaning technology or actual test results that take into consideration fiber, fabric, and garment construction variables.

Costs

Assumptions

The costs of running a professional clothes cleaning business include rent, basic operating expenses, equipment, and labor. The equipment capacity, equipment type, and location of the facility will affect the costs and economic viability of a professional cleaning operation. While some fabricare technologies have been in use for many years, others are still prototypes and have not yet been commercially marketed. As manufacturers gain expertise with new machines, and their production quantities increase, it is expected that there will be a decrease in the cost of production of new machines relative to established technologies and therefore a decrease in the cost of these options to fabricare operators (Pindyck and Rubinfeld, 1989).

The cost categories considered in this analysis are capital equipment cost, annualized cost of that equipment, annual solvent cost, energy cost, hazardous waste disposal cost, regulatory compliance costs, cost of filters and other supplies, and maintenance cost. These cost elements were chosen for evaluation because of their importance to facility operation, their potential for highlighting differences among technologies, and the availability of data. Figure 9 presents operating factors that are associated with fabricare operations, many of which are outside the scope of this document.

Figure 9. Potential Operating Factors Associated with Fabricare Facilities

Revenues
- Sale of product
- Marketing of by-product
- Change in process throughput
- Change in sales from improved corporate image and market share

Utilities
- Electricity
- Cooling and process water
- Refrigeration
- Fuel (gas or oil)
- Plant air and inert gas
- Sewerage

Direct Labor
- Operating labor and supervision
- Clerical labor
- Inspection (QA & QC)
- Worker productivity changes

Materials
- Direct product materials
- Solvents
- Wasted raw materials
- Transport and storage

Waste Management (Materials and Labor)
- Pre-treatment and on-site handling
- Storage, hauling, and disposal
- Insurance

Future Liability
- Fines and penalties
- Personal injury

Regulatory Compliance
- Equipment monitoring and lab fees
- Personal protective gear
- Reporting, notification, inspections, and manifesting
- Training (right-to-know, safety) and training materials
- Workplace signage and container labeling
- Penalties, fines, and solvent-use fees
- Insurance, closure and post-closure site maintenance

Indirect Labor
- Maintenance (materials and labor)
- Miscellaneous (housekeeping)
- Medical surveillance

Source: EPA, 1997

Wherever possible, the cost information reported is based on current prices of equipment and supplies offered by domestic manufacturers or distributors. If current prices are not available (e.g., equipment is no longer sold), then historic prices provided by a vendor are used if they are available. Costs or cost ranges may also be derived from secondary sources (materials published by EPA, state and local governments, and industry). If prices were obtained from both current sources and published materials, the current prices are used, and the information from published sources is noted in the text. Where applicable, sample calculations are included for each cost element. Figure 10 lists cost and revenue elements associated with fabricare facilities.

Only those process-dependent cost components (i.e., equipment and chemicals) that are directly related to the various cleaning processes are included in these cost analyses. Operating costs that do not vary with the process used, such as storefront operations and rent, are excluded from these analyses. Some of the costs are based on the average of prices offered by several vendors, while others are based on reported prices from a single vendor. Solvent and detergent cost estimates are adjusted to 1997 dollars using the Producer Price Index for Chemicals and Allied Product. All other cost estimates are adjusted to 1997 dollars using the Producer Price Index for Capital Equipment (BLS, 1997).

Figure 10. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technology Options[a]

Fabricare Technology[b]	Capital Cost of Base Equipment[c]	Capital Cost Total[d]	Annualized Cost of Equipment[e]	Annual Cost Solvent[f]	Annual Energy Cost[g]	Regulatory Compliance Costs[h]	Annual Cost Hazardous Waste[i]
Perchloroethylene	$38,511	$38,511	$4,228	$1,434	$136	$3,680	$4,594
Hydrocarbon	$37,432	$37,432	$4,110	$2,236	NA	NA	$9,820
Wetcleaning	$11,102	$11,102	$1,219	$763	$788	NA	NA

Figure 10. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technology Options[a] (Cont'd)

Fabricare Technology[b]	Annual Cost Filters and Detergent[j]	Annual Cost Maintenance[k]	Total Annual Operating Cost[m]	Total Annual Cost[n]	Total Annual Cost/Pound
	$1,913	$6,000	$14,077	$18,305	$0.34
Hydrocarbon	$1,551	$6,000	$19,607	$23,717	$0.44
Wetcleaning	$3,162	$376	$5,089	$6,308	$0.12

NA means that the category is not applicable for the technology or that data are not available at this time.

[a] The values include the price of equipment and services directly related to the various drycleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333-pound (24,191-kg) annual volume of clothes cleaned per facility.

[b] Configurations for fabricare technology include perc dry-to-dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (Perc-C), as required by the perc NESHAP regulation; hydrocarbon transfer with recovery dryer and condenser (Hydrocarbon-A2); and Unimac UW30 washer and DTB50 dryer.

[c] List price of 35-pound perc dry cleaning system includes control equipment, distillation unit, and filters; list price of 35- to 40-pound hydrocarbon dry cleaning system includes control equipment, filters, and an explosion kit.

[e] Base machine costs (actual or implied) are added to cost of control capital.

[e] Annual cost of drycleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[f] Perc solvent cost based on $6.83 per gallon for perc in 1997 dollars (BLS, 1997; EPA, 1993) and "mileage" from EPA engineering estimates; hydrocarbon solvent cost based on $2.24 per gallon for hydrocarbon solvent and "mileage" based on engineering estimates; wetcleaning solvent cost based on $3.06/100 feet^3 for water (BLS, 1997; EPA, 1993).

[g] All technology energy costs are based (EPA, 1991c) on $0.0764/kWh national average electricity cost (BLS, 1997).

[h] Regulatory compliance costs for perc are based on 1.84% of total annual revenues of $200,000 (Gottlieb et al., 1997; NCAI, 1998).

[i] Hazardous waste disposal costs for perc and hydrocarbon are based on $6.94 per gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates, excluding disposal cost for potentially hazardous spotting chemicals. Hazardous waste associated with perc-based machines includes filters, distillation residues, and spent carbon. Hazardous waste associated with hydrocarbon-based machines includes spent cartridge filters and vacuum still bottoms.

[j] Cost includes cleaning detergents, spotting chemicals, and replacement filters (Hill,1994b; EPA, 1993).

[k] Annual maintenance cost for perc and hydrocarbon are based on 3.0% of total revenues of $200,000 annually; costs for wetcleaning are based on 3.39% of total capital costs (Murphy, 1994).

[l] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[m] Includes all operating costs and annual capital costs.

The cost estimates for the hydrocarbon machines assume a 40-pound (18.1-kg) nominal capacity machine that includes a washer/extractor (with filter and explosion kit) and a basic dryer. The solvent machines are assumed to operate at 80 percent capacity (Jenkins, 1994), resulting in a daily throughput of six loads per day.

The cost estimates for wetcleaning machines assume a 30-pound (13.6-kg) nominal capacity. Manufacturer estimates indicate that wetcleaning equipment is designed to be operated at 100 percent capacity, resulting in a daily throughput of six loads per day.

Cost Factors

Capital Equipment

Capital costs for equipment and the costs of retrofitting machines with control technologies are converted to annual cost equivalents using a 7 percent real cost of capital and a 15-year lifespan (equivalent to using a capital recovery factor of 0.1098), to be consistent with previous clothes cleaning analyses (EPA, 1993).

Maintenance

The International Fabricare Institute (IFI) estimates annual equipment maintenance costs for perc-based operations to be 2.27 percent to 3.26 percent of total annual revenue, based on an annual sales volume of $100,000 to $300,000 (IFI, 1992). For the purpose of the CTSA, perc and hydrocarbon annual equipment maintenance costs are calculated as 3 percent of total annual revenues.

Energy

Energy costs are based on the national average commercial electricity price of $0.0764 per kilowatt-hour (EIA, 1997). Energy use estimates for each technology include only actual cleaning and drying equipment and do not include non-cleaning processes such as pressing. In cases where data are available, energy costs are provided for machines and emissions control technologies, based on estimates by equipment manufacturers and suppliers.

Installation costs are included in the cost of retrofitting machines with emissions control technologies, as these costs are a necessary and unavoidable part of the retrofitting process. For the purpose of this analysis, installation costs are not included for new equipment because the installation costs of a new machine vary significantly.

Installation

In this summary, the model clothes cleaning plant for each technology is assumed to process an annual average clothing volume of 53,333 pounds.[1] This annual clothing volume for the average facility is derived by dividing the total volume of clothes cleaned using perc and

[1] The total throughput of the model plant is 66,666 pounds, of which 80% is dry cleaning or another process and 20% is washing (Faig, 1998). It is assumed that the revenue per pound is constant at $3, generating a revenue per facility of $200,000.

hydrocarbon solvents in the commercial sector (1.92 billion pounds) by the number of firms using perc and hydrocarbon solvents in the commercial sector (36,000) (Wolf, 1998; Wong, 1998). Facilities are assumed to operate 312 days annually [6 days per week and 52 weeks per year (Shaffer, 1995)] and to have an average daily throughput of approximately 171 pounds of clothing.

The cost estimates for perc assume a 35-pound (15.9-kg) nominal capacity machine with a distillation unit and filtration system, unless otherwise noted. This is the machine size most commonly used in the commercial sector (EPA, 1991c). The price of retrofitting machines with emission control equipment is estimated for the same cleaning capacity. It is assumed that the perc machines operate at 90 percent capacity (EPA, 1993) and that six loads per day are needed to process the throughput.

Solvent and Other Material

Solvent costs may vary based on per-gallon and bulk prices. Perc solvent costs range from $5.50/gallon to $8.01/gallon, based on estimates provided by manufacturers and distributors. A median perc solvent price of $6.83/gallon is used for the purposes of this analysis.

Hydrocarbon solvent costs range as follows: (1) Stoddard solvent costs $1.50/gallon to $4.00/gallon, with a median price of $2.24/gallon; (2) DF-2000 costs $3.49/gallon to $5.01/gallon, for a median price of $3.79/gallon; and (3) Drylene solvent costs $7.50/gallon. For the purpose of this analysis, the median price of Stoddard solvent ($2.24/gallon) will be used to calculate total hydrocarbon solvent costs, although it should be recognized that costs will vary depending upon which hydrocarbon solvent is used.

Water for wetcleaning costs $2.73/100 cubic feet in 1993 dollars or $3.06/100 cubic feet in 1997 dollars (BLS, 1997; EPA, 1993). This price includes the average cost of water and sewerage fees.

Filters/Cleaning Supplies

Perc filters are estimated to cost $606 annually, and detergents and spotting chemicals for perc machine configurations are calculated to cost $1,307 annually, for a total of $1,913 (BLS, 1997; EPA, 1993). For the hydrocarbon configurations, the filters cost $244 annually, while the detergents and spotting agent costs are estimated at $1,307 annually, for a total of $1,551 (BLS, 1997; Hill, 1994a). Annual costs for wetcleaning detergent, fabric softener, and spotting chemicals are calculated to be $2,877, $40, and $245, respectively, for a total of $3,162 (BLS, 1997).

Hazardous Waste Disposal

Because perc is a hazardous waste, this document compares the costs of hazardous waste disposal. For the purposes of this analysis, all hazardous waste cost estimates include only the cost of disposal and do not include the cost of associated paperwork and other regulatory compliance activities noted in Figure 10. The cost of disposing of potentially hazardous spotting chemicals is not included in this analysis. Hazardous waste disposal costs for perc- and hydrocarbon-based equipment are calculated using a cost of $6.94 per gallon and engineering estimates of volume.

Regulatory Compliance

Compliance with government regulations imposes industry-specific costs upon the private sector. Figure 9 lists many of the regulatory compliance cost categories pertinent to the fabricare industry, including expenditures for waste management. The range of equipment age and types currently in use will result in variations in regulatory compliance costs within and across process categories. In addition, regulatory compliance costs will vary regionally due to differing local and state fees, taxes, and permitting procedures. The use of spotting agents is not factored into the regulatory cost estimates.

Labor

Labor costs associated with professional clothes cleaning operations vary based on the mix of employee job functions, qualifications and experience of workers, productivity of workers, equipment type and configuration, facility size, and geographic location of the facility. For example, rough pressers tend to earn a lower wage than specialized pressers, who are trained to work on intricate garments such as wedding dresses and expensive fabrics such as silks (Seitz, 1996). It is also noted that one employee may perform several job functions within a fabricare shop, each of which requires different skill levels. For example, an employee may work at the drop-off counter during part of his or her shift, in addition to sorting and washing clothing in the back of the facility. Because of this variability and the lack of available quantitative data, the labor costs associates with fabricare operations are not included.

Performance

Several performance demonstrations and laboratory studies have been performed to assess wetcleaning technologies in both the U.S. and Canada. They have provided useful information comparing wetcleaning to more traditional drycleaning technologies. These studies also contain information on consumer perceptions of the cleaning process, as well as information on the costs to run the performance demonstration sites. The reader should note that this document is not intended to derive conclusions about the suitability for individual drycleaners of the alternatives that have undergone the performance testing. When evaluating cleaning performance, it is also important to note that variations in technology and the knowledge base of operators will cause a range of results (Blackler et al., 1995). Also, not all of the criteria used in this assessment are universally applied or accepted by the public and private sectors. Indeed, other performance considerations may become apparent as clothes cleaning studies expand to include additional emerging technologies.

Establishing the Protocols for Performance Testing

The following organizations have established protocols used in conducting performance testing and measuring:

- International Fabricare Institute - Established drycleaning control standards.
- The American Association of Textile Chemists and Colorists (AATCC) - Developed historical criteria for "troubleshooting" drycleaning problems and test methods for standard soil and fabric combinations (Patton, 1994).
- The American Society of Testing and Materials (ASTM) and AATCC - Developed performance specification and test methods, respectively, for acceptable dimensional change (shrinkage and stretching) after laundering and drycleaning. In general, the maximum allowable shrinkage is 2 percent after three drycleanings and 3 percent after five launderings (CNT, 1996). Scientists at both the ASTM and the AATCC have developed performance criteria regarding colorfastness, soil removal, odor, fiber damage, shrinkage, and hand (fabric texture). These standards are linked to care labeling guidelines and will inevitably affect specifications for soap and detergents, as well as clothes cleaning equipment (ASTM, 1998).
- The European Wetcleaning Committee (EWCC) - Performed a study to develop a test method for wetcleaning. The EWCC hopes that the combined results of the study and a second series of tests will provide data adequate to establish consensus guidelines for wetcleaning care labels (den Otter, 1996).

Physical and Chemical Characteristics of Clothes Cleaning

Several industry sources have recommended that all professional clothes cleaning technology should strive to achieve the following goals, which are based on a variety of fabricare characteristics (Wentz, 1994; Hohenstein, undated):

- Optimize soil removal by overcoming the physical and chemical forces that bind soils to textiles;
- Transport soils away from the textile through the cleaning medium; and
- Preserve and/or restore the original attributes of textiles, including dimensions, dye character, hand, and overall fabric finish.

The cleaning ability of a process depends on the following factors:

- soil chemistry,
- textile fiber type,
- transport medium (aqueous vs. non-aqueous),

- chemistry of additives (detergents, surfactants),
- use of spotting agents, and
- process controls (time, temperature, and mechanical actions).

These factors work interactively to provide a range of cleaning abilities for all clothes cleaning processes.

In general, non-aqueous (solvent-based) cleaning processes are effective in dissolving non-polar soils (e.g., oils, fatty stains). Aqueous (water-based) cleaning processes tend to dissolve polar soils (e.g., sugar, salt, perspiration) with greater success. Neither process type removes particulate soils significantly better than the other (Wentz, 1996). However, the cleaning ability of a particular process option may be enhanced with the use of spotting agents, detergents, surfactant additives, and other process modifications such as cleaning time, temperature, or mechanical action.

Non-aqueous cleaning processes are most effectively used with textiles that contain hydrophilic fibers, low-twist yarns, low-count fabrics, and polar colorants. Aqueous cleaning processes are effective with textiles containing hydrophobic fibers, high-twist yarns, high-count fabrics, and non-polar colorants (Wentz, 1996).

Water-based cleaning methods tend to cause expansion of natural and cellulose fibers, leading to a loss of strength, wrinkling, color loss, and dimensional change (shrinkage, stretching). However, such alterations are not necessarily apparent when synthetic fibers are subjected to similar water-based cleaning methods. Textile manufacturers have developed a number of fiber treatments and modifications that may minimize such alterations. For synthetic fibers, non-aqueous cleaning methods may not be appropriate due to potential fiber deterioration (Wentz, 1996).

Other process characteristics that affect cleaning performance include detergent type, mechanical action of equipment, cleaning time, and temperature of cleaning medium. Such characteristics affect not only soil and stain removal, but also potential damage to garments. These individual factors vary in importance according to the cleaning method (Hohenstein, undated).

Pre-treatment and post-treatment spotting is often necessary, regardless of the cleaning method chosen. Spotting agents can be brushed, sprayed, or dripped onto clothing prior to final rinsing, and are chosen based on the chemical nature of the target soils. The choice of spotting agent and the application procedure are important considerations because they can cause color changes and dye transfers (Hohenstein, undated).

Another factor in the success of a particular fabricare process is the skill and experience of the clothes cleaning operators. Their ability to properly sort garments and to choose the appropriate process conditions, as well as their knowledge of textiles and cleaning processes, will have a decisive influence on the success of a particular cleaning method. Clothes cleaning operators can also prevent potential damage to garments by being aware of adverse interactions between textiles and cleaning methods (Wentz, 1996). As indicated previously, the ability of cleaning processes to successfully remove soils from a variety of textiles occurs within a range.

Because human skill affects that range, textile properties alone cannot be used as a strict guideline for evaluating the ability of a cleaning process (Wentz, 1996; Blackler et al., 1995).

Summary of Performance

Most researchers agree that many garments labeled "dryclean only" can be effectively wetcleaned. The results from *The Greener Cleaner, Cleaner by Nature,* and other ongoing demonstration studies indicate that the cleaning performance associated with modern wetcleaning equipment makes this technology an acceptable cleaning process for a significant fraction of consumer garments. There continues to be debate as to the actual percentage of clothing types traditionally drycleaned that can be safely and effectively wetcleaned. Researchers note that the debate should focus not necessarily on what percentage of clothing, but on which types of clothing and fabrics can be successfully wetcleaned (Adamson, 1996; Riggs, 1998).

Given the limited number of performance studies available for comparing clothes cleaning processes, it is difficult to draw conclusions. The variations associated with clothing fibers and soils result in performance differences for all process options considered. A number of studies mention that the skill of the cleaners follows a distinct learning curve, resulting in greater performance as they adapt to new technology. Greater use of these cutting-edge technologies in the fabricare industry will produce advancements in equipment design and operator skills, resulting in increased cleaning performance.

Process Trade-Offs

In order to implement pollution prevention and possibly reduce exposures and/or risks associated with the chemicals used in clothes cleaning, clothes cleaners may consider either controlling emissions from their current technology and/or adding a different technology. Cleaners must consider the costs of running an operation, the service that they can provide to consumers, and at what cost. Choices made may be limited by regulatory requirements and levels of necessary capital investment. Such decisions involve numerous trade-offs among relative costs, performance, health and environmental risks related to a particular process, and other factors unique to each drycleaning shop. These trade-offs are summarized in Figure 11.

Environmental Improvement Approaches

There are certain techniques that may be employed by fabricare operations to prevent pollution, reduce chemical consumption, and minimize waste, particularly for perc and hydrocarbon technologies.

Perc and Hydrocarbon Drycleaners

On September 22, 1993, EPA finalized the NESHAP for perc drycleaners (58 *FR* 49354) This regulation set standards for the reduction of perc emissions from drycleaning operations. Included in the NESHAP were requirements that owners or operators of drycleaning machines and control devices follow their manufacturers' instructions for proper operation and maintenance. Owners or operators are required to keep a copy of any manufacturers' specifications or operating and maintenance recommendations at the drycleaning facility.

EPA realized that some drycleaners may no longer have equipment manuals for older drycleaning machines and control devices. However, owners or operators of older machines and control devices should make every reasonable effort to obtain these manuals. These efforts include contacting manufacturers, if the manufacturers are still in business, and contacting local, state, and national trade associations.

In case efforts to obtain manufacturers' manuals are unsuccessful, EPA's Office of Air Quality Planning and Standards has developed many recommendations for operating and maintenance practices for owners and operators of perc drycleaning machines and emission control devices. Many of these recommendations are summarized in Figure 12.

For more comprehensive details on this very important subject, please refer to Chapter 9 of the *Cleaner Technologies Substitutes Assessment (CTSA) for Professional Fabricare Processes*.

Wetcleaning Processes

Information on pollution prevention opportunities, best management practices, and control options for these emerging technologies is very limited. Several of the following may be considered but should not supersede available manufacturers' information:

- Automated addition of water and chemicals to washing machines, particularly decreasing the amount of human error due to spillage or addition of excessive detergent amounts.

- Good housekeeping practices, such as keeping detergent storage containers tightly closed to reduce chance of spillage.

- Recycling/recovery of rinse water/steam condensate.

Figure 11: An Overview of Trade-Off Factors for Alternative Cleaning Technologies[a]

Characteristic	Perchloroethylene	Hydrocarbon	Wetcleaning
Health and Environmental Risks	**Health:** Risk of cancer to workers, co-located residents. Risks of non-cancer effects, including potential for developmental and reproductive effects for workers. Possible cancer and non-cancer risks to co-located children. **Environmental:** Potential risk to aquatic organisms for effluent not treated by POTW.	**Health:** Risk of neurotoxic effects and skin and eye irritation for workers. **Fire:** Highest for Stoddard solvent, less for 140°F and DF-2000, based on flashpoint. **Environmental:** Potential to contribute to smog and global warming.	**Health:** Risk not evaluated quantitatively. Potential risks of skin and eye irritation for workers. **Environmental:** Potential risk to aquatic organisms from specific detergent component releases.
Costs[b]			
Potential Liability Costs	Groundwater contamination and worker illness.	Fire damage.	Damaged clothing labeled "Dryclean Only."
Capital Costs[c]	$38,511	$37,432	$11,102
Hazardous Waste Disposal[d]	$4,594	$9,820	NA
Annual Operating Costs[e]	$14,077	$19,607	$5,089
Total Annual Costs[f]	$ 18,305	$23,717	$6,308
Market Considerations			
State of Technology	Dominant in market.	Well-established in market; use of some hydrocarbons may be limited by local fire codes.	Commercial use since 1994 in U.S.; numerous detergent suppliers.
Consumer Issues			
Odor	Yes	Yes; may be less for particular hydrocarbons	No
Cleaning Performance	Wide range of clothes.	Wide range of clothes.	Wide range of clothes.

NA means that the cost category is not applicable for the technology or that data are not available at this time.

[a] Configurations for fabricare technology include perc dry-to-dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (Perc-C), as required by the perc NESHAP regulation; hydrocarbon transfer with recovery dryer and condenser (Hydrocarbon-A2); and Unimac UW30 washer and DTB50 dryer.

[b] The values include the price of equipment and services directly related to the various fabricare cleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333-pound (24,191-kg) annual volume of clothes cleaned per facility.

[c] List price of 35-pound perc drycleaning system includes control equipment, distillation unit, and filters; list price of 35- to 40-pound hydrocarbon drycleaning system includes control equipment, filters, and an explosion kit.

[d] Hazardous waste disposal costs for perc and hydrocarbon based on $6.94-per-gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates, hydrocarbon solvent waste may not be considered hazardous waste under the Resource Conservation and Recovery Act, therefore, this is a high-end estimate. Hazardous waste costs associated with spotting chemicals or certain detergent components are not included.

[e] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[f] Includes all operating costs and annual capital costs.

Figure 12: Maintenance Schedule for Drycleaning Equipment

Component	Frequency	Maintenance Procedure
Machine Component		
Dry-to-Dry Machine Cylinder	Weekly	Check door seatings and gaskets for leaks.
	Monthly	Check exhaust damper (vented machines) for leaks.
Transfer Washer/Extractor Cylinder	Weekly	Check door seatings and gaskets for leaks.
Transfer Dryer (Reclaimer)	Weekly	Check door seatings and gaskets for leaks.
	Monthly	Check exhaust damper for leaks.
Heating and Condensing Coils	Monthly	Check for lint build-up.
	Annually	Clean coils.
Button Trap	Daily	Clean strainer.
	Weekly	Check lid for leaks.
Fans	Annually	Inspect and lubricate.
Lint Trap	Daily	Clean lint bag, check lint build-up on temperature probe, and check ductwork for lint build-up.
	Weekly	Dryclean or launder lint bag.
Auxiliary Equipment		
Filters	a	Clean and change filters (filters drained and muck stored in sealed containers).
Distillation Unit	Bi-weekly	Check seals and gaskets for leaks.
	Monthly	Check steam and condensation coils.
	Semi-annually	Clean steam and condensation coils.
Muck Cooker	Monthly	Check steam and condensation coils.
	Semi-annually	Clean steam and condensation coils.
	Annually	Lubricate motor and gear box.
Water Separator	Weekly	Clean separator tank.
	Monthly	Check vent.
Pumps	a	Check for vapor and liquid leaks.
Tanks	a	Check for vapor and liquid leaks.
Control Device		
External Refrigerated Condenser	Daily	Clean any lint filters in air stream.
	Weekly	Measure temperature on exhaust for dry-to-dry machines/transfer dryer reclaimer. Measure temperature on inlet and exhaust for transfer washer.
	Weekly	Check seals, gaskets, and diverter valve for leaks.
	Monthly	Check refrigerant coils for lint build-up.
	Annually	Clean refrigerant coils.
Carbon Adsorber	Daily or before saturation	Desorb.
	Weekly	Measure concentration of perc in exhaust air stream or in machine drum, clean all lint filters, and check gaskets and ductwork.

Source: EPA, 1994.[a] Maintain according to manufacturer's or media supplier's specifications or recommendations.

Conclusion

Fabricare Industry Trends

Although the use of perc-based technologies continues to dominate the U.S. professional fabricare industry, the industry is undergoing significant change. Until as recently as 5 years ago, there were few to no hydrocarbon dry-to-dry machines or wetcleaning machines in use. Today, the major U.S. hydrocarbon equipment manufacturer is producing 60 percent hydrocarbon clothes cleaning machines and more than 30 commercial fabricare facilities are performing wetcleaning only.

The development of new and emerging solvents and cleaning processes was motivated by stricter state and federal regulation of perc, as well as by increasing evidence of perc's negative impact on human health and the environment. For example, many drycleaners are faced with the financial liability stemming from the cleanup of perc-contaminated soil and ground water surrounding their facilities. These concerns have made many property owners reluctant to renew leases or to rent to drycleaners (Lummis, 1996). Also, many states have imposed taxes on perc, resulting in as much as a twofold increase in perc prices.

The extensive adoption of wetcleaning and hydrocarbon solvents in Germany, in response to strict perc regulation, may perhaps indicate the level of adoption likely to occur in the U.S. However, direct comparisons among countries must be gauged within the context of differences in garment type, fabric type, lifestyle, geography, and climate. Further, differing perceptions of cleaning quality among countries will affect customer acceptance of new and emerging cleaning technologies.

Increasingly, fabricare professionals are proving that many garments that were traditionally drycleaned can now be wetcleaned effectively. Most professional cleaners possess a wetcleaning washer and dryer and wetclean a larger fraction of the clothing stream than 5 years ago (Seitz, 1995). A major challenge facing the professional fabricare industry is the continuing decline in the total volume of clothing being drycleaned. Several reasons have been cited for this decrease, including the increase in casual wear among office workers (Levine, 1997). The fabricare industry is addressing this phenomenon by attempting to broaden the services offered to customers. For example, some facilities emphasize pressing and finishing services rather than cleaning services.

The professional fabricare industry is also collaborating with clothing designers and apparel manufacturers in an effort to make fabricare considerations an integral part of textile and garment manufacturing decisions. By encouraging the use of fiber types, textile types, and garment construction methods that are compatible with all professional clothes cleaning techniques, the fabricare industry hopes to maintain and increase its economic viability.

Through the Agency's Design for the Environment (DfE) Program and its Garment and Textile Care Program (GTCP), EPA plans to continue partnering with the fabricare industry, textile manufacturers, and garment designers. EPA hopes that the efforts of the GTCP partnership will encourage improvement and expansion of new fabricare choices and remove barriers that prevent the adoption of economically viable cleaning processes that also offer environmental benefits.

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16. Abstract (Limit 200 words)

Recognizing that not all professional cleaners have the time to read the full fabricare CTSA, EPA prepared this summary document which was abstracted directly from that June 1998 publication (EPA 744-B-98-001). In this summary report, the reader is first introduced to the clothes cleaning industry and provided an overview of professional fabricare technologies. New and emerging technologies are also covered including liquid carbon dioxide (CO_2), ultrasonics, and solvents based on chemicals such as glycol ethers, although there is much less information available on these systems. Summary information is presented on release, exposure, health and environmental relative risk, selected federal regulations, costs, performance, process trade-offs, environmental improvement approaches, and industry trends. A complete list of references is included.

The Cleaner Technologies Substitutes Assessment (CTSA): Professional Fabricare Processes was developed as part of an effort to explore opportunities for pollution prevention and reduced exposure to traditional drycleaning chemicals (primarily perchloroethylene [PCE]). The intended audience for the CTSA is technically informed and might consist of individuals such as environmental health and safety personnel, cleaning facility owners, equipment manufacturers, and other decision makers. It is expected to be used as a technical supplement by USEPA and stakeholders to develop information products suitable for a broad audience. These products will help professional cleaners make informed technology choices that incorporate environmental concerns.

17. Document Analysis

a. Descriptors: Drycleaning, wetcleaning, clothes cleaning, perchloroethylene, PCE, perc, chlorinated solvents, hydrocarbon solvents, garment care, petroleum solvents, alternative solvents, alternative technologies, fabricare processes, fabricare technologies, dry cleaning, wet cleaning, propylene glycol ether, liquid carbon dioxide, DF 2000, ultrasonic cleaning, wetcleaning cost, drycleaning cost, Stoddard solvent, Rynex, drycleaning performance, wetcleaning performance.

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