Case Study:
Pollution Prevention in the Dry Cleaning Industry: A Small Business Challenge for the 1990s

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The dry cleaning industry is presently undergoing a significant transition. Due to existing and pending regulations, the industry is likely to lose much of its small business character. As the “mom and pop” nature of dry cleaners in business today changes, they will have to become more sophisticated and willing to invest in equipment to comply with more stringent governmental requirements.

Perchloroethylene (PERC) is the most widely used solvent in commercial dry cleaning. However, there is great regulatory pressure to reduce the use of this chemical, which is a suspect carcinogen. Although there are currently other solvents used in dry cleaning, none of the potential substitutes is likely to be adopted in place of PERC.

Indeed, all of these chemicals pose their own problems; some of them will be banned over the next few years and others have restrictions on their use. As a result, PERC will remain the most widely used solvent in dry cleaning, and pending air regulations will, instead, force a movement to use equipment that produces less emissions.

The most critical and problematic issue facing all dry cleaners today is the disposition of the water containing small PERC concentrations that are generated in the dry cleaning process. Historically, this water has been poured in the sewer, resulting in soil and groundwater contamination. Over the next few years, however, tougher regulations will discourage this practice and a better method of dealing with this water will have to be identified and implemented.

This article presents the options for reducing PERC use in the retail dry cleaning industry. It begins by presenting an overview of the various types of dry cleaners and the solvents that are most often used in the cleaning process. The sections that follow describe the equipment and processes, summarize the current and future regulations that affect dry cleaners, and analyze possible measures for
eliminating or reducing PERC use in dry cleaning. A final section evaluates key issues and problems faced by dry cleaners, and some strategic pollution prevention options that may be relevant to other small and medium-sized businesses.

Characteristics of the Dry Cleaning Industry

There are three types of dry cleaning establishments. The first type is the industrial facility, which provides rental services for items such as uniforms to commercial and industrial customers. The retail dry cleaner is the second and most common type of facility. The retail category includes small, independently operated neighborhood or franchise shops which offer such services as one-hour martining. Some retail dry cleaners provide specialty cleaning services like leather cleaning and fur cleaning. The third type of facility is the coin-operated unit, which is usually part of a laundromat that offers self-service dry cleaning.

The typical commercial dry cleaner processes 75,000 pounds of clothing annually. Some dry cleaners process as few as 50,000 pounds annually and other, much larger facilities process as much as 375,000 pounds. The average machine capacity is thirty-five pounds of clothing, but the size range can vary from twenty-five pounds to a hundred pounds.

Four solvents are used today to some extent in dry cleaning. PERC, as mentioned earlier, is the most widely used solvent. Petroleum solvents, which are flammable, are used in some locations where fire regulations do not restrict their use. Trichlorotrifluoroethane (CFC-113) is also used in the retail sector for dry cleaning specialty items. 1,1,1-trichloroethane (TCA) is used in fifty to one hundred commercial units nationwide.

There are some 34,000 dry cleaning facilities of all types in the United States today. (In California, there are at least 4,000 commercial dry cleaners, which implies that the official U.S. estimate may be too low.) The majority of these facilities—about 28,000—use PERC. The commercial dry cleaning sector accounts for approximately 90 percent of the industry, and about 25,000 of these dry cleaners use PERC. Annual consumption of PERC in the dry cleaning industry amounts to about 120 thousand metric tons. This article focuses on the use of PERC in the retail dry cleaning sector.

The Dry Cleaning Process

There are three categories of dry cleaning machines used in retail dry cleaning today.

1. In the transfer machine, the clothing is washed in one unit and physically transferred to a dryer for drying. Emissions from the washer and dryer can be uncontrolled or they can be routed to a control device.

2. In the dry-to-dry vented unit, the clothing is washed and dried
Nearly all dry cleaners use distillation to remove oils and fats from the solvent.

in the same cylinder. The PERC emitted from the unit can be uncontrolled or, again, it can be vented to a control device.

3. In the dry-to-dry closed loop unit, the wash and dry cycles also take place in the same unit. The PERC emissions are controlled within the unit itself with a refrigerated condenser.

At the beginning of the process, a small amount of detergent and water is added to the PERC. The garments are weighed and placed in the wash wheel of the dry cleaning machine. The tube of the dry cleaning unit fills with solvent and the wheel rotates. The wash cycle, which lasts five to ten minutes, is followed by a spin cycle to extract solvent from the garments. During the wash cycle, the solvent is recirculated from the unit tub to a filter to allow for continuous removal of the insoluble soils from the clothing. When the wash cycle is completed, the solvent drains through a valve on the bottom of the unit to a holding tank.

During the extraction step, the wheel is rotated at a higher speed and the solvent in the clothing is forced out by extraction and returned to the holding tank. Extraction can remove twenty-five to thirty gallons of solvent from a hundred-pound load of clothing. After extraction, perhaps one or two gallons of solvent remain in the clothing.

Recirculating warm air is used to dry the clothing. As air enters the tumbler, it passes through steam-heated coils, then through the clothing and, finally, to the exhaust fan. The drying cycle requires twelve to twenty-four minutes. The dryer exhaust is cooled to remove solvent and then reheated and recirculated to the dryer.

After drying, fresh air is circulated through the garments in the deodorizing or aeration step to remove excess solvent. This process helps to cool the garments to avoid wrinkling. The PERC-laden air is emitted directly to the atmosphere or it is vented to a control device.

Most dry cleaners use filtration to remove soils like dust, hair, and lint from the contaminated solvent. The most common method uses cartridge filters. Cartridge filters have a filter medium of activated carbon or activated carbon and clay. The solvent enters the filter through a perforated outer metal shell and is filtered by passing through a treated pleated paper. It then passes through a second metal filter containing activated carbon and a perforated center post covered with a fine mesh wrap. This cycle is repeated several times. About 90 percent of the dry cleaners use cartridge filters. The remaining 10 percent use either tubular filters, which are cleaned at the end of the day, or regenerative filters, which are refined tubular filters. In tubular and regenerative filters, diatomaceous earth and activated carbon generally form the filter element.

Nearly all dry cleaners use distillation to remove oils and fats from the solvent. After filtration, the solvent flows to the distillation unit where it is heated to between 190° F and 250° F, the boiling point of PERC. The PERC is condensed and recovered and the sludge that
The dry cleaning industry is increasingly being affected by more stringent environmental laws, especially in the regulatory bellwether state of California.

remains can contain up to 50 percent PERC. Some dry cleaners reclaim the PERC in a muck cooker or a cooker/still combination.

The filters and the still bottom are hazardous waste and are generally picked up by a service firm. These firms remove the hazardous waste and leave new drums for disposal every four to six weeks. The PERC is recycled by the recycling firms and sold back into the dry cleaning or metal cleaning markets to replace virgin solvent.

The solid materials remaining are incinerated.

Water is added to the PERC in small quantities to remove soils that are water soluble. Water is also produced during the cleaning process because it is brought in on the clothing. It is used to distill, cool, and reclaim the solvents. The contact water becomes contaminated with PERC and, generally, dry cleaners use a water separator to separate the PERC from the water. Even after decantation, PERC remains in the water at about the saturation level of 150 parts per million (ppm). Historically, dry cleaners have poured the so-called separator water into the sewer. In recent years, as described in more detail later, it has been shown that this practice has caused ground contamination at many dry cleaning sites. Apparently, the PERC travels through the concrete of the sewer into the soil and the groundwater below.

About 30 percent of the retail dry cleaners in the nation have transfer machines and about 70 percent have dry-to-dry units. In Southern California, a survey conducted three years ago indicated that 26 percent of the units were transfer machines, 21 percent were dry-to-dry vented units, and 53 percent were dry-to-dry closed loop units. Over the last few years, more dry-to-dry units have replaced transfer machines and today the fraction of dry-to-dry units in California may be even higher. All the dry-to-dry closed loop units have internal refrigerated condensers. Some dry-to-dry vented units and some transfer machines are routed to controls, either a refrigerated condenser or a carbon adsorber, and some are not. About 50 percent of the dry cleaning machines in the United States are vented to one of the control devices.

About half the emissions in the dry cleaning process are vented emissions. In transfer units, such vented emissions occur in the washer and the dryer. In dry-to-dry units, vented emissions occur during the drying cycle. The remaining half of the emissions are fugitive emissions from physical transfer of the clothing, process equipment leaks, and from storage of solid wastes.

Current and Future Regulations

The dry cleaning industry is increasingly being affected by more stringent environmental laws, especially in the regulatory bellwether state of California. The existing and impending federal laws discussed in detail below focus on the workplace, air emissions, waste generation, and water. In many cases, the California regulations are featured.
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Worker exposure
On January 19, 1989, the Occupational Safety and Health Administration (OSHA) adopted a 25 ppm permissible exposure level (PEL) for PERC. PERC is a suspect carcinogen and the OSHA action is intended to minimize worker exposure to the chemical. Before December 31, 1993, dry cleaners can meet the mandated PEL by using personal protective equipment (respirators). After that date, however, the PEL must be met with controls. OSHA claims it is feasible for the dry cleaning industry to achieve the 25 ppm PEL with a dry-to-dry machine using engineering controls like a carbon adsorber or refrigerated condenser and work practice controls. Transfer units, even if they are controlled, are unlikely to be able to meet the PEL unless throughput is restricted.

Air regulations
PERC is currently regulated under Section 111 of the Clean Air Act (CAA) as a precursor to photochemical smog. EPA regulates PERC as a photochemically reactive substance and has developed control technology guidelines (CTGs) that establish standards to be used by state agencies in the development of state implementation plans (SIPs). Local air districts also generally regulate PERC as photochemically reactive and may have rules that specify control technology for the dry cleaning industry. Nevertheless, there has been evidence for several years that PERC is not photochemically reactive and EPA has recently granted a petition that will exempt PERC from regulation under the Clean Air Act.

The Montreal Protocol currently calls for a worldwide ban of CFC-113 and TCA, two of the potential alternative solvents to PERC in dry cleaning. Title VI of the CAA Amendments of 1990 also calls for a ban on the CFCs in 2000 and TCA in 2002. President George Bush announced in February 1992 that the ban on the CFCs and TCA would be effective in the United States on December 31, 1995. At an international meeting scheduled for later this year, the worldwide ban date is likely to be accelerated to the date announced by President Bush.

Section 112 of the CAA as amended in 1990 (Title I) contains a list of 190 hazardous air pollutants for which EPA must develop national emission standards. EPA was required to propose regulations on PERC in dry cleaning by November 1991 and intends to promulgate standards by November 1992. The proposal requires no controls for existing transfer machines using less than 300 gallons a year or existing dry-to-dry machines using less than 220 gallons a year. Dry cleaners with dry-to-dry machines using more than 220 gallons a year of PERC would be required to install a carbon adsorber, refrigerated condenser, or equivalent control device. Dry cleaners with transfer machines using between 300 and 2,000 gallons a year of PERC would be allowed to continue using refrigerated condensers, but existing uncontrolled units and new units would be required to...
have carbon adsorbers. Dry cleaners using units with capacity greater than fifty pounds would have to comply within eighteen months of promulgation (about May 1994). Compliance for machines with capacity less than fifty pounds would be required within thirty-six months (approximately November 1995).

The EPA-proposed regulations under Title III of the CAA are quite permissive and, in California, upcoming state and local laws are likely to override the impending EPA rule changes. The California Air Resources Board (CARB) declared PERC a toxic air contaminant (TAC) on October 10, 1991, and is now in the process of developing regulations for the dry cleaning industry. These regulations are likely to be much stricter than proposed rules under Title III of the CAA and may require all dry cleaners in the state to adopt dry-to-dry closed loop systems. In areas where California's local air district regulations have historically been fairly strict, the EPA regulations will have virtually no effect.

The CARB will hold three important meetings in 1992; the first two, to be held in the spring and summer, will focus on preparing draft regulations and a technical background document. In the fall, CARB will hold a hearing at which it will release the proposed regulation and the final technical reports and take public comments. The Board will make a decision at this hearing.

The effective date of the regulation will be during the summer of 1993. At that time, the local air districts in California will adopt CARB regulations and the sources of pollution may be expected to comply by 1994 or later, as stated in the final regulation. The local districts must implement a regulation as demanding or more stringent than the CARB requirements.

The CARB regulation will probably be control technology-based, which means that it will specify the controls dry cleaners must adopt. In contrast, some local air districts in California also have in place, or plan to implement, risk-based regulations for the dry cleaning industry. Although the risk posed by PERC is currently in contention, if a new risk factor that is fourteen times higher than the current risk factor is adopted, virtually no new dry cleaners will be able to be sited in California because dry cleaner emission levels, in most cases, would exceed the allowable risk. Even existing facilities, in certain instances, may be required to shut down.

The new regulations on PERC will affect dry cleaners currently using CFC-113 and TCA. Because these latter chemicals will be banned, dry cleaners using them will have to purchase new equipment and convert to PERC and, in California, they may not be granted a permit to do so. The concern of the local air district is to minimize emissions of photochemically reactive substitutes because they contribute to smog.

**Hazardous waste regulations**

Still bottoms, cartridge filters, and filter muck are regulated as
hazardous waste under the Resource Conservation and Recovery Act (RCRA). Dry cleaners who generate 100 kilograms (220 pounds) or more of such waste each month are regulated under RCRA and must dispose of their wastes at a licensed hazardous waste facility. Most dry cleaners generate between 100 and 1,000 kilograms of waste each month and are regulated as small-quantity generators under RCRA. Land disposal of the PERC was banned in 1986 and recyclers commonly pick up the dry cleaning waste and reclaim it for reuse. The residue from the recycling process is generally incinerated.

**Water regulations**

On November 23, 1988, EPA proposed amendments to the wastewater regulations which affected dry cleaners who generate 100 kilograms of hazardous waste each month. Dry cleaners are required to notify publicly owned treatment works of the type, volume, and concentration of hazardous waste they produce. The slightly contaminated wastewater generated by dry cleaners from various sources is considered hazardous waste under RCRA because it was derived from an F002 waste. The toxicity characteristic leaching procedure (TC) cutoff for PERC is very low—at 0.7 ppm. The separator water, which contains about 150 ppm, is therefore hazardous waste under the “derived-from” rule and because it exceeds the TC level.

Because dry cleaners have historically poured the separator water into the sewer, there is good evidence, at this stage, that PERC has made its way through the concrete in the sewers into the soil and, in some cases, particularly in California, into the groundwater. In response, the Regional Water Quality Control Boards in some California communities are requiring dry cleaners to perform soil borings to determine if the PERC is present. Dry cleaners may be required to clean up the contaminated sites at a high cost. Local sanitation districts are also beginning to pass laws preventing dry cleaners from pouring their water into the sewer.

**Measures for Reducing/Eliminating the Use of PERC**

There are a variety of options that could be effective in reducing or eliminating the use of PERC in dry cleaning. One choice for eliminating the use of PERC is to use only fabrics that do not need dry cleaning. However, this option is not realistic, as it would require dramatic changes in the way people take care of clothing. Another way to eliminate PERC use is to substitute a different dry cleaning agent for the chemical.

The options for reducing the use of PERC in dry cleaning by lowering emissions include (1) purchasing more efficient equipment, (2) adopting emission controls in the case of uncontrolled units, and (3) adopting additional emission controls. Means to reduce the PERC generated as hazardous waste include (1) use of steam distillation, (2) use of disc filtration, and (3) purchasing a unique filtration/distillation machine added to any dry-to-dry or transfer cleaning unit. Two
options for handling the separator water—purchasing an evaporator and shipping the water off-site as hazardous waste—are also identified. The options for eliminating or reducing PERC use are evaluated below.

**Substitute alternative chemicals**

Potential alternatives to PERC in dry cleaning include solvents in use to some extent today, including petroleum solvents, CFC-113 and TCA, solvents like CFC-11 that were once used, and new solvents including certain HCFCs and HFCs.

For a solvent to perform as an acceptable dry cleaning agent, its properties should be similar to those of PERC, which is an excellent dry cleaning agent. *(Table 1)* lists these solvents and compares certain aspects of their properties with the characteristics for PERC. In particular, an effective dry cleaning solvent must be able to easily remove oils and fats, which are the principal contaminants. The Kauri Butanol (KB) number is a rough measure of the solvency of a chemical. In general, the higher the KB value, the stronger the solvent. For dry cleaning, the KB value should lie between thirty and one hundred. Solvents with KB values below thirty make very poor cleaners; solvents with KB values above one hundred will dissolve the dyes used in clothing.

Other desirable properties include a heat of vaporization that is less than 180 BTUs per pound so that rapid evaporation of solvents from the clothing will occur. A solvent must not leave an odor in the garments and it should be easily distilled. It should not be readily absorbed onto the textile fibers; it should have a low viscosity so it will flow well in the equipment; and its density should differ from that of water so it can be separated easily. The solvent should not weaken, dissolve, shrink textile fibers, or cause bleeding of dyes, and it should be compatible with commonly used detergents. It must be noncorrosive to textiles and metals of construction in dry cleaning equipment. The boiling point of the solvent should be between about 100°F and 300°F so that simple distillation (rather than vacuum distillation) can be performed. Finally, the solvent should ideally have no flash point.

As indicated in Table 1, the KB values of CFC-113, Stoddard solvent and 140F are quite low—in fact, they are at the low end of the acceptable KB range. All three solvents have traditionally been used to clean delicate clothing. Although they are sometimes used to clean other items, their solvency for contaminants is not high. CFC-113, in particular, is a very gentle solvent that would not remove heavy soils well. HCFC-225 has a KB value in the same range as CFC-113, making it less desirable as a replacement for the much stronger cleaner PERC. TCA’s KB value is relatively high and it is a good solvent. The KB values for HCFC-141b and HCFC-123 have not been measured, but they are estimated to lie between those of CFC-113 and TCA and would likely be acceptable cleaners.
Table 1. Characteristics of Dry Cleaning Solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Chemical Formula</th>
<th>Kauri Butanol Value</th>
<th>Heat of Vaporization (BTU/lb)</th>
<th>Boiling Point °C (°F)</th>
<th>Flash Point °C (°F)</th>
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</thead>
<tbody>
<tr>
<td>PERC</td>
<td>CCl₂CCl₂</td>
<td>92</td>
<td>90</td>
<td>121.1 (250)</td>
<td></td>
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<tr>
<td>CFC-113</td>
<td>CCl₂FCCl₂</td>
<td>31</td>
<td>63</td>
<td>47.6 (118)</td>
<td></td>
</tr>
<tr>
<td>CFC-11</td>
<td>CCl₃F</td>
<td>60</td>
<td>77.5</td>
<td>23.8 (75)</td>
<td></td>
</tr>
<tr>
<td>TCA</td>
<td>CCl₃CH₃</td>
<td>124</td>
<td>104</td>
<td>75 (167)</td>
<td></td>
</tr>
<tr>
<td>Stoddard</td>
<td>Mixture</td>
<td>32-36</td>
<td>118</td>
<td>154.4 (310)</td>
<td>39 (103)</td>
</tr>
<tr>
<td>140F</td>
<td>Mixture</td>
<td>34-39</td>
<td>NA</td>
<td>185 (365)</td>
<td>60 (138.2)</td>
</tr>
<tr>
<td>HCFC-141b</td>
<td>CCl₃FCH₃</td>
<td>60-70 (est.)</td>
<td>95.4</td>
<td>43 (89.6)</td>
<td></td>
</tr>
<tr>
<td>HCFC-123</td>
<td>CHCl₃CF₂</td>
<td>60-70 (est.)</td>
<td>74.9</td>
<td>28.7 (83.7)</td>
<td></td>
</tr>
<tr>
<td>HCFC-225</td>
<td>Mixture of Isomers</td>
<td>30-34</td>
<td>NA</td>
<td>51.5-56.1 (124-133)</td>
<td></td>
</tr>
</tbody>
</table>

*Various petroleum fractions.

bFlammability limits, volume percent in air; upper = 12.5 percent, lower = 7.5 percent.

cFlammability limits, volume percent in air; upper = 17.7 percent, lower = 7.6 percent.

Mixture of HCFC-225ca (CF₃CFCHCl) and HCFC-225cb (CClCFCHClF)

Stoddard solvent and 140F have high boiling points, indicating that significant energy is required to distill them. A vacuum still would perform better on these chemicals than a simple pot still. PERC has a relatively high boiling point; the boiling points of TCA, CFC-113, and HCFC-225 are best for a dry cleaning solvent. As the values of Table 1 indicate, the boiling point of CFC-11 is much lower (it is nearly a gas at room temperature), so losses of the chemical in dry cleaning are very high. Both CFC-11 and the HCFCs have boiling points that are too low for an acceptable dry cleaning solvent. Given the high losses from CFC-11 and the HCFCs in existing dry cleaning equipment, the machinery would have to be designed to minimize emissions from these chemicals.

CFC-113 is employed primarily for delicate items and less for general cleaning. Only dry-to-dry equipment is used for CFC-113 because of its low boiling point and high price. TCA is also currently used to a limited extent in dry cleaning. CFC-11 was once used as a dry cleaning agent in Europe. Its major drawback (in addition to its low boiling point) is that it will be banned in the United States on
December 31, 1995. Likewise, CFC-113 and TCA will be banned in this country in 1995. Therefore, none of these chemicals can be considered a feasible alternative to PERC.

Stoddard solvent is used today by many dry cleaners, primarily in the Gulf Coast states. Cleaning must be performed in explosion-proof machines because of the low flash point of the solvent. Local fire codes may prohibit use of the solvent altogether; other local codes may require extensive building modifications to accommodate use of the highly flammable material. Local city ordinances frequently also prevent use of Stoddard solvent.

EPA and most local air districts have stringent regulations on petroleum solvent dry cleaners because the solvent is photochemically reactive. Although PERC is currently regulated as a photochemically reactive material, a petition to exempt it from this regulation has been granted. Unless it is highly refined, petroleum solvent can contain benzene fractions, and benzene is considered to be a human carcinogen.

The flammability and photochemical reactivity of petroleum solvents make it improbable that the substance could be adopted in place of PERC on a wide scale. Most dry cleaners are conveniently located near housing, and local regulations are likely to prevent the use of flammable materials. Indeed, there has been a movement away from petroleum solvent use to PERC over the last several years.

A few dry cleaners employ 140F. It is so named because its flash point is 138.2°F, which is higher than the flash point of petroleum solvent. 140F is a particular distillate of petroleum solvent (a cut of the higher boiling range materials) and is a somewhat safer solvent than petroleum because of the higher flash point. Its use is allowed in certain areas where petroleum solvent use would not be permitted. Nevertheless, it is still a combustible solvent and cannot be used in most areas of the country. Like petroleum solvent, 140F is photochemically reactive and heavily regulated for that reason.

The major drawbacks to 140F as a PERC replacement are the worker danger and the smog regulations. As is the case for petroleum solvents, substantial institutional changes would be required to allow widespread use of the solvent.

As shown in Table 1, there are three HCFCs with properties that make them potential alternatives to PERC in dry cleaning. Commercial production is just beginning for two of these, HCFC-123 and HCFC-141. Unlike the CFCs, the HCFCs contain hydrogen, which means they are less stable in the atmosphere and break down in the lower atmosphere more readily than the CFCs. Under the Montreal Protocol, the HCFCs are slated to be banned in the 2020 to 2040 time frame because they do contribute to ozone depletion. At the international meeting scheduled for later this year, it is likely that the phaseout date for the HCFCs will be accelerated.

All three of the HCFCs are undergoing toxicity tests which are being sponsored by a consortium of CFC manufacturers. Initial
results for HCFC-123 indicate that the chemical causes benign pancreatic and testicular tumors in male rats. DuPont, one of the manufacturers, has assigned the chemical a worker exposure level of 10 ppm. This will preclude its use in solvent applications. A European equipment manufacturer has designed a dry cleaning machine for use with HCFC-123, but because of the low worker exposure level, the chemical will not be marketed in dry cleaning.

The ozone depletion potential of HCFC-141b has been found to be very high. It is higher than that of TCA, which will be banned in 1995. Because ozone depletion is more serious than was previously thought, EPA probably will not allow the use of HCFC-141b in solvent applications. An additional technical drawback is that although HCFC-141b has no flash point, it would become flammable in the concentrations required in dry cleaning equipment.

HCFC-225 is a product being offered by Asahi Glass, a Japanese CFC manufacturer. It has properties that are very similar to those of CFC-113 so, in principle, it could function as a dry cleaning agent. It is produced in two isomers, one of which is toxic. It is not clear whether the desired isomer could be selectively produced cost-effectively. The chemical is still in toxicity testing and it probably will not be available on a commercial scale until 1997. Because it may be banned over the next several years for its contribution to ozone depletion, it is not a promising substitute for PERC in dry cleaning.

Other potential alternatives include new classes of chemicals: the hydrofluorocarbons, or HFCs, and the fluorocarbons, or FCs. These chemicals contain no chlorine, so they do not deplete the ozone layer. They do, however, contribute to global warming and may ultimately be regulated for this reason. A technical drawback of the materials is that they are better displacement solvents than cleaning solvents and, because they do not clean effectively, they probably would not serve as good solvents for dry cleaning.

**Purchase better equipment**

Given that there are no viable alternatives to PERC, the adoption of better equipment is the most promising solution for minimizing emissions from the chemical. Perhaps 30 percent of the dry cleaners have older transfer machines, and some of the remaining 70 percent have dry-to-dry vented units. The dry-to-dry closed loop units are the best technology, and dry cleaners can reduce emissions and use of PERC substantially by converting to these units.

Dry cleaners have three options. First, cleaning establishments with transfer or dry-to-dry vented units can purchase a new dry-to-dry closed loop machine at a cost of between $40,000 and $60,000. Second, dry cleaners with transfer units can purchase a reconditioned unit for $18,000 to $22,000, less than half the cost of a new machine. Old discarded dry-to-dry vented units can be converted to closed loop units, reconditioned, and sold at a much lower price than a new unit. Third, dry cleaners with dry-to-dry vented units can have their
machines converted to dry-to-dry closed loop units at a cost of $6,000 to $10,000. Transfer machines cannot be converted to dry-to-dry closed loop units because the cost would be too high.

One dry cleaner converted from a transfer machine to a reconditioned dry-to-dry closed loop machine at a cost of $22,000. The PERC use declined from 900 to 180 gallons a year, a reduction of 80 percent. At a PERC price of about $4.30 a gallon, the annual savings in avoided PERC purchases is approximately $3,100. The payback period is slightly more than seven years.

A second dry cleaner converted a dry-to-dry vented unit to a dry-to-dry closed loop unit at a cost of $6,500. The PERC use declined from 700 to 200 gallons, for a net annual savings in PERC purchases of $2,150. In this case, the payback period is about three years. A third dry cleaner purchased two new dry-to-dry closed loop units to replace two dry-to-dry vented units at a cost of $80,000. The PERC use declined from 1,400 to 450 gallons per year. The savings in PERC purchases amounted to about $4,100 annually, establishing a payback period of roughly twenty years.

The examples above demonstrate the dramatic reductions in PERC use that can be achieved by adopting dry-to-dry closed loop units. In California, the Department of Commerce is offering low-interest loans for small businesses and dry cleaners that can qualify for very low interest rates to purchase new or reconditioned equipment, or to convert existing equipment.

Adopt emission controls

About half of the existing stock of dry cleaning equipment nationwide is currently uncontrolled. That is, the emissions from transfer units and from dry-to-dry units are vented directly to the atmosphere. The dry cleaners without controls could purchase a carbon adsorber or a refrigerated condenser to control emissions. Carbon adsorbers operate by adsorbing the PERC to the surface of a bed of activated carbon. Regeneration of the carbon is generally accomplished by using steam, and the water/PERC mixture that collects is separated by decantation. The PERC is reused in the cleaning process and the contaminated water has traditionally been poured into the sewer. In some cases, carbon adsorbers are directly plumbed to the sewer. The capital cost of a typical carbon adsorber is about $7,000. They are capable of reducing process emissions by 95 percent when used with both transfer and dry-to-dry units.

In the case of transfer units, refrigerated condensers remove condensible vapors (PERC and also water that might be present) from the exhaust streams of washers and dryers, or from the cylinder of a dry-to-dry vented unit. The solvent-laden air is cooled to lower the temperature of the air below the dew point of the vapor, which causes it to condense. Refrigerated condensers are capable of achieving only 85 percent efficiency for transfer units, but the efficiency is high (95 percent) for dry-to-dry machines. It is for this reason that EPA's
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Proposed regulations would require transfer machines to adopt carbon adsorbers rather than refrigerated condensers. However, the advantage of refrigerated condensers over carbon adsorbers is that they require less maintenance—desorption is not required—and they do not generate large quantities of contaminated water. The capital cost of a condenser ranges from about $6,000 to $10,000, depending on the size of the machine requiring controls.

The proposed EPA regulations, evaluated from the perspective of wastewater generation, probably should not require the use of carbon adsorbers for transfer machines. As discussed later, carbon adsorbers generate 1,500 gallons of contaminated separator water annually, compared with the fifty gallons created by refrigerated condensers. But the advantage of the adsorber's greater efficiency in reducing PERC emissions may be outweighed by the disadvantage of the increased volume of separator water it produces.

As described earlier, the cost of retrofitting a dry-to-dry vented unit to a closed loop unit is between $6,000 and $10,000. The capital cost of a carbon adsorber or refrigerated condenser is in the same range. It is reasonable to expect that dry cleaners with dry-to-dry vented units would always choose the retrofit option because their PERC use could be reduced further than by simply adding a control device.

The cost of purchasing a new closed loop machine is in the $40,000 to $60,000 range. A less costly option for a transfer machine owner would be to purchase a reconditioned dry-to-dry closed loop unit for $18,000 to $22,000. An even less costly option would be to purchase a carbon adsorber for $7,000. The latter option would likely reduce PERC use less than purchasing a new or reconditioned unit. The savings, nevertheless, would still be substantial. For transfer machine owners who do not have the capital, or cannot obtain a loan to purchase a reconditioned unit, the carbon adsorber is a reasonable choice.

**Adopt additional emission controls**

Other systems that can achieve even greater recovery of vapor emissions than the closed loop equipment are available. In closed loop machines, the PERC that is left in the cylinder after the wash/dry cycle is emitted when the door is opened to remove the clothing. One German manufacturer offers add-on or an original purchase machine that routes the PERC in the cylinder of a dry-to-dry closed loop unit to a carbon adsorber. The machine, the Permac Consorba, thus has a carbon adsorber used sequentially in the same configuration with a refrigerated condenser. There are presently about five units operating in this country and another will be installed in Southern California over the next few months.

The add-on feature is reported to cost about $15,400, but data on the PERC use reductions that can be achieved are not available. The manufacturer claims that the Consorba achieves more than the 95%

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*Other systems that can achieve even greater recovery of vapor emissions than the closed loop equipment are available.*
percent efficiency that can be obtained with a refrigerated condenser or carbon adsorber alone. The manufacturer also claims that it can reduce PERC use by about 50 percent in a dry-to-dry closed loop unit. A disadvantage of the system is that it requires five or six additional minutes to complete a cycle.

Dry cleaners with dry-to-dry closed loop units use between one hundred and two hundred gallons of PERC annually, depending on the size of the dry cleaning machine. Use of the Consorba may reduce use by fifty to one hundred gallons a year. At a PERC cost of $4.30 a gallon, this amounts to a savings of $215 to $430 a year. Using the higher figure and assuming a cost for the Consorba of $15,400, the payback period would be thirty-six years. This simple analysis does not consider the advantages of the Consorba in enabling compliance with future air regulations or the avoided costs for future fees that might be levied on PERC, particularly in California. Nonetheless, the Consorba is very expensive and is not likely to prove cost-effective for most dry cleaners.

The Diversitron Solvation Recovery System is another add-on control device. The process is substituted for the normal deodorizing and aeration cycle in a machine, and it involves passing the PERC vapors through a tank filled with water and an antifoaming agent. The manufacturer claims that the system reduces PERC atmospheric losses. Such systems, if used alone, apparently achieve only about an 84 percent efficiency. If they are used in conjunction with a carbon adsorber, a 95 percent efficiency is obtained. The 84 percent efficiency will not satisfy the proposed EPA regulations for hazardous air pollutants. The 95 percent efficiency is no greater than a carbon adsorber, or a refrigerated condenser alone, so there is no benefit to using the device.

**Employ steam distillation**

Dry cleaning waste consists of still bottoms from distillation and the spent cartridge or regenerative filters. Many dry cleaners practice steam distillation, where steam is injected into the bottom to recover more PERC. The water and PERC form an azeotrope which boils at about 190° F, well below the 250° F boiling point of PERC. The water/PERC mixture that is separated from the less volatile contaminants is collected and decanted to separate the PERC and the water. The PERC can be reused in the cleaning process.

The disadvantage of this option is that a secondary water stream contaminated with PERC at the saturation level of 150 ppm is generated. As discussed later, the disposition of this water is the major issue facing dry cleaners today.

**Adopt disc filtration**

As many as 90 percent of dry cleaners use cartridge filters. Disc filtration is an alternative to cartridge filters. The system is composed of a hard screen in the form of a tubular canister. Inside the canister,
several discs with fabric (nylon) filters are lined up in a row. The dirty solvent flows through the discs which, in some cases, contain a filter medium like diatomaceous earth or, in other cases, are powderless. Periodically, when the canister is full, the solvent is emptied and the canister is spun. This action slings the soils containing PERC into the still where the usable PERC is recovered.

For a dry cleaning machine with a capacity of thirty-five or forty pounds, a standard filter/still module would cost about $7,500. For machines with fifty pounds or more of capacity, the cost would be higher, between $12,000 and $17,000. Waste disposal costs can be reduced by about half through use of these filters.

A more sophisticated disc filtration system called the Hydro-Tek is available. Instead of a fabric filter, this system employs a permanent steel filter which the manufacturer claims gives a much better filtration surface. During cleaning, the filter discs are rotated at high speed and the filter drain valve is opened to allow the sludge to drop into the still. After draining is complete, the filter drain valve is closed and the filter is refilled with diatomaceous earth and put back in operation. The still contains an auger which is activated for forward and reverse mixing during the distillation step. After an initial distillation, the system performs a steam sweep distillation. After separation from the PERC, which is reused in the dry cleaning process, the water is recycled for reuse in the next steam sweep pass. When the still is cool, the auger action causes the dry solids to be placed into a bag which is removed for disposal. The cost of disposal of hazardous waste for a typical dry cleaner is about $1,500 annually.

Manufacturers of the Hydro-Tek system claim that waste disposal costs are reduced substantially from the standard cartridge filter system. One dry cleaner who has implemented the system claims he has saved about $200 a month in disposal costs. The cost of the Hydro-Tek system is very high, at $20,000, and it may not be cost-justified for most dry cleaners.

**Purchase a filtration/distillation machine**

One unique machine purportedly eliminates hazardous waste generation altogether. Like the Hydro-Tek unit described above, it employs a permanent steel filter and uses azeotropic distillation. It can be added to any transfer or dry-to-dry unit and it bypasses the filtration and distillation in the existing machine. The contaminants—the hair, particles, and body oil—are flushed into the sewer with the water used to backflush the filter and to perform the distillation. The manufacturers claim that the PERC concentration in the effluent can be lowered to 5 parts per billion. The $31,000 cost of the unit is very high. If all hazardous waste generation is eliminated, then a typical dry cleaner would save $1,500 a year in waste disposal costs and the payback period would be more than twenty years.

Apart from the high cost, there is a strong disadvantage to the DCI unit. PERC is released to the sewer and, as discussed below, it may be
Industry representatives are also warning dry cleaners against pouring the water into the sewer, and some establishments are taking action.

unwise to release PERC in even small concentrations to the sewer. Still, the concept has merit and it will be demonstrated in the Southern California area to determine the PERC concentration in the effluent and to assess its advantages and disadvantages. Once the tradeoffs are better understood, an equipment manufacturer might use the information to design a new dry-to-dry closed loop unit that incorporates the good features of the DCI unit into the design from the outset. That way, the total system would be less costly because the filtration and distillation functions would not be redundant.

**Purchase an evaporator**

A typical dry cleaner with a refrigerated condenser generates about a gallon of “separator water” contaminated with PERC at the 150 ppm level each week. This amounts to about fifty gallons of separator water a year. A typical dry cleaner with a carbon adsorption unit might generate fifteen gallons of contaminated water twice a week for an annual generation of about 1,500 gallons. A large dry cleaner with a carbon adsorption unit might generate twice as much contaminated water, about 3,000 gallons a year. Dry cleaners therefore generate between about fifty and 3,000 gallons of water a year containing between 0.1 and six pounds of PERC.

Many dry cleaning sites are contaminated in California (and elsewhere), because the separator water was historically poured into the sewer. The Regional Water Quality Control Board in California has found PERC contamination in wells in many locations, and in some cases, they have traced the contamination to specific dry cleaning plants. Dry cleaners are being required to do well-borings to determine if the soil is contaminated. If the contamination reaches to the groundwater, dry cleaners may be required to clean it up. Because dry cleaners are generally small businesses, the industry is aware that they must have assistance in the cleanup. Various mechanisms for establishing funds for cleanup are being explored.

Industry representatives are also warning dry cleaners against pouring the water into the sewer, and some establishments are taking action. Some still use the sewer to dispose of separator water; some reportedly pour it in their cooling towers. Others boil the water off in the still or put it in the boiler.

Vendors are offering so-called evaporators for handling the separator water. These evaporators contain a carbon filter through which the contaminated water is passed. Most of the PERC is adsorbed to the filter. The water, which still may be lightly contaminated with PERC, is then boiled off and the water and remaining PERC evaporate. One of these devices contains a carbon filter to capture the PERC before it is emitted to the atmosphere, but the other device does not. The TC cutoff level for PERC is 0.7 ppm. Before the PERC enters the filtration step, it has a much higher concentration, about 150 ppm. It is definitely hazardous waste at that stage. After the water exits the filter and before evaporation, it is not known what the PERC concen-
tration is. If it is above 0.7 ppm, then it is still considered hazardous waste during the evaporation step.

In California, many of the local air districts and the California Air Resources Board oppose the use of evaporators because the PERC is boiled off and emitted to the atmosphere. The California Department of Toxic Substances Control (DTSC) is evaluating the evaporators and has concluded that they constitute treatment. This implies that dry cleaners with such units require a treatment permit or a variance. In California, it is almost impossible to obtain a full treatment permit because of the public involvement, and dry cleaners would not be able to demonstrate the financial responsibility that would be required.

The DTSC has recently adopted a program called Permit By Rule (PBR). It was designed to bring certain treatment processes into a special category that would have more lenient requirements than a full treatment permit. Adsorption—the first step in the evaporator treatment process—is included under PBR. Evaporation—the second step—is not included under PBR. In California, evaporators would be covered under PBR if the PERC content of the water after adsorption were below 0.7 ppm. If the PERC content were higher, then a full treatment permit would be required.

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In response to an informal request, EPA evaluated the process. Although the agency admits that the evaporator falls into a gray area, the water is definitely hazardous on two counts. First, it exceeds the TC cutoff level when it enters the device. Second, it is a “derived-from” waste. That is, the contaminated water is derived from an RCRA F002 waste. Thus, it appears that under RCRA, the water is hazardous waste before it goes through the adsorption step and also before it is evaporated, regardless of the PERC concentration. This suggests that an RCRA treatment permit would be required by dry cleaners to use the device. The Institute for Research and Technical Assistance has asked EPA for a formal ruling to resolve the issue definitively.

The other methods dry cleaners are using to handle the separator water constitute treatment of a hazardous waste as well. This will be the case unless the PERC and water are “recycled” rather than treated. It is not obvious how the process might be changed so it could be reclassified as recycling.

The carbon filter in the evaporators must be discarded as hazardous waste when it is saturated with PERC. Dry cleaners often do not desorb carbon adsorbers as frequently as they should and, as a result, PERC emissions are uncontrolled. In the case of the evaporators, dry cleaners may not change the filter as often as required. One way of dealing with this issue is to have recyclers offer to change the filter for the dry cleaner periodically and dispose of the contaminated filters properly as hazardous waste.

Over the next few months, the issue of evaporators will require resolution in California. On the one hand, the local sanitation districts do not want dry cleaners to pour contaminated water into the sewer, which is their jurisdiction. The sanitation districts favor evaporators.
The air districts do not like evaporators because the PERC enters the medium over which they have jurisdiction—the air.

The DTSC, and perhaps EPA, cannot allow dry cleaners to use evaporators as they are currently constructed unless they have a permit or a variance because the water they are treating is hazardous waste. A meeting of the regulators must be convened. The attendees should focus on identifying the best technical method of dealing with the separator water that also minimizes environmental damage. Then legislation could be written to ensure that appropriate changes to the law are made.

**Ship contaminated water off-site**

Currently the only legal way of handling the separator water is to send it off-site as hazardous waste. Recycling firms will take the water with the still bottoms and the filters at a cost of about $4 a gallon. For dry cleaners who generate fifty gallons a year, the cost—$200—is not unreasonable given that the waste disposal cost for a typical dry cleaner is about $1,500 a year. For dry cleaners who generate 3,000 gallons a year, however, the disposal cost of $12,000 would be prohibitive.

**Regulation and the Industry Outlook**

Over the next several years, the regulations on dry cleaners are expected to become increasingly stringent. PERC, the solvent used in dry cleaning, is a suspect carcinogen and is defined as a hazardous air pollutant requiring controls under the Clean Air Act. In California, PERC is designated as a toxic air contaminant, and the Air Resources Board is in the process of evaluating much stricter controls. Also in California, many of the local air districts are implementing risk-based rules that could prevent new dry cleaners from opening and might even close down those that are operating today.

Most dry cleaners in California have polluted sites because the PERC they poured into the sewer made its way through the concrete, into the soil and, in some cases, into the groundwater. A method of avoiding some of the problems caused by the regulations would be to adopt a chemical alternative to PERC. As this article demonstrates, however, although there are certainly several technically suitable alternatives that are used today, they all pose health or environmental problems of their own. Because of the characteristics of the new chemicals that are entering the market, it is unlikely that any of them will prove suitable as a substitute, either.

Changes in workplace exposure and air regulations over the next several years will force dry cleaners to use more conservative equipment. New dry-to-dry closed loop units are expensive and cost between $40,000 and $60,000. But there are other less expensive, feasible alternatives. Reconditioned closed loop units are less than half the cost, and dry-to-dry vented units can be converted to closed loop units for $6,000 to $10,000.
The new disc filtration systems result in the generation of less hazardous waste. Filter/still modules can be purchased for $7,500 to $20,000, and they can reduce disposal costs substantially.

In California, the issue of the separator water disposition is urgent. Most dry cleaners have contaminated sites and they may be required to pay substantial cleanup costs over the next several years. The industry has advised against pouring additional separator water into the sewer to prevent future contamination. But the only legal way to dispose of the separator water currently is to ship it off-site as hazardous waste. This can be very expensive for dry cleaners with carbon adsorbers. The evaporators being marketed constitute treatment and require a permit or a variance. In the future, a major challenge for the industry will be to identify a method of allowing dry cleaners to manage the disposal of separator water.

Concluding Lessons

The experiences of the dry cleaning industry described in this article are important examples for other industries dominated by small firms. On a fundamental level, the increasingly stringent regulations will impose new environmental mandates that will require a more sophisticated response. As a result, some of the small-business character of the industry—and others like it—may be lost.

Several other themes also emerge from the analysis presented here. First, the increasing use of risk-based environmental rules at the state and local level will have an adverse impact on small firms and may even cause many to close down. For example, furniture refinishers who employ methylene chloride (a suspect carcinogen) for stripping wood furniture may have difficulty meeting risk-based standards. Service stations, which emit benzene—an established human carcinogen—will also be strongly affected. Dry cleaners, furniture refinishers, and service stations pose high risks to the surrounding communities primarily because they are located very near housing. This was done so that these businesses could offer convenient services to the community. Now they may be penalized for serving their customers too well.

Second, small firms are less equipped to deal with the maze of complex regulations that are in place today. Dry cleaners currently have no cost-effective way of treating their separator water. Evaporators, which could be a reasonable solution, will likely require a full treatment permit. Because dry cleaners are unsophisticated about legal issues and have limited funds, they have little chance of obtaining such a permit. Other industries with a substantial small-business base face similar challenges. Furniture refinishers may be able to reduce the emissions with expensive control equipment, but most cannot afford it, nor do they have the knowledge to operate the equipment properly.

Third, programs that help small businesses purchase pollution prevention equipment should be established on a widespread basis.
The Department of Commerce program in California, which provides low-interest loans, serves as a model.

Fourth, chemical substitutes for heavily regulated chemicals are feasible for some industries, but not for others. In metal cleaning, for instance, water-based cleaning formulations can be used in place of PERC in nearly all applications. In some industries like dry cleaning, however, chemical substitutes do not offer a solution. Industries like the furniture refinishing business face a similar dilemma.

Finally, and perhaps most significantly, small firms will need more technical assistance in the future as regulations become increasingly demanding. This assistance can be provided only by individuals who have detailed knowledge of the industry, the regulations, and the pollution prevention options.

Each industry is a special case. The challenge of pollution prevention in the 1990s is to understand the characteristics of each one sufficiently to balance the needs to protect human health and the environment and also to preserve the small-business character of these industries.

Notes


