Comparative assessment of wet and dry garment cleaning: Part 2. Performance, economic and regulatory assessment

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Abstract

An assessment of the environmental burdens and human health effects of perchloroethylene-based dry cleaning and aqueous-based wet cleaning was documented in the first paper of this two part series. This paper investigates key performance, economic and regulatory issues that affect the viability of wet cleaning as an alternative to dry cleaning. In two demonstration studies, over 60% of the test garments were successfully wet cleaned with a high level of finished quality. The most significant performance issue was garment shrinkage. Approximately 30% of garments wet cleaned in each of two studies experienced unacceptable shrinkage although no correlation between fabric or garment type and shrinkage was found. Preliminary cost data from recent demonstration projects indicate that wet cleaning can be cost competitive with dry cleaning. Higher labor and water utility costs for wet cleaning are offset by higher cleaning agent costs and equipment costs related to the purchase, control, and disposition of perchloroethylene for dry cleaning. In addition, dry cleaners in the United States must meet the regulations of the Clean Air Act, Resource Conservation and Recovery Act, Superfund Amendment and Reauthorization Act, Clean Water Act, and Occupational Safety and Health Act. In certain states, dry cleaners must also pay special taxes levied on the usage of perchloroethylene.

It appears that the garment cleaning industry is not willing to sacrifice perchloroethylene's superior cleaning performance to avoid environmental and low level human health risks associated with well-maintained dry-to-dry equipment. Mixed mode dry and wet facilities may provide an interim strategy to reduce the usage of perchloroethylene and gradually expand the application of wet technology. © 1998 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Perchloroethylene or tetrachloroethylene which is also commonly referred to as perc has served as the predominant dry cleaning solvent since the 1960s when it replaced petroleum solvents such as Stoddard [1]. Advantages of perc over petroleum solvents are its non-flammability and superior solvent properties [2]. Perc has been estimated to account for 82–85% of the dry cleaning solvent used in the United States, and this percentage is increasing as ozone depleting solvents such as TCA and CFC-113 are phased out [3,4]. A USEPA report indicated that 50% of the perc produced was used in dry cleaning and textiles, 13% for parts degreasing, and 27% as a feedstock for production of CFC-113 and three other C2 chlorofluorocarbons [5].

Perc usage by the dry cleaning industry can be analyzed with regard to data on perc production and changes in dry cleaning technology. The trend in perc production is indicated in Fig. 1 [6,7]. Several factors may account for the decline in perc production. First, perc was one of the 17 chemicals targeted by the USEPA's 33/50 program. Second, a recent decline in perc demand has been attributed to the phase out of ozone depleting substances for which perc is an intermediate feedstock [8]. Lastly, some of the observed decline is due to the increased efficiency in perc use by the dry cleaning industry. Significant improvements in dry cleaning technology have dramatically reduced perc consumption. Fig. 1 also plots yearly revenues for the dry cleaning industry which have remained relatively constant over the last two decades.

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Consequently, the decline in perc production cannot be attributed to changes in the demand for dry cleaning. A 1991 USEPA study estimated that recycled perc accounted for less than 5% of the total perc used by the dry cleaning industry [4]. Thus, an increase in perc recycling is not expected to be a major contributor to the decline in perc production.

In a 1994 study, Rydberg compared the cleaning performance of perc with four commercial solvents: dibasic esters, isooctane, isopropyl lactate and limonene [9]. He concluded from a qualitative environmental assessment that these alternatives were environmentally preferable to perc but none emerged as a readily viable substitute for perc due to certain limitations in cleaning performance. Aqueous-based systems were recommended as the most promising option.

Chlorinated organic solvents have been eliminated in a variety of process applications. In many industries elimination is achieved through process substitutions. For example, in the electronics industry aqueous solutions are often used instead of chlorinated solvents and CFCs to remove the flux residue during soldering [10]. Moreover, low-solids fluxes (LSF) that leave very little residue may completely eliminate any need for cleaning in the future. At AT&T, a LSF spray applicator has eliminated the use of 114,000 liters of PCE solvent annually [11]. At one of its manufacturing facilities, Ford substituted an aqueous-based solution for trichloroethylene [12]. Cleaning parts with a low emissions vapor degreasing process in an airtight chamber has been shown to reduce solvent emissions by 99% compared with conventional open-top vapor cleaners [11]. Performance tradeoffs may exist, however, in certain applications using these substitute technologies. For example, aqueous cleaning may not effectively remove contaminants from certain parts with complex geometries, porous surfaces, or corrosion-sensitive substrate metals.

Solvent substitution and process improvements leading to solvent use reduction have been effective in curbing solvent emissions and waste. This later case may be considered to be analogous to the change from transfer machines to dry-to-dry machines by the dry cleaning industry.

In Part 1 of this two part paper the environmental burdens and human health effects of wet cleaning and dry cleaning were analyzed [13]. A major health concern related to perc use in the dry cleaning industry is its potential carcinogenicity, although this classification is controversial. The current evidence does not indicate serious human health effects, including cancer at the low exposure levels achievable in well-operated and maintained dry cleaning facilities that employ dry-to-dry machines with refrigerated condensers. However, perc is inherently toxic, and the use of perc, ranging from 2.0 to 5.2 kg per 100 kg of clothing cleaned in dry-to-dry machines, poses a greater environmental and human health concern than does wet cleaning [13].

Part 2 of this paper presents a comparative assessment of key performance, economic, and regulatory factors that affect the future evolution of dry cleaning and wet cleaning technologies. This assessment combined with the environmental and human health assessment presented in the first paper will provide a framework to guide stakeholders in achieving a more economically and ecologically sustainable garment cleaning industry. This paper will also offer overall conclusions based on an integration of results from the environmental and human health comparative assessments with the performance, economic, and regulatory comparative assessments.
2. Methodology

This study focuses on a comparative assessment of dry-to-dry machines equipped with refrigerated condensers and wet cleaning technology including wet machines, dryers, and multiprocess wet cleaning. A description of these technologies was provided in the previous paper. The methodology, also detailed in the previous paper, is based on the three analytical components of the life cycle design framework developed for the USEPA which include systems analysis, multiobjective analysis, and multistakeholder analysis [14].

The definition of the system under investigation is a critical element of any comparative assessment and is defined by a functional need. In this case, the need is to remove dirt, stains, and odors from clothing and return the clothing to an acceptable clean state. The focus of this investigation is on the garment cleaning process rather than on the full life cycle of the garment which also includes the cleaning stage. This paper attempts to reflect the views and perspectives of the stakeholders most directly influencing the garment cleaning system such as individual garment cleaning practitioners, perc manufacturers, regulators, industry associations, educators, and customers.

Performance data compiled from recent wet cleaning demonstration projects in Canada and the United States include customer satisfaction surveys, analyses of customer claims and rejects, garment and fabric swatch studies, and process evaluations. Data on capital and operating costs were also obtained from these wet cleaning demonstration projects and equipment manufacturers. The main demonstration projects and related studies, detailed in the previous paper and referenced within this comparative analysis, were performed by the Center for Neighborhood Technology (CNT) [15], the Environment Canada (EC) [16], and the University of Michigan (UM) [18]. In addition to performance and economic assessments, a summary of regulations impacting the dry cleaning industry in the United States was compiled and evaluated. A review of the major studies and findings follows.

3. Performance assessment

Performance criteria are among the most important criteria for evaluating the effectiveness of a garment cleaning system. Cleanliness and general appearance are the primary performance criteria. Various protocols are available to evaluate these subjective criteria relating to the garment condition. However, in addition to these two garment-related criteria, performance criteria should evaluate the operational efficiency of the cleaning process such as turnaround time, pressing time, and type and quantity of garments rejected. Operational parameters depend on equipment and facility design.

Little quantitative data have been collected on the performance of dry cleaning. However, the widespread use of the process is evidence of its effectiveness and satisfactory performance. As the study of wet cleaning progresses, results will become more available on the performance of wet cleaning with respect to customer satisfaction and garment cleanliness as well as facility operations.

3.1. Customer satisfaction

A small survey of Chicago residents commissioned by CNT asked survey respondents to rate their perc dry cleaners on relevant cleaning performance issues [15]. On a scale from 1 (poor) to 7 (excellent), each of the qualitative criteria received a score within the very good to excellent range indicating that those surveyed were satisfied with the performance of perc cleaning. Similarly, EC found that 98% of the dry clean customers surveyed felt that their clothes were clean and that they would dry clean again.

Table 1 summarizes the results of EC and CNT wet cleaning customer satisfaction surveys performed during their wet cleaning demonstration projects. Additional information on size of the demonstrations and the breakdown of cleaning methods is included in Table 1.

The first two phases of the EC wet clean project received higher percentages of overall satisfied customers (97.1% and 98.7%) than did the CNT study (86%). However, for those customers that did not return a survey card or did not make a claim, EC assumed that the customers’ garments had been satisfactorily cleaned. Therefore, if any unsatisfied customer failed to come forward then the survey results artificially inflate the number of satisfied customers.

Both surveys received a significant percentage of unsatisfactory responses for wet cleaning with the CNT survey receiving the largest number of unsatisfactory responses (6.5%). Respondents expressed the greatest dissatisfaction with changes in size, and spot and stain removal (14% each). The EC survey also received high percentages of negative responses for stain and spot removal (6% in phase I and 7% in phase II). However, the quality of pressing and finishing received the greatest number of negative responses (7% in phase I and 10% in phase II).

Each of the surveys had a relatively small response rate. The EC phase I project had the greatest response rate (27%), and its phase II project had the smallest response rate (10%). However, assuming that each garment represented one customer and, therefore, one survey card, CNT sent out the greatest number of surveys (16,055) and received the greatest number of responses...
Table 1
Summary of customer survey results

<table>
<thead>
<tr>
<th>Criteria</th>
<th>EC16</th>
<th>CNT15</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total garments cleaned</strong></td>
<td>3791</td>
<td>1563</td>
</tr>
<tr>
<td><strong>Cleaning method</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine wet cleaned</td>
<td>62.4%</td>
<td>66.9%</td>
</tr>
<tr>
<td>Multiprocess wet cleaned</td>
<td>37.2%</td>
<td>19.9%</td>
</tr>
<tr>
<td>Dry cleaned</td>
<td>0%</td>
<td>12.9%</td>
</tr>
<tr>
<td><strong>Customer survey results (% of garments)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey return rate</td>
<td>27%</td>
<td>10%</td>
</tr>
<tr>
<td>Satisfactory/ excellent or good</td>
<td>97.2%</td>
<td>98.7%</td>
</tr>
<tr>
<td>Unsatisfactory/poor</td>
<td>2.2%</td>
<td>0.9%</td>
</tr>
<tr>
<td><strong>Aggregate results (of garments)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rejects</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Claims</td>
<td>0.4%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

*No breakdown of machine cleaned versus multiprocess wet cleaned is available.

*EC stated that if the customer did not respond negatively to any questions on the survey card, did not return a survey card, or did not return the garment to the depot and make a claim, then the garment was satisfactorily cleaned.

(1766). For this reason, CNT’s results may be more representative of customer opinion than EC’s results.

3.2. Claims and rejects

Table 1 also lists reject and claim rates for wet cleaning. Rejects are those items which the cleaner does not accept for processing. Claims are those items which have been processed, however, the customer is seeking financial compensation for damage which allegedly happened during the wet cleaning process. EC rejected garments for wet cleaning if there was a potential for dye run, if the cleaning would be too expensive (cushions or pillows) or too difficult (suede or fur), or if the wet cleaner noted prior damage for which the customer refused to assume responsibility. EC rejected a total of 16 garments out of 5354 garments during phases I and II of its demonstration project. CNT rejected 19 garments out of 16,055 garments, all for potential problems with colorfastness.

EC had the greatest number of claims for colorfastness/dye run issues (six). Five claims were made for shrinkage problems. Garment damage and stains each received two claims. Similarly, CNT had the greatest number of claims filed for shrinkage problems (seven). Four claims were for lost garments, and two claims were for colorfastness/dye run issues. Reject and claim rates for dry cleaning were not available.

3.3. Garment studies

In addition to customer satisfaction surveys, each demonstration project also performed intensive evaluative garment studies. Table 2 summarizes the results of these garment studies.

EC selected 13 sample garments. For each of the 13 garments there were three identical samples; one sample was dry cleaned five times, one was wet cleaned five times, and one was never cleaned. Cleaning occurred at two different sites in order to test the effect of facility size on the cleaning process. The first, third and fifth cleanings took place at a small facility, and the second and fourth cleanings took place at a medium to large facility. Trained observers evaluated dry and wet cleaned samples after the fourth and fifth cleanings. A total of 26 observations were recorded for the 13 garments tested.

CNT evaluated 84 garments as they were processed through their wet clean only demonstration facility. Trained observers randomly selected garments before cleaning for baseline evaluations. After the garments were cleaned, observers again evaluated each garment, comparing results to the pre-cleaned data.

In both studies observers followed, to the extent possible, standardized evaluative procedures set forth by such institutions as the American Association of Textile Chemists and Colorists, the American Society for Testing and Materials, and the International Fabricare Institute.

3.3.1. General appearance

EC found that more wet cleaned garments received a top rating (69.2%) than did dry cleaned garments (50.0%) for finished quality and general appearance. However, wet cleaning also produced garments which were deemed unacceptable due to major defects (15.4%) while dry cleaning produced only garments which were...
in top condition (50%) or which had only minor defects (50%). CNT found similar results. A majority of wet cleaned garments were in top condition (59%). However, a significant percentage of wet cleaned garments were in unacceptable condition (23%). CNT measured general appearance including color unevenness or splotchiness, and problems resulting from cleaning and pressing quality. Since no problems were documented with color or garment damage, all results therefore relate to pressing quality.

EC noted the following as unacceptable conditions resulting from wet cleaning: puckers, seam damage and discoloration. Unacceptable conditions noted by CNT were seam impressions, shiny seams and wrinkles on the wet cleaned garments. Neither EC or CNT found any tears, rips or missing or damaged buttons and/or garment decorations.

Although no similar studies have been done on dry cleaning, the EC customer survey and informal surveys of garment cleaning practitioners indicate that dry cleaning may result in more damage to buttons and garment decorations than wet cleaning. EC found that approximately 1% of surveyed wet clean customers complained of damage to buttons or decorations. However, 6% of the dry clean customers surveyed by EC made the same complaint. Historically, professional cleaning associations have cautioned dry cleaning practitioners that perc can dissolve or melt beads and glued trimmings leaving behind stains on garments which cannot be removed [17].

### 3.3.2. Dimensional change

More wet cleaned garments had shrinkage problems than did dry cleaned garments. For most garment and fabric types, the maximum allowed dimensional change after five dry cleanings is 3% [15]. EC measured shrinkage in length whereas CNT measured shrinkage in seven possible dimensions: length, length/front, length/back, sleeve, width, shoulder, and inseam. EC found that four of its 13 wet cleaned test garments experienced greater than 3% dimensional change either after the fourth or fifth, or both cleanings. However, by the completion of the fifth wet cleaning, two of the four garments had been returned to acceptable condition. Twenty-three of the 84 garments evaluated by CNT also had a greater than 3% dimensional change. Both studies found that some of the shrinkage problem could be removed by working the garment back into shape during pressing and finishing or by drip drying the garment. Only one of the 13 garments dry cleaned by CNT experienced unacceptable shrinkage.

The greatest percentage of wet cleaned shrinkage documented by EC was 15.6% in the fourth wet cleaning of a pair of 100% cotton knit shorts. This same pair of 100% cotton knit shorts also experienced a 4.2% shrinkage during its fifth dry cleaning. EC noted minimal stretching for both dry cleaning and wet cleaning in any of its 13 test garments. CNT documented a 10% shrinkage in a cotton/acrylic/nylon blend sweater and a 9% stretching in a wool/nylon blend shirt.

Determining which fabrics or blends of fabrics are most sensitive to dimensional change and especially shrinkage is difficult with such small sample sizes. Three out of the four problem shrinkage garments for EC were blends, however, each was a different type of blend. CNT also had problems with blends, however, they had just as many stretching problems as shrinkage problems. More extensive studies done by EC on fabric swatches (undyed text swatches and dyed consumer sample swatches) found that problem shrinkage occurred with wool, rayon, cotton/lycra and acetate/rayon while moderate shrinkage occurred with acetate, mercerized cotton, worsted wool, linen and wool/cashmere. Swatch tests for dry cleaning exhibited only moderate shrinkage for cotton/lycra, rayon, wool, worsted wool, linen and acetate. If these fabrics had been tested as garments and not swatches, some of the shrinkage may have been minimized or eliminated during pressing and finishing or by drip drying instead of machine drying.
3.3.3. Pressing time

EC also studied the time required to press and finish its 13 test garments. For garments which had not experienced significant shrinkage, pressing times for the wet and dry cleaned clothes were within 0–15% of each other with wet cleaned clothes requiring less time in some cases. For clothes which had experienced shrinkage, pressing time could be 1.5–2 times greater for wet cleaned clothes in order to gently return the garment to its original condition. Overall, EC concluded that a 100% wet clean shop would spend 54% more time on pressing and finishing than a dry clean shop. However, 50% of a 100% wet cleaned clothes stream requires from 0 to 1.2 times more additional pressing time with the remaining 50% requiring from 1.5 to 3 times more additional pressing time. Therefore, a 50% wet clean/50% dry clean shop would experience only an insignificant addition in pressing time and facility space requirements. CNT did not document the time required to press and finish garments.

3.3.4. Soil and stain removal

CNT evaluated 35 of its 84 randomly selected wet cleaned test garments for effectiveness of soil and stain removal. Sixty-two percent of the garments were found to have stain or soil not removed. The study does not draw any conclusions as to which fabrics or fabric blends were more or less susceptible to stain and soil removal. Furthermore, there are no similar results for dry cleaning with which to compare. In customer surveys, results for stain and spot removal were more favorable. In customer surveys done by CNT and EC, from 4 to 8 times as many people responded that any stains or spots present before cleaning had been removed than those indicating stains and spots were not removed. Furthermore, in a similar EC survey for dry cleaning, 11 times as many people responded that dry cleaning successfully removed any stains or spots present.

Although EC did not evaluate their test garments for soil and stain removal, they did perform these tests in their swatch studies. After dry cleaning and wet cleaning swatches with identical soiling, EC found that both processes were equally capable of removing carbon and mineral oil. Dry cleaning removed more cocoa (18%) than wet cleaning (7%) but less blood (8%) and red wine (4%) than wet cleaning (58% and 20%, respectively). In addition, wet cleaning had the least amount of redeposition of soil (15% as compared with 6%).

Because perc is a chlorinated organic solvent, it has an excellent capability to dissolve lipophilic stains such as oils, greases, fats and waxes. However, perc has little ability to dissolve water soluble stains such as sweat and many foods. Water does not dissolve lipophilics but easily dissolves many soils perc cannot. Both solutions show strengths as well as weaknesses in soil and stain removal. Therefore in practice, both cleaning agents are used in coordination with supplemental stain treatments in order to enhance their soil and stain removal capabilities.

3.3.5. Odor

CNT evaluated 60 of their randomly selected wet cleaned garments for odor. Ninety-three percent were found to have no odor or an insignificant odor. Of the remaining 7%, one smelled “fresh”, one smelled like softener, one smelled of bleach and one had a “chemical” smell. In CNT and EC customer surveys, never did more than 3% of respondents complain of odor in wet cleaned garments. In the EC dry cleaning survey, 5% of respondents complained of an unpleasant odor in dry cleaned garments.

4. Economic analysis

A comparative economic analysis of the alternatives is important in evaluating the feasibility of a complete transition from dry cleaning to wet cleaning or the extent to which wet cleaning can replace dry cleaning. Several studies have been conducted that provide a partial characterization of the capital and operating costs for model facilities and demonstration facilities [15–18]. However, a comprehensive total economic assessment which analyzes hidden costs, liability costs and less tangible costs such as worker morale is not available.

Tables 3 and 4 summarizes cost estimates from two studies for the major parameters affecting the economic feasibility of a dry and wet cleaning facility. All data are given in units of US$ per 100 kg of clothes cleaned. A general overview of the two facilities as well as costs of capital equipment, cleaning agents, utilities, and labor will be discussed.

4.1. Study parameters

4.1.1. University of Michigan study

The UM model dry cleaning facility was defined as a commercial-sized operation utilizing a 50 lb, dry-to-dry, closed-loop machine with a refrigerated condenser. Perc mileage was estimated to be 2.5 kg perc per 100 kg of clothes cleaned based on the USEPA’s monitoring of perc usage for this type of machine. An estimated 36,262 garments with an average weight of 1 kg were cleaned per year. The model wet cleaning facility was assumed to process the same quantity and garment profile. The wet cleaning facility utilized a 50 lb wet clean washer and a 30 lb wet clean dryer. In this model facility, 70% of incoming garments were processed in a wet clean machine, and the remaining 30% were cleaned by multiprocess wet cleaning. Additional parameters are defined in Blackler et al. [17].
Table 3  
Cost analysis for select categories (US$ per 100 kg of clothes cleaned)

<table>
<thead>
<tr>
<th>Category</th>
<th>Dry</th>
<th>Wet</th>
<th>Dry</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs (amortized)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 lb dry to dry machine</td>
<td>n/a</td>
<td>13.73</td>
<td>n/a</td>
<td>34.05</td>
</tr>
<tr>
<td>Refrigerated condenser</td>
<td>n/a</td>
<td>2.72</td>
<td>n/a</td>
<td>2.17</td>
</tr>
<tr>
<td>Aerocooling unit</td>
<td>n/a</td>
<td>0.55</td>
<td>n/a</td>
<td>11.71</td>
</tr>
<tr>
<td>Boiler</td>
<td>n/a</td>
<td>2.60</td>
<td>n/a</td>
<td>9.08</td>
</tr>
<tr>
<td>Equipment maintenance</td>
<td>n/a</td>
<td>2.47</td>
<td>n/a</td>
<td>0.86</td>
</tr>
<tr>
<td>Misc. capital</td>
<td>n/a</td>
<td>11.98</td>
<td>n/a</td>
<td>11.71</td>
</tr>
<tr>
<td>Aqua Clean System</td>
<td>n/a</td>
<td>—</td>
<td>n/a</td>
<td>9.08</td>
</tr>
<tr>
<td>Spray gun</td>
<td>n/a</td>
<td>—</td>
<td>n/a</td>
<td>0.46</td>
</tr>
<tr>
<td>Scrub board and sink</td>
<td>n/a</td>
<td>—</td>
<td>n/a</td>
<td>0.06</td>
</tr>
<tr>
<td>Capital costs total</td>
<td>n/a</td>
<td>34.05</td>
<td>n/a</td>
<td>24.33</td>
</tr>
<tr>
<td>Cleaning agents</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perc</td>
<td>3.56</td>
<td>2.10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Detergent</td>
<td>8.53</td>
<td>4.63</td>
<td>1.86</td>
<td>4.72</td>
</tr>
<tr>
<td>Sizing/finish</td>
<td>2.30</td>
<td>—</td>
<td>3.34</td>
<td>11.12</td>
</tr>
<tr>
<td>Spotting solvents</td>
<td>2.95</td>
<td>1.85</td>
<td>2.95</td>
<td>1.85</td>
</tr>
<tr>
<td>Filter purchase</td>
<td>n/a</td>
<td>4.62</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Filter disposal</td>
<td>n/a</td>
<td>5.65</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Separator water disposal</td>
<td>n/a</td>
<td>1.89</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Still bottom disposal</td>
<td>n/a</td>
<td>2.32</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cleaning agents total</td>
<td>17.34</td>
<td>23.07</td>
<td>8.16</td>
<td>17.69</td>
</tr>
<tr>
<td>Electric use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning unit</td>
<td>1.91</td>
<td>1.87</td>
<td>0.21</td>
<td>0.95</td>
</tr>
<tr>
<td>Heating unit</td>
<td>—</td>
<td>—</td>
<td>0.08</td>
<td>n/a</td>
</tr>
<tr>
<td>Drying unit</td>
<td>—</td>
<td>—</td>
<td>0.26</td>
<td>0.36</td>
</tr>
<tr>
<td>Refrigerated condenser</td>
<td>—</td>
<td>0.97</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Aerocooling unit</td>
<td>—</td>
<td>0.09</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Electric use total</td>
<td>1.91</td>
<td>2.92</td>
<td>0.54</td>
<td>1.31</td>
</tr>
<tr>
<td>Water use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chiller water</td>
<td>1.21</td>
<td>0.00</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Charge water</td>
<td>n/a</td>
<td>0.00</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Washer</td>
<td>—</td>
<td>—</td>
<td>1.40</td>
<td>2.01</td>
</tr>
<tr>
<td>Hand wash hot water heater</td>
<td>—</td>
<td>—</td>
<td>0.08</td>
<td>n/a</td>
</tr>
<tr>
<td>Full immersion</td>
<td>—</td>
<td>—</td>
<td>n/a</td>
<td>0.10</td>
</tr>
<tr>
<td>Partial immersion</td>
<td>—</td>
<td>—</td>
<td>n/a</td>
<td>0.01</td>
</tr>
<tr>
<td>Water use total</td>
<td>1.21</td>
<td>0.00</td>
<td>1.49</td>
<td>2.12</td>
</tr>
<tr>
<td>Natural gas use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean unit</td>
<td>2.60</td>
<td>n/a</td>
<td>0.11</td>
<td>n/a</td>
</tr>
<tr>
<td>Drying unit</td>
<td>—</td>
<td>n/a</td>
<td>3.61</td>
<td>n/a</td>
</tr>
<tr>
<td>Natural gas total</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>86.04</td>
<td>n/a</td>
<td>86.04</td>
</tr>
<tr>
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<td>43.02</td>
<td>n/a</td>
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<td>—</td>
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<td>$333.04</td>
<td>$13.91</td>
<td>$329.02</td>
</tr>
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</table>

n/a = data not available.
— data not applicable to the category (e.g. use of perc for wet cleaning).
Electricity use for the refrigerated condenser is included in the amount required for the cleaning unit.
Water for these uses was measured at very small quantities.
4.1.2. Environment Canada study

EC measured the resource use in one month for dry cleaning and wet cleaning at its project demonstration site. The EC site utilized a 55 lb (25 kg) closed-loop, dry-to-dry, refrigerated condenser machine, a 50 lb (23 kg) wet clean washer and a 50 lb wet clean dryer. During the study month, the facility processed approximately 110 pieces per day (extrapolated to 28,600 pieces per year) with an average weight of 0.5 kg per piece. The perc mileage achieved was 2.0 kg perc per 100 kg of clothes cleaned. For the wet cleaning process, garments were either machine wet cleaned or multiprocess wet cleaned. However resource consumption for multiprocess wet cleaning was not detailed. Additional parameters are defined in Environment Canada [16].

The most notable difference between the two studies’ parameters is the difference in unit of clothing. UM recorded processed volume by the unit “garment”. The unit “garment” was defined by the USEPA as two pieces of clothing which together make a complete garment, such as a jacket and pants [18]. EC measured volume by the unit “piece” which was considered a single item of clothing, such as a jacket or pants [16]. There is no discrepancy in the units since two “pieces” at 0.5 kg is equivalent to one “garment” at 1.0 kg. The greatest discrepancy in the parameters is in the volume processed. UM estimated the model facility to process 36,262 garments or 72,524 pieces per year while EC would process only 28,600 pieces per year or 14,300 garments, nearly a third less (based on monthly values normalized to the unit kg to minimize discrepancies. All analysis was normalized to the unit kg to minimize discrepancies. However, the UM results may reflect the effects of economies of scale.

The economic assessment did not utilize identical unit costs for the EC and the UM data. Rather, each study had unique unit costs representative of the geographic area in which the study was performed. With the exception of electricity and water, EC unit costs were greater than UM unit costs. As a result, the two sets of data for a single cleaning method, dry or wet, are not directly comparable. However, they do represent the market variability of two different geographic regions. When the four data points for a single cost category are examined collectively, a relative difference between dry and wet cleaning is discernible.

4.2. Capital costs

The UM study found that dry cleaning requires a significantly greater initial capital expenditure. For a dry cleaner, a 50 lb (23 kg) closed-loop, dry-to-dry machine, refrigerated condenser, aero-cooling unit, and 20 horsepower (15 kW) boiler costs an estimated $63,700. Conversely, a 50 lb (23 kg) wet clean washer, 50 lb (23 kg) wet clean dryer, 10 horse-power (7.5 kW) boiler, spray gun, scrubbing board, and industrial sink for wet cleaning costs $39,500. Amortizing these capital costs over the estimated useful life of the equipment (15 years for both the dry and wet cleaning equipment) yields a yearly capital expenditure of $7100 for dry cleaning and $4300 for wet cleaning.

4.3. Cleaning agents

The use and disposal of perc is primarily responsible for the higher cleaning agent costs for dry cleaning compared to wet cleaning. According to the UM study, 72% of the total cleaning agents cost in dry cleaning is spent on perc, emission control supplies, and hazardous waste disposal. UM estimated higher cleaning agent costs for dry cleaning than did EC due to the inclusion of these waste disposal estimates. Making more efficient use of perc is one way in which a dry cleaner can reduce cleaning agent costs. Better mileage is attainable with advanced equipment such as solvent distillation systems which claim perc mileage rates as low as 0.75 kg perc per 100 kg of clothes cleaned. A sensitivity analysis by UM indicated that dry cleaning becomes more profitable than wet cleaning below a perc mileage of 0.93 kg perc per 100 kg of clothes cleaned.

4.4. Utilities

Both studies indicated higher utility costs for wet cleaning (UM: $3.43/100 kg of clothes cleaned and EC: $5.75/100 kg of clothes cleaned) compared to dry cleaning (UM: $2.92/100 kg of clothes cleaned and EC: $5.72/100 kg of clothes cleaned) although differences existed among utility categories between studies. Higher electricity costs associated with dry cleaning can be attributed to the use of the refrigerated condenser and aero-cooling unit as well as the energy intensive, closed-loop, dry-to-dry machine. Variability in water use costs reflects differences in the scope and boundaries of the water use inventory as was indicated in part I of this paper series. The potential for water reuse in a wet cleaning machine can reduce water use costs by an estimated 25% [17]. Natural gas used in the production of steam was inventoried only by EC.

4.5. Labor

Considerable disagreement exists as to the relative amount of labor required for wet and dry cleaning. Given that direct labor costs (excluding benefits, tax, and insurance expenses) represent over 40% of the total annual operating costs of a professional clothes cleaner, assumptions about labor dramatically affect the results of the UM model facility analysis [17]. In the UM study, wet cleaning is estimated to have a greater total labor cost: $103,000 compared to $99,000. Although the over-
all difference may not be significant given the uncertainty of the model, significant differences were identified for specific cost categories. While less labor was estimated for spotting, UM estimated a 33% increase in the time required for pressing wet cleaned clothes based on an informal survey of stakeholders [18–23]. A discussion of results of EC's pressing time study are found in the performance assessment.

Uncertainties over the labor required to run a wet cleaning shop are critical to the determination of the profitability of wet cleaning. Under the most pessimistic assumption about labor rates, wet cleaning may fail to earn a profit. A sensitivity analysis done by the UM study found that a labor increase for pressing wet cleaned clothes above 33% resulted in wet cleaning earning less profit than dry cleaning. A more comprehensive cost assessment would also address differences in wages associated with potential differences in skill-level requirements for wet cleaning employees relative to those for dry cleaning employees.

4.6. Other costs

A range of other costs not included in Table 3 that are difficult to evaluate can influence the overall economic performance of dry cleaning versus wet cleaning. Potential liability costs associated with the use of perc on the premises can severely harm an owner's prospects for selling property where a dry cleaner once operated. Owners may also be liable for cleanup of contaminated soils and groundwater. In Florida, a surcharge of approximately $5.00 per gallon ($1.32 per l) on perc helps to finance an insurance fund to pay for liabilities associated with spills of perc during transport. This Florida tax would raise the costs of perc use reported in Table 3 from $2.10 to $4.12 per 100 kg of clothes cleaned for the UM study and from $2.30 to $4.80 per 100 kg of clothes cleaned for the EC study. Furthermore for dry cleaning facilities, perc use poses additional regulatory compliance costs related to recordkeeping requirements. The practice of drip drying clothes by wet cleaners would involve additional costs not included in this study. For example, some wet cleaners use cedar closets to dry certain types of garments which also require extra facility space. In addition, drip drying generally adds time to the cleaning process which can increase labor and service time for customers.

It is important to realize that this new wet cleaning process is an emerging technology. As more manufacturers enter the market to sell wet cleaning machines, dryers, and detergents, competition may drive down prices. Therefore, a professional clothes cleaner choosing between wet and dry cleaning must analyze the current costs involved in each technology as well as anticipate how costs may change in the future.

In this regard, wet machine cleaning certainly deserves increased consideration by professional cleaners. Until more conclusive studies of labor requirements, liability costs, and intangible costs are completed, cleaners are likely to continue their reliance upon the known profitability of traditional dry cleaning.

5. Regulatory assessment

Current and proposed state and federal regulations strongly influence the future status of traditional perc dry cleaning and wet cleaning technologies in the United States. These regulations affect equipment requirements, capital and operating costs, liabilities to garment cleaners, and the time and cost requirements associated with tracking and interpreting regulations. The traditional perc dry cleaner must comply with significantly more regulations than a wet cleaner because perc is listed as hazardous under the Occupational Safety and Health Act, the Clean Air Act (CAA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Since many states have their own regulations which either meet or exceed federal regulations, this analysis will focus primarily on the federal regulations which are the minimum standards for compliance.

5.1. Occupational Safety and Health Administration (OSHA) regulatory requirements

OSHA sets industry standards, such as Permissible Exposure Levels (PELs) to protect workers. On 19 January 1989, OSHA reduced the PEL for perc from 100 parts per million (ppm) to 25 ppm [24]. In July 1992, an appeals court vacated the 1989 OSHA standard revising the PELs for perc and 427 other substances [25]. Today, OSHA recommends that dry cleaners limit indoor air emissions of perc to 25 ppm but can only enforce the old PEL of 100 ppm total weighted average of perc.

5.2. 1990 Clean Air Act Amendments (CAAA)

Section 112 of the CAAA specifies that emissions of one or more of a list of 189 toxic air pollutants, including perc, must be controlled using Maximum Achievable Control Technology (MACT) [26]. In December 1991, USEPA, acting on the authority assigned it in the CAAA, proposed National Emission Standards for Hazardous Air Pollutants (NESHAP) to regulate the dry cleaning industry's emissions of perc. These regulations went into effect in September 1993, were amended on 20 December 1993, and were to be fully implemented by 23 September 1996 [27]. NESHAPs set a range of technology requirements that limit perc air emissions but
do not penalize dry cleaners who have just purchased emissions control equipment prior to the passage of the law.

NESHAP is very specific about which emission control technologies meet the MACT standard, but the requirements differ depending on whether the facility being regulated is new or existing, whether it is classified as a small (purchased less than 140 gallons (530 l) of perc per year), large (purchased between 140 and 2100 gallons (7949 l) of perc per year), or major perc user (purchased more than 2100 gallons (7949 l) of perc per year), and which type of equipment is in place (transfer or dry-to-dry). Because of the fragmented nature of the industry and the lack of enforcement personnel in the USEPA, enforcement of NESHAP is primarily through recordkeeping, reporting, monitoring, and self-inspections. Under the new regulations, dry cleaners must keep track of their perc purchases and maintain a running record of their annual consumption, conduct weekly inspections for equipment leaks, and follow specific guidelines in repairing leaking equipment.

5.3. Resource Conservation and Recovery Act (RCRA)

The use, storage, and disposal of perc is regulated under RCRA’s 1984 amendments. The 1984 Hazardous and Solid Waste Amendments (HSWA) to RCRA required the USEPA to phase out the land disposal of untreated hazardous wastes by 1992 at the latest. The halogenated solvents were restricted from land disposal on 8 November 1986 [28]. However, the USEPA excluded many dry cleaners from complying with this rule by designating a category called conditionally exempt small quantity generators (CESQG) [29]. This exemption is for businesses that produce less than 100 kg of hazardous waste per month. Cleaners which do not meet the RCRA small quantity generator exemption contract for hazardous waste disposal services.

5.3.1. Solid hazardous waste

While much of the perc used in a dry-to-dry machine is filtered and recycled, solid hazardous waste is generated from several sources including still bottoms from the perc distillation, spent filter cartridges and/or filter catch solids such as hair and soil particles, and sludge from muck cookers. Improper management of drums can lead to costly fines and unnecessary spills and leaks. Under RCRA, generators must inspect hazardous waste storage areas for spills and leaks on a weekly basis [30].

5.3.2. Hazardous wastewater

Water is used in dry cleaning for operation and maintenance of emission control devices and perc filtration devices. These include carbon adsorbers, cartridge stripping cabinets, stills, muck cookers, and refrigerated condensers [25]. A small quantity of water is also used as an additive to perc for removing water soluble stains from clothing. The concentration of perc in contaminated water reaches as high as 150 ppm which is the solubility limit for perc.

RCRA classifies slightly contaminated wastewater which is generated by dry cleaners from various sources as an F002 category hazardous 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 because it exceeds the TC level [31]. Historically dry cleaners, however, have poured separator water down the drain.

Technically, dry cleaners are required to notify their publicly owned treatment works (POTWs, local regulatory agencies that set standards for wastewater) of the type, volume and concentration of hazardous wastewater they produce. Since separator water has not been of great concern to POTWs from a treatment viewpoint, they often do not enforce the notification requirement. Now that perc contamination is a growing liability concern, POTWs are paying closer attention to the dry cleaning industry. Dry cleaning industry associations no longer recommend sewer discharge of separator water [32]. Alternative ways to deal with the separator water are to pay a service to dispose of it or to evaporate the perc and the water completely (which may also require permits in some states or sanitation districts).

5.4. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA (also known as Superfund and the 1986 Superfund Amendment and Reauthorization Act) liability has serious implications for perc dry cleaners. Superfund is a liability statute that holds all potentially responsible parties (PRPs) responsible for the release of hazardous waste. A PRP is defined as a past or current owner or operator of a waste site, a generator of the waste, or a transporter or arranger of transport of the waste. CERCLA has joint and several liability, strict liability, and retroactive liability. Under retroactive liability, PRPs can be held liable for releases of hazardous waste regardless of whether or not the disposal methods used were legal at the time of the release [33]. Percladen separator water has caused groundwater and soil contamination at many dry cleaning sites by permeating concrete or seeping through cracks in sewers [31].

As of fiscal year 1993, the USEPA’s Records of Decision database showed perc contamination at 203 out of a total of 1302 sites on the Superfund list (National Priority List) since it began in 1981 [34]. Under the current strict liability clause in CERCLA (Section 107) any future buyers of a property (who are aware of its potential for perc contamination), as well as the current owners and possibly even creditors could be held liable.
for the cost of cleanup should the site be listed on the NPL. Therefore, it will be increasingly more difficult in the future to sell property that has hosted dry cleaning facilities.

In 1994, when CERCLA was up for reauthorization, dry cleaning industry associations submitted an amendment to CERCLA proposing the establishment of a dry cleaning industry-paid-for fund to be used for cleanup of contaminated sites not on the NPL.

In the amendment, the industry (was) not seeking an exemption from Superfund, but instead the shifting of liability from a plant-by-plant basis to the industry as a whole, via the establishment of a National Dry Cleaners Cleanup Fund [35].

However, the amendment died when the Senate expressed concern regarding the appearance of imposing a new “tax” on an industry.

5.5. State standards

Several states including California, New York, Florida and Connecticut have developed stricter regulations to address issues of particular concern to their state. Perc is listed by the State of California as a known carcinogen. A California Air Resources Board (CARB) regulation, which was implemented in 1994, bans all transfer machines and requires dry cleaners to use closed-loop, dry-to-dry machines with refrigerated condensers. This rule also bans carbon adsorbers as the primary emissions control technology but recommends it as a secondary control to be used in conjunction with a refrigerated condenser. The New York State Department of Environmental Conservation (NYSDEC) regulations imposed phase out of transfer machines, addition of vapor barriers or room enclosure, and installation of room ventilation systems providing for a complete air exchange every 5 minutes in order to protect residents living in apartments located above and next to perc dry cleaning facilities [36].

Florida and Connecticut passed a state tax on dry cleaning to establish a fund to pay for future liability claims against dry cleaners. Florida dry cleaners now pay a 1.5% gross receipts tax on sales and a $5.00 per gallon tax on perc to the state’s retroactive liability fund [37]. In Connecticut, concern over the potential loss of property value resulting from contamination and liability issues has inspired the dry cleaning industry to sponsor legislation for a state cleanup fund.

5.6. Wet cleaning

According to Ecomat, a wet cleaner in New York City, there are no federal or state statutes specifically regulating the wet cleaning process [19]. The wet cleaners under analysis use biodegradable detergents instead of perc, and nonchlorinated spotting agents which are not regulated as toxic under federal statutes. One area of potential concern for wet cleaners is the wastewater they produce. The wet cleaning process produces wastewater at levels of quality and quantity currently acceptable to POTWs in the areas where wet cleaning is currently operating [38]. However, if a dry cleaner converts to wet cleaning, there would be an increase in sewer usage that would be associated with an increase in monthly sewer service fees.

5.7. Care labeling requirements

The Federal Trade Commission (FTC) has jurisdiction over the rule requiring textile manufacturers to state care instructions for textile wearing apparel and certain piece goods. The Care Labeling Rule (Part 423, Section 6(b)) states that

...if either washing or dry cleaning can be used on the product, the label need have only one of these instructions [39].

Since “washing” is a very broad and an undefined category, whereas dry cleaning is well understood and generally a uniform process, as a matter of convenience and to avoid ambiguity, textile manufacturers most often list “dry cleaning” as the method of care even though “washing” and “dry cleaning” may both be viable options [40].

For fear of damaging the garment, most cleaners refuse to process garments with a method other than that indicated on the care label. If a garment is damaged during professional cleaning, the customer expects the cleaner to compensate for the damage. Only if the damage occurs while following the care label instructions can a cleaner legally make a claim against the textile manufacturer. Since professional cleaners have much at risk (e.g. loss of customers, high reimbursement costs relative to total profits), they are extremely diligent in adhering to care label instructions.

In light of these issues, the USEPA Design for the Environment (DfE) project asked the FTC to revise the Care Label Rule. On 15 June 1994, the FTC requested public comment on the Rule. The DfE participants submitted the following comment:

The United States Environmental Protection Agency’s (EPA’s) Dry Cleaning Project believes that FTC’s Care Labeling Rule should be revised to require textile manufacturers to explicitly state whether a garment can be effectively cleaned by solvent-based methods, water-based methods, or both. We believe this change is necessary to advance the use of water-based cleaning methods [39].

6. Conclusions

This paper along with part 1 of this two paper series provides a framework for evaluating the current status
and future directions for dry cleaning and wet cleaning technologies. Key environmental, health, performance, economic and regulatory issues were analyzed for each technology, and interrelationships between factors were identified. Conclusions from the performance, economic, and regulatory assessments are presented, and recommendations based on an overall assessment of both cleaning technologies are proposed.

6.1. Performance

Recent studies have greatly increased the amount of available information and the understanding of wet cleaning. In each of the studies identified in this report, a significant percentage of garments was successfully wet cleaned. Eighty-five percent of the wet cleaned garments evaluated by EC and 77% evaluated by CNT were returned to good or fair condition. However, these same studies also identified problems with wet cleaning specific garments and/or fabric types. The most documented problem was garment shrinkage. Thirty-one percent of EC and 27% of CNT wet cleaned garments exhibited problem shrinkage. The studies were not able to make a positive determination as to which garments or fabric types may not be suitable for wet cleaning. The studies also did not extensively investigate the effect of repeated wet cleanings on the life of a garment.

Additional issues remain of which little or no information is available. For example, more time consuming and different cleaning techniques (e.g. greater sorting, drip drying and longer pressing times) for wet cleaned clothes may slow throughput to the extent that more space and time are required to process the same amount of clothing. Additional space and time would also affect the economic viability of wet cleaning.

Both the operational and the cleaning performance limitations suggest that wet cleaning may become more widespread if supplemented with dry cleaning. A professional garment cleaner selectively applying wet cleaning to easily-wet-cleaned garments could increase the percentage of wet cleaning with little or no difficulty. The percentage of wet cleaned clothes will most likely depend on several variables specific to individual cleaners such as the profile of the garment stream, the cleaners expertise and practical experience with wet cleaning, and the size of the operation.

6.2. Economics

Preliminary economic analyses did not favor one technology over another. However, several tradeoffs were identified. Water utility costs were greater for wet cleaning than for dry cleaning. In addition, extra space requirements for drip drying wet cleaned garments may lead to higher facility costs. Higher wet cleaning labor costs are expected due to smaller load sizes, extra pressing, and potentially higher skill levels needed. Since labor was such a dominant factor in this economic assessment, further analysis is necessary to better understand the quantity and type of labor required. Furthermore, wet cleaning may benefit from economies-of-scale cost reductions in equipment and supplies if the demand for this technology expands substantially.

Higher cleaning agent costs were found for dry cleaning compared to wet cleaning. Even though perc mileage is decreasing, total dry cleaning costs may not decrease accordingly. For example, higher operating and capital equipment costs required to enhance perc mileage along with anticipated higher fees for perc disposal may offset potential cost savings from enhanced perc mileage. Furthermore, potential costs form perc contamination remain a serious liability facing owners of dry cleaning establishments.

6.3. Regulations

The use of perc in the dry cleaning industry is highly regulated in the United States under the CAA, RCRA, CERCLA, CWA, and OSHA. Regulations have been a major driving force in the implementation of newer dry-to-dry equipment technologies. Despite stricter federal regulations requiring dry cleaners to adopt this technology by 1996, some are exempted from compliance. As of 1991, only one-third of dry cleaners used the closed-loop, dry-to-dry machine with a refrigerated condenser. This suggests that without strong regulatory standards the industry does not readily adopt new technology. The relatively large capital investment required of the typically small commercial garment cleaning enterprise can be a barrier to upgrading equipment or investing in wet technology. Recent data also indicate that enforcement or other incentives/disincentives is necessary to ensure compliance with many existing regulations. For example, although dry cleaners are required to maintain a log of their leak detection and repair activities, about 90% of the industry were not keeping logs according to a US EPA survey [41]. The lack of participation in USEPA self monitoring requirements will result in less corrective action to control fugitive emissions.

Regulations on dry cleaning play an important role in encouraging the development of wet cleaning and other alternatives. Both technology-based standards and special taxes on perc use ultimately have a strong influence on the economic outlook for garment cleaning industry. Special taxes levied on the use of perc cannot only be used to encourage greater perc mileage, but tax revenues can also be directed toward research and development funding of alternative technologies such as wet cleaning.
7. Recommendations

In the near future, larger cleaners can consider operating mixed mode facilities that use both dry cleaning and wet cleaning equipment. Wet cleaning equipment can be used on a fraction of the garment stream that does not create unacceptable shrinkage problems or take excessive time to process. Mixed mode facilities would enable operators to gain experience with wet technology and potentially overcome shrinkage problems through better control of drying parameters. Additionally, garment manufacturers can encourage wet technology by implementing more accurate labeling of garments and utilizing fabrics that are amenable to wet technology. Surveys have identified a small subset of the population willing to pay higher costs for more environmentally preferable products and technologies. Green pricing in certain communities may also support the establishment and start up of new wet facilities [42].

Dry cleaning represents a mature industry that has undergone continuous improvement in perc mileage. Accordingly, environmental and human health risks have been reduced. Perc, however, is inherently toxic, and, therefore, alternative technologies such as wet cleaning that are environmentally preferable should be encouraged. Successful implementation of new technologies requires institutional change, refinement of wet cleaning and other technologies, education and training of the garment industry, and provision of environmental information to customers. In addition, the internalization of the full environmental costs of perc and implementation of more stringent environmental regulations can accelerate the adoption of wet cleaning technologies. The framework provided herein and within part 1 of this paper highlights relationships among the multiple factors influencing the viability and future success of garment cleaning technologies as well as important tradeoffs between these factors. Elucidation of these relationships and tradeoffs can assist all stakeholders in taking the necessary actions that will lead to more sustainable garment cleaning systems.

References

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