

**A Technical and Socio-Economic
Comparison of Options to Products
Derived From the Chlor-alkali Industry**

Final Report

Prepared for: Environment Canada

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Foreword

The report "A Technical and Socio-economic Comparison of Options to Products Derived From the Chlor-alkali Industry" forms part of the Canadian government's Chlorinated Substances Action Plan, first announced in October, 1994. The Chlorinated Substances Action Plan outlines Canada's approach to the management of chlorinated substances, and indicates that the approach is to "prune the chlorine-use tree, not cut it down". The Chlorinated Substances Action Plan has five parts, one of which is to study public health and socio-economic aspects of the chlorine and alternative sectors.¹ This study fits within this part of the Chlorinated Substances Action Plan, and is referred to in the October, 1996 Progress report.

The purpose of the study is to provide descriptive background information on chlor-alkali industry products, their applications and options (or alternatives) to the use of these products. Products derived from the chlor-alkali industry are defined as those originating from chlorine and caustic soda which are made by electrolysis of sodium chloride. The report compares the socio-economic and technical importance of products derived from the chlor-alkali industry, and options to these products, in the Canadian economy for the base year 1993. The definition of the Canadian economy used is that of the national accounts, with the magnitude of economic activity represented by gross domestic product (GDP). Market and technology trends are also described for products derived from the chlor-alkali industry and their options.

The study focuses on various products derived from the chlor-alkali industry throughout the production chain from initial electrolytic production of chlorine and caustic soda to most end-use consumption areas. The study provides a socio-economic examination of all Canadian production of base chlor-alkali commodities, including elemental chlorine, caustic soda, hydrochloric acid and polyvinyl chloride (PVC) resin precursors, namely ethylene dichloride (EDC) and vinyl chloride monomer (VCM).

The study provides a socio-economic examination and direct replacement cost analysis of options in 28 market applications which account for approximately three-quarters of the net domestic consumption of chlorine contained in products derived from the chlor-alkali industry. Pharmaceuticals and pesticides, which in total contain a relatively small quantity of chlorine, are not examined quantitatively, but qualitatively. Numerous other applications using relatively small amounts of chlorine and chlorinated substances were not analyzed. Although the majority of the study focuses on the chlorine tree, a direct replacement cost analysis is also provided for caustic soda since it is a co-product of elemental chlorine production.

¹ The other parts are targeted action, improved scientific understanding, improved access to information and promoting and leading international efforts for global action.

The three principal variables used to compare the relative economic importance of products derived from the chlor-alkali industry and options to these products are: annualized direct replacement costs; domestic revenues; and manufacturing employment. For context, these variables are compared to three indicators of economic activity, namely: domestic revenues of industries that use chlor-alkali products (end-use revenues); GDP; and total manufacturing employment.

The method used to derive direct replacement costs is to estimate the costs of substitution of non-chlor-alkali derived materials (or processes) in major chlor-alkali product applications (e.g., water treatment, pulp and paper, PVC products). Direct replacement costs refer to the direct annualized capital and incremental operating costs of substituting for current uses of chlor-alkali industry products with options to those uses. Low and high cost estimates are presented in some applications to reflect different options available to products derived from the chlor-alkali industry. For costing purposes, the options selected are assumed not to incorporate products derived from the chlor-alkali industry. However, in certain cases (e.g., water treatment), it is recognized that the options may require small quantities of products derived from the chlor-alkali industry. In the majority of applications, the selected options currently compete with chlor-alkali industry products, either domestically or internationally. However, in areas where alternative materials do not have a significant portion of the Canadian market, simplifying assumptions and the consultant's best judgment are applied to select options which could replace chlor-alkali industry products.

The study does not analyze and estimate life cycle costs associated with product substitution. One reason is that, for many durable products, there is a high level of uncertainty regarding lifespan and ultimate disposal methods. Furthermore, present value analysis used in life cycle costing is inconsistent with the national accounts framework and market prices on which this study is based and comparisons are made. Lastly, in the case of durable products with a long life expectancy, the use of a positive discount rate (i.e., 9%) dampens the present value of costs that would be incurred during the life of the products, and particularly disposal costs incurred at the end of the product's life. For competitive durable products (e.g., pipe, siding, windows) which have a long life expectancy, the estimated current direct replacement costs would likely not be significantly different from comparative life cycle costs.

The report is not, and should not be interpreted as, an economic impact analysis (EIA) of a chlorine phase-out. The study differs from an EIA in several respects, the two most important being that it does not project into the future and it does not analyze and value environmental damages. More specifically, the report does not project a given scenario into the future through the use of a macro-economic model in order to evaluate long-run socio-economic costs, as roughly indicated by projected changes in consumer surplus. Nor does the report assess and value the comparative environmental damages associated

with the production and use of chlor-alkali industry products and options to those products. In an EIA, the avoided net environmental damages (chlor-alkali products versus options) would represent the benefits side of the cost-benefit analysis, while the costs would be represented by changes in consumer surplus generated through long-run price increases in relevant product markets.

Finally, this report has had an extensive process of external stakeholder review. The review committee consisted of representatives from industry, non-government organizations, academia, and government. All written comments provided by government and stakeholders were addressed by the consultant. While many views were incorporated into the study, not all concerns could be fully resolved. The review process included opportunities for Environment Canada and stakeholders to: review the interim report; review a draft final report; attend a technical workshop; review the workshop proceedings; and review the final draft of the Executive Summary and Summary.

Acknowledgments

This is the final report for a project which began in January 1995, after the terms of reference were set by Environment Canada. A multi-stakeholder Technical Review Committee was formed to review the project. An interim draft report covering the Pulp and Paper and Polyvinyl Chloride (PVC) sections was distributed for stakeholder review in August 1995. A complete draft report was distributed for stakeholder review in July 1996. A technical stakeholders workshop was held in February 1997. A review of the Executive Summary and Summary sections was distributed for stakeholder review in August 1997.

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The multi-stakeholder Technical Review Committee consists of representatives of:

- industries producing chlor-alkali derived products,
- industries producing options to those products,
- industry associations,
- environmental non-government organizations,
- academic institutions, and
- government

The authors and editors wish to thank the following individuals who participated in the Technical Review Committee, provided written comments on the interim draft report, draft report or summaries or participated in the technical workshop. This participation does not imply agreement, support or endorsement of the material contained within.

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Disclaimer - Use of this Report

The purpose of this report is to provide a background document for Environment Canada and other stakeholders interested in products derived from the chlor-alkali industry and options to the use of those products in Canada.

The scope of the study is broad. The analysis includes a number of simplifying assumptions, market estimates, along with some projections based on information gathered in conducting this study. Detailed market investigations or business assessments were not possible within the study's constraints, nor were they required to meet the study objectives. The accuracy of information, analysis and findings contained in the report is sufficient to establish reference situations for discussions within the limited context of the client's (Environment Canada) purpose. The report should not be used for business purposes which require a more in-depth analysis.

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Executive Summary

E.1 Scope of Analysis

The report presents a technical and socio-economic comparison of products derived from the chlor-alkali industry with options to the use of these products in the Canadian economy. Chlor-alkali products are defined as products originating from the electrolysis of sodium chloride into elemental chlorine and caustic soda. The scope of chlor-alkali products investigated falls into three broad categories:

1. **base commodities** produced by the chlor-alkali industry
(e.g., elemental chlorine, caustic soda, hydrochloric acid);
2. **polyvinyl chloride (PVC) resin products**
(e.g., pipe, siding, windows, flooring, wire & cable, bottles, film & sheet); and
3. **other chlorinated substances**
(e.g., household bleach, chlorinated solvents, refrigerants, flame retardants, etc.).

The purpose of this report is to provide a background document for individuals, industry groups and government departments interested in products derived from the chlor-alkali industry and options to the use of those products in Canada. The report is not, and should not be interpreted as, an economic impact analysis (EIA) of a chlorine phase-out. The study differs from an EIA in several aspects, the most important being that it does not project into the future, and does not assess and value health and environmental impacts resulting from the use of chlor-alkali based products and options. In addition, the study does not assess and estimate the life cycle costs associated with product substitution. One reason is that there is a high level of uncertainty regarding product lifespan and disposal characteristics. Furthermore present value analysis used in life cycle costing is inconsistent with the national accounts framework which makes comparison of results with standard economic indicators problematic.

The market position and technical characteristics of options are compared for each chlor-alkali product studied in the report. Three principal economic variables are used to characterize and compare chlor-alkali products and options to those products:

1. direct replacement cost;
2. domestic revenues; and
3. manufacturing employment.

These economic variables are placed in context through the use of aggregates pertinent to the total size of the economy. The aggregate measures are, respectively: gross domestic

These economic variables are placed in context through the use of aggregates pertinent to the total size of the economy. The aggregate measures are, respectively: gross domestic product (GDP), domestic revenues of industries that use chlor-alkali products (end-use revenues) and total manufacturing employment.

For this study, the comparison focused on various products derived from the chlor-alkali industry throughout the production chain from initial electrolytic production of chlorine and caustic soda to various end-use consumption areas. The study provides a socio-economic comparison of all Canadian production of base chlor-alkali commodities (chlorine, caustic soda, hydrochloric acid) and the PVC precursors EDC and VCM.

Following the chlorine "tree" from production to end use, certain applications were selected for comparison based on the earliest point at which options were commercially available. For example, while there are options to direct chlorine end-use in water treatment, the evaluation of options to chlorine used for PVC had to be carried out in tertiary PVC markets, where alternatives are available, rather than at the intermediate manufacture of EDC and VCM. The study provides a socio-economic examination and direct replacement cost analysis of options in 28 chlorine and derivative applications which account for approximately three-quarters of the net domestic consumption of chlorine contained in products derived from the chlor-alkali industry. The remaining volume of chlorine not covered in the analysis includes many smaller applications¹. Many pharmaceuticals and pesticides which contain a relatively small quantity of chlorine were not examined quantitatively, but only qualitatively. Although the majority of the study focuses on the chlorine tree, a direct replacement cost analysis was also provided for caustic soda since it is a co-product of elemental chlorine production.

E.2 Approach and Methodology

The general approach in this study was to define where chlor-alkali derived products are used and identify options to the use of these products, which had a competitive position in the marketplace, either domestically or internationally.² The reference year for quantity data used in the analysis is 1993, while calculations of costs and revenues data for products with volatile prices are based on average prices for the period 1988 to 1993. In early 1995, when

¹ Smaller applications include: about 10% of PVC products (4% of net domestic consumption of chlorine); smaller hydrochloric acid applications (12%); non-household uses of sodium hypochlorite bleach (2%); chlorine use in production of propylene oxide and aluminum chloride (3% and 2% - both discontinued after 1993); miscellaneous chlorinated solvent uses (1%); and miscellaneous uses (1%).

² In some cases (e.g., water treatment), the identified options include smaller quantities of chlor-alkali industry products. In a few cases, the consultant's best judgment was used in selecting options to chlor-alkali based products which are not currently in the marketplace. These options are found in PVC flexible sheet used in vehicle trim and swimming pool liners, PVC wire & cable, and polychloroprene.

the study was initiated, 1993 was the latest year for which final economic statistics were available.

A comparison of the technical characteristics of products derived from the chlor-alkali industry and options is provided. The purpose of the technical comparison is to identify the important characteristics of options, screen and select the best option(s) and provide context to the cost analysis. The results of the technical comparison are not an endorsement of any of the products analysed.

The direct replacement cost analysis involves the development of models of substitution for primary producers, manufacturers, municipalities, household consumers or other economic entities which would directly incur the costs of adopting the various options. Only direct capital and operating costs are included in the analysis. Direct replacement costs are calculated from capital costs, annualized at a rate of 9% over 20 years, added to annual incremental operating costs. These total annualized costs are compared to end-use revenues for selected applications of study. End-use revenues refer to the domestic revenues³ of sectors or industries which use chlor-alkali products. Employment data is also compared. Employment associated with products derived from the chlor-alkali industry is compared with manufacturing employment in Canadian sectors providing options.

Information for this study was collected from literature sources, industry participants and associations, consultants and the files of CHEMinfo Services. Environment Canada coordinated a stakeholder review process for the report in order to ensure that relevant information and perspective from industry participants, environmental non-government organisations (ENGO) and other stakeholders was incorporated in the study.

E.3 Summary of Results

There are two estimates provided for the total annual direct replacement costs for chlor-alkali based products covered in this study. The low and high cost estimates reflect the choice of different products or processes that are available as options. The total annual direct replacement costs for the chlor-alkali products assessed in this study is \$1.9 billion for the low cost estimate and \$4.3 billion for the high cost estimate. For selected products where end-use revenues could be identified and quantified, the total low and high direct replacement costs account for 0.7% and 1.7% of end-use revenues respectively. In this analysis of selected products, the total end-use revenues identified are \$170 billion, accounting for roughly 24% of GDP in 1993 (\$712 billion). In the context of the entire

³Domestic revenues are defined as the revenues generated by shipments of domestically produced goods. Domestic sales are defined as the domestic consumption of goods. Domestic revenues equal domestic sales plus the trade balance. The trade balance is calculated as the value of exports minus imports.

economy, the low and high direct replacement costs represent 0.3% and 0.6% of GDP in 1993, respectively. The low and high direct annualized replacement costs also represent 7.9% and 18.5%, respectively, of average annual growth in nominal GDP for the 5-year period 1988 to 1993⁴. Table 1-1 summarizes the key results of this study.

Table E-1: Overall Summary of Results

	Direct Replacement Cost (\$ million/yr)		Domestic Revenues (\$ million/yr)		Employment	
	Low	High	Chlor-alkali	Product or Sector Options	Chlor-alkali	Product or Sector Options
Base Commodities	618	1495	485	1675	1305	4356
PVC	553	2171	2072	31138	6908	173931
Other Chlorinated Substances	681	681	133	2057	475	4099
Total	1852	4347	2690	34870	8688	182386

The total annual domestic revenue for chlor-alkali products studied is estimated at \$2.7 billion. This represents 0.38% of GDP in 1993. Option products come from a broad range of industrial sectors, some of which are quite large (e.g., wood products) and include products which may not directly compete with those derived from the chlor-alkali industry. The total domestic revenues of specific industrial product options and all broad sectors offering options to chlor-alkali products is \$35 billion, representing 5% of GDP. These totals are aggregated from Tables S-15, S-18 and S-20 in the Summary chapter, which rank the domestic revenues of chlor-alkali products with the domestic revenues of specific product options and sectors providing options. In the base commodities category, chlor-alkali products ranked third (caustic soda), eighth (elemental chlorine) and ninth (hydrochloric acid) out of ten chemical commodities assessed. Total PVC products ranked fifth out of six industrial sectors providing option products. In the other chlorinated substances category, chlor-alkali products ranked fifth (household bleach), sixth (chlorinated refrigerants) and ninth (chlorinated additives) out of twelve products assessed. However, in many market segments in which there is direct competition among specific options, chlor-alkali based products command a significant market share. This is reflected in Tables S-2, S-3 and S-4 in the Summary chapter.

⁴ Statistics Canada: Report 13-201 PPB

Total employment for chlor-alkali products is estimated at 8,688 people. This represents 0.49% of total manufacturing employment (1,787,000) in Canada in 1993. The total manufacturing employment for all sectors providing options is 182,386, representing 11% of total manufacturing employment in Canada. The majority of employment is in sectors providing options to PVC products. These totals are aggregated from Tables S-22, S-24 and S-26 in the Summary chapter, which rank the relative employment levels of chlor-alkali products and their product or sector options. In the base commodities category, chlor-alkali employment ranks second out of eight chemical commodities producing industries. In the PVC products category, PVC employment ranks fifth out of six industrial sectors. In the other chlorinated substances category, chlor-alkali products rank second (household bleach), fifth (chlorinated refrigerants) and tenth (chlorinated paraffins) out of ten industries assessed.

The low estimate for direct annualized replacement costs is dominated by two applications: chlorinated refrigerants and PVC flooring. The identified options are hydrofluorocarbon refrigerants (\$481 million) and polyolefin sheet flooring (\$336 million), respectively. The high estimate is dominated by costs for four applications: chlorine and chlorine dioxide use in chemical pulp production, PVC siding, chlorinated refrigerants and PVC flooring. The options identified are, respectively: totally chlorine free (TCF) pulp bleaching (\$986 million), clay brick facing (\$1,253 million), hydrofluorocarbon refrigerants (same as low cost estimate - \$481 million), and a combination of ceramic tile and carpet flooring (\$426 million).

The total PVC manufacturing industry accounts for approximately 77% of domestic revenues (\$2,072 million) associated with chlor-alkali industry products. Production of PVC and manufactured items also account for 80% of employment associated with chlor-alkali products. The individual chlor-alkali products having the highest domestic revenue value are all PVC products: windows (\$556 million), flooring (\$360 million), and pipe (\$358 million). Caustic soda, with revenues of \$336 million, has the highest revenues of any other chlor-alkali product, because of the large merchant market. Elemental chlorine and hydrochloric acid are relatively low value commodities, with domestic revenues of \$80 million and \$29 million respectively. The highest revenues associated with industrial sectors supplying options to PVC products are: wood products (\$19,083 million), other plastic products (\$4,655 million), aluminum metal products (\$3,707 million) and textile products (\$2,876 million). In terms of base commodities, the options having the highest domestic revenue value are: sulphuric acid (\$554 million) and sodium chlorate (\$440 million). For chlorinated solvents used for cleaning applications, the sector offering product options with the highest domestic revenue is the soaps and detergents industry (\$1,600 million).

E.4 Context of Results

Products derived from the chlor-alkali industry are used widely in the Canadian economy. Practically every industrial, commercial and institutional facility as well as consumers come into daily contact with products that contain chlor-alkali products or are made from processes using chlor-alkali products. Paper, paint, pipe, house siding, wire and cable, and potable water are all examples of items that incorporate products derived from the chlor-alkali industry. However, in general, all of these products are also made using materials derived from other industries. In most cases, there are costs associated with using options that provide comparable functionality to products derived from the chlor-alkali industry. With some exceptions, these additional costs generally represent a relatively small proportion of the total revenues of the sector or industry using or incorporating chlor-alkali industry products.⁵

Direct costs differences are not the only factor influencing product use in a dynamic economy, characterized by the continual process of development and growth of new industries and markets, and the demise of others over time. Other factors include: product and process innovation, social pressure, and government influence. There have been several major trends over the last decade affecting the chlor-alkali industry that are illustrative of these other factors.

The two principal trends affecting chlor-alkali industry products have been the decline in elemental chlorine use in chemical pulp production, and the growth of PVC products in construction. In the case of chemical pulp bleaching, environmental concerns and related government regulation have influenced the substitution of ECF (elemental chlorine free) bleaching for elemental chlorine bleaching. This trend has led to the contraction of the chlor-alkali industry's production of elemental chlorine, and the growth in the production and use of sodium chlorate and oxygen in Canada. Sodium chlorate is the raw material for production of chlorine dioxide used as a substitute for elemental chlorine in ECF bleaching. Oxygen has been adopted by numerous chemical pulp mills as an effective agent to assist in the delignification and bleaching of wood pulp. In the construction market, PVC products with lower costs and comparable technical properties have substituted for traditional materials such as iron, aluminum, wood and concrete. The PVC industry has grown while the market share of traditional materials industries has contracted.

In both cases, chemical pulp production and construction continue while competing industries have adjusted to supply inputs to these economic activities. The observation of

⁵ Markets where the direct replacement costs represent more than 10% of end-use revenues include: chemical pulp bleaching (TCF option); titanium dioxide, choline chloride, household bleach, paint stripper and commercial refrigeration.

a dynamic, innovative and competitive economy addressing social needs is an important perspective to be retained in considering the importance of chlor-alkali products, and options to those products, in the Canadian economy.

Summary

S.1 Introduction

The report is a technical and socio-economic comparison of options to products derived from the chlor-alkali industry in the Canadian economy. Chlor-alkali products are defined as products originating from the electrolysis of sodium chloride into elemental chlorine and caustic soda. For the purposes of this report chlor-alkali products are classified into three broad categories:

1. **base commodities** produced by the chlor-alkali industry
(e.g., elemental chlorine, caustic soda, hydrochloric acid);
2. **polyvinyl chloride (PVC) resin products**
(e.g., pipe, siding, windows, flooring, wire & cable, bottles, film & sheet); and
3. **other chlorinated substances**
(e.g., household bleach, chlorinated solvents, refrigerants, flame retardants, etc.).

The classification stems from the observation that most Canadian chlor-alkali plants which manufacture elemental chlorine and caustic soda limit production to these two basic commodities, along with some hydrochloric acid. The exception is the Dow Chemical plant located in Fort Saskatchewan, Alberta, which also manufactures ethylene dichloride and vinyl chloride monomer, the precursors necessary for the production of polyvinyl chloride (PVC) resin. Since the PVC industry is the single largest domestic use of elemental chlorine, and employs a sizeable domestic manufacturing base, it will be considered as a separate category. The other chlorinated substances category refers to various higher value-added chlorinated products which are primarily imported¹ into Canada.

Both the basic commodities and the many chlorinated substances have many and varied applications. The method employed in this study was to choose the major products and applications of the chlor-alkali industry and develop a technical description and quantitative socio-economic analysis of (1) the chlor-alkali product, and (2) the alternatives to that product, within the particular application studied. The products and applications areas studied are listed in Table S-1.

¹ The significant exceptions where other chlorinated substances are manufactured in Canada are: household bleach (sodium hypochlorite), chlorinated paraffins, and the refrigerant HCFC-123.

Table S-1: Products and Applications Studied

Base Commodities		Polyvinyl Chloride		Other Chlorinated Substances	
Products	Applications	Products	Applications	Product	Applications
Elemental chlorine	Pulp and Paper, Water and wastewater treatment, Titanium dioxide	Pipe (Water, Sewage, etc.)	Municipal/ Industrial Construction	Sodium hypochlorite	Household bleach
		Siding	Residential Construction	Tetrachloroethylene	Dry Cleaning
Caustic soda	Pulp and paper, Alumina, Soaps and detergents, Metal mining (gold), Petrochemicals (oil sands)	Windows		Trichloroethylene	Metal Degreasing
		Flooring	Residential/ Commercial Construction	Methylene Chloride	Paint stripper, Polyurethane slab
Hydrochloric acid	Steel pickling, Choline chloride	Wire and Cable		Chlorinated Flame Retardants	Plastics
		Food Wrap	Packaging	Short Chain Chlorinated Paraffins	Metal Working
		Bottles	Packaging	Chlorinated Refrigerants	Refrigeration units, Mobile air conditioners
		Sheet, rigid	Packaging	Polychloroprene	Automobiles
		Sheet, flexible	Transportation equipment, Swimming pools		

This report does not address potential or real environmental damages or risks generated by chlor-alkali products, or alternatives. However, references to environmental regulation or environmental or public health considerations will be used where this information is appropriate in explaining market trends.

Two applications, pharmaceutical and pesticides, are not analyzed quantitatively, but qualitatively. These two industries employ a small amount of chlorine to generate a myriad of products. A quantitative analysis of the products generated by these two industries is beyond the scope of a study of this nature and so the assessment was limited to a qualitative technical and socio-economic description. This description is found in Chapters 19 and 20.

The report is organized to correspond to the classification of chlor-alkali products suggested above. Part One (Chapters 2-8) covers the base commodities of the chlor-alkali industry, Part Two (Chapters 9-10) describes the polyvinyl chloride industry, and Part Three (Chapters 11-20) describes other chlorinated substances.

S.2 Methodology

In each chapter, the report compares chlor-alkali products and options in five sections; market analysis, technical description, direct replacement cost, direct replacement cost compared to end-use revenues and socio-economic profile. The socio-economic profile contains information on production, imports and exports, revenues and employment. Due to considerations of data availability, the base year for the study is 1993.²

For various applications, the market analysis describes the market size, share and trends for products. The technical description evaluates the technical characteristics (e.g., durability, flammability) of the chlor-alkali product and their options and identifies substitution issues. The direct replacement costs are estimates of the capital³ costs and incremental operating⁴ costs associated directly with immediate substitution. A full life cycle costing approach was not used due to: a lack of data; technical difficulties involved in projecting over the life span of products; uncertainties associated with determining relative product characteristics and the nature and cost of disposal.

In order to provide context, the direct replacement costs are compared to the revenues of the end-use sector which employs the chlor-alkali product.⁵ End-use refers to a product which is either purchased by a domestic consumer, or exported. For example, elemental chlorine is used as an input in the production of chemical pulp in pulp and paper mills. In this application, chemical pulp is considered to be the end-use of elemental chlorine, and the direct replacement costs between elemental chlorine and alternatives (e.g., chlorine dioxide) are compared to the domestic revenues generated by the sale of chemical pulp.

The key socio-economic indicators derived from the profile are the value of domestic sales, the trade balance, domestic revenues and employment. A proxy for labour intensity used is

² In cases where materials had volatile prices, an average price from 1988-1993 was used in the direct replacement cost analysis. The same method was used to estimate revenues.

³ Capital costs are amortized over a twenty year period at a 9 % interest rate.

⁴ Operating cost components can include: material, labour (installation, operating, maintenance), utility and distribution costs.

⁵ While not a direct analogy, this ratio is similar to the increase in price of the end-use product given substitution for chlor-alkali products.

the ratio of employment⁶ to domestic revenues. Domestic revenues are the sum of the value of domestic sales and the trade balance. The trade balance is calculated as the value of exports minus the value of imports. Domestic revenues are equivalent to the value of shipments of goods of domestic manufacture recorded in Statistics Canada publications. They are used as a proxy for contribution to gross domestic product (GDP)⁷.

Information and data collected for the market, technical, costing and socio-economic components of this study were drawn from three key sources: 1) publicly-available databases; 2) literature review; and 3) interviews with various stakeholders.

The sections in this summary will follow the format of the chapters, with the exception of the technical description. Interested readers should refer to the main body of the report for a description of the technical characteristics of chlor-alkali products and alternatives.

S.3 Domestic Market Share and Trends

In the majority of applications, the options selected are products (or processes) which directly compete commercially with products of the chlor-alkali industry, either domestically, or in markets in other countries⁸. In some applications, only one alternative was identified and quantified. In others, two or more alternatives were identified. Simplifying assumptions were required to reduce the complexity of the analysis.

Some of these applications with multiple alternatives were segmented further and a multi-layered substitution model was developed. The models for PVC pipe, flooring, and wire & cable are examples. In some applications, two alternative substitution models with different costs were considered as "low" and "high" cost alternatives. The terms "low" and "high" cost alternative are used solely to describe two different alternatives that have been identified as reasonably possible substitution models. The use of these terms is not meant to imply that there are no alternatives with either lower or higher costs than these two values.

⁶ Employment is defined as Canadian employment in plants manufacturing chlor-alkali, and alternative, products.

⁷ In reality the contribution to GDP is measured by value added throughout the production chain for goods and services in the economy. For reasons of practicality domestic revenues were used as a proxy for contribution to GDP. This will tend to over estimate the value of goods by a factor of two. For example, in 1993 domestic revenues for plastic products industries were \$ 6.1 billion, while the value added was \$ 2.9 billion.

⁸ A limited number of exceptions were made in applications where there was no fully commercialized direct substitutes. The assumptions that an option would be able to substitute for a chlor-alkali product were made based on best available input from industry technical experts contacted. These exceptions include: polyolefin for PVC flooring, some options to PVC compound in wire and cable, PVC flexible sheet for swimming pools, short-chain chlorinated paraffins in metal working fluids and polychloroprene.

The following sections will describe market share, and trends in the use of chlor-alkali products. A high market share refers to a market share over 70%, a medium market share to a market share between 30 and 70%, and a low market share refers to a market share under 30%. The trend description refers to the trend in the use of the chlor-alkali product.

S.3.1 Base Commodities

Table S-2 lists the alternatives, and their domestic market share, for the base commodities of elemental chlorine, caustic soda, and hydrochloric acid. In most applications, the product of the chlor-alkali industry dominates the alternatives, with the exception of chemical pulp production. While elemental chlorine pulp bleaching was the dominant production technology up to the late 1980's, this technology has been rapidly displaced by elemental chlorine free (ECF) bleaching technology using chlorine dioxide (which is generated using sodium chlorate). Environmental concerns and related regulations, at both the federal and provincial levels are primarily responsible for this downward trend.

The decline in use of elemental chlorine bleaching has also affected the use of electrolytic caustic. The use of ECF bleaching technology (chlorine dioxide) generates the by-product of salt cake (sodium sulphate). Salt cake is an alternative source of caustic, and has been displacing electrolytic caustic soda use in the pulp and paper industry, leading to a slight declining trend in the use of electrolytic caustic. For details, see Chapter 4.

The chlor-alkali industry has responded to both of these trends through plant closures, reduced production and increasing exports of elemental chlorine. In 1993, almost 25% (293 kilotonnes) of the domestic supply of elemental chlorine (1,185 kilotonnes) was exported⁹. In the twelve years between 1988 and 2000, domestic production of elemental chlorine is expected to decline 45% from 1,700 to 940 kilotonnes, with a corresponding 34% decrease in employment from 1506 to 989 people.

Environmental concerns have influenced adoption of alternatives to chlorine based technology for potable water, wastewater treatment, and titanium dioxide production. In water and wastewater treatment, environmental concerns related to chlorinated by-products in drinking water, and concerns of chlorinated wastewater effluent have prompted the installation of alternative technologies such as ozone and UV radiation, at some treatment facilities. In the case of titanium dioxide production, environmental concerns resulted in the opposite trend as the chloride process of making the pigment displaced the use of the older sulphate process.

⁹ In 1993, the largest domestic use of elemental chlorine (460 kT - 39% of the total) was for the production of EDC, a precursor of PVC resin. About half of this EDC (214 kT of contained chlorine) was exported and the remainder was used domestically to produce VCM for PVC resin. See Chapter 9 for details of the PVC production industry.

Table S-2: Domestic Market Shares and Trends, 1993
(Base Commodity Chlor-Alkali Products and Alternatives)

Base Chlor-alkali products and applications	Share Chlor-alkali Product	Alternative Product or Process 1	Share Alternate Product 1	Alternative Product or Process 2	Share Alternate 2	Trend
Electrolytic Caustic	high	Soda ash, lime	low	Salt cake	low	Slight Down
Elemental Chlorine						
Chemical Pulping	low	ECF (Elemental chlorine free) bleaching	medium	TCF (Total chlorine free) bleaching	low	Strong Down
Water Treatment	high	Ozonation	low			Slight Down
Wastewater Treatment	high	Ultraviolet radiation	low			Slight Down
Titanium Dioxide	medium	Sulphate process	low			Slight Up
Hydrochloric Acid						
Steel Pickling	medium	Sulphuric Acid	low			Stable
Choline Chloride	high	Choline Bitartrate	low			Stable

S.3.2 Polyvinyl Chloride Products

In contrast to the base commodities, many PVC products do not dominate their applications, but many have expanding market shares. The largest uses of PVC and those applications with increasing market share, are related to municipal utilities and the residential housing and commercial construction industry. Table S-3 describes alternatives, market share, and trends in the use of PVC products.

Table S-3: Domestic Market Shares and Trends, 1993
(PVC Products and Alternatives)

PVC Products and Applications	Share (PVC)	Alternative Product (1)	Share (alt 1)	Alternative Product (2)	Share (alt 2)	Trend in PVC use
Water Pipe	Medium	HDPE	Low	Ductile iron	Low	Slight up
Sewer Pipe	Medium	HDPE	Low	Concrete	Medium	Slight up
Drainage Pipe	Low	HDPE	Medium	Concrete	Medium	Stable
DWV (Drain, Waste, Vent) pipe	Low	ABS	Medium	Copper/Iron	Medium	Slight up
Other Pipe (Industrial)	Medium	HDPE	Medium	HDPE	Medium	Stable
Siding	High	Aluminum	Low	Clay brick	Low	Slight up
Window Profiles	Medium	Wood	Medium	Aluminum	Low	Strong up
Flooring	Low	Polyolefin	Low	Ceramic tile, Carpet	Low	Slight down
PVC Compound, Wire and Cable	Medium	PE, XLPE, TPE	Low			Slight down
Food Wrap	High	PE	Low			Stable
Plastic Bottles	Low	PET	High	HDPE	Low	Slight down
Rigid Sheet, Thermoformed Packaging	High	PET	Low	OPS	Low	Stable
Flexible Sheet, Vehicle Trim	Low	Fabric	High	TPOs, TPUs	Low	Slight down
Flexible Sheet, Swimming Pools	High	Concrete	Low	Fibreglass	Low	Slight up

Plastics Acronyms:

PE - polyethylene

PET - polyethylene terephthalate)

TPE - thermoplastic elastomer

HDPE - high density polyethylene

ABS - acrylonitrile-butadiene-styrene

TPO - thermoplastic olefin

XLPE - cross-linked polyethylene

OPS - oriented polystyrene

TPU - thermoplastic urethane

In contrast to the base commodities, environmental concerns do not play a major part in explaining trends in the use of PVC products. The explanation of trends in PVC products stems from both the cost characteristics of PVC products (generally, but not exclusively, less expensive than alternatives), and the technical and aesthetic characteristics of PVC products. Costs will be analyzed in the next section on direct replacement costs.

In some applications, technical factors partially account for increasing use of PVC products. Some examples are non-corrosivity (pipe), ability to produce flexible compounds (wire & cable, film, sheet), and fire retardancy (commercial DWV pipe, wire and cable). A slight

declining trend is observed in PVC flooring, flexible sheet used in car upholstery, and bottles, which is due mostly to competition from alternatives having higher aesthetic appeal.

S.3.3 Other Chlorinated Substances

The category of other chlorinated substances is more mixed in terms of market share than either the base commodities or PVC compounds categories. In the major other chlorinated substance uses (dry cleaning, household bleach, refrigerants, paint stripper) the chlorinated substances dominate the market, while in some of the smaller applications (degreasing, flame retardants, polychloroprene) the chlorinated substances have a relatively small market share. Table S-4 describes alternatives, market share, and trends in the use of other chlorinated substances.

Table S-4: Domestic Market Shares and Trends, 1993
(Other Chlorinated Substances and Alternatives)

Other Chlorinated Products	Chlorinated Substance Share	Alternative 1	Alternate 1 Share	Alternative 2	Alternate 2 Share	Trend
Sodium hypochlorite (Household Bleach)	high	Hydrogen Peroxide	low	Sodium perborate	low	Stable
Tetrachloroethylene (Dry Cleaning)	high	Hydrocarbon solvents	low	Aqueous Cleaning	low	Slight down
Trichloroethylene (Metal Degreasing)	low	Hydrocarbon solvents	high	Aqueous & Semi-Aqueous Cleaning	low	Slight down
Dichloromethane (Paint stripper, Polyurethane slab)	high	Hydrocarbon solvents	low	CO2 injection	low	Slight down
Chlorinated Refrigerants (CFCs, HCFCs)	high	Hydrofluoro carbons (HFCs)	low			Slight down
Chlorinated Flame Retardants (Plastics)	low	Aluminum trihydrate	medium	Phosphate esters	low	Stable
Short Chain Chlorinated Paraffins (Metal Working)	high	Over based sulfonate package	low			Stable
Polychloroprene (Rubber)	low	NBR	low	EDPM	low	Stable

As with the base commodities category, the principal factors explaining market trends in other chlorinated substances are environmental concerns and environmental regulation. All of the chlorinated solvents cited (tetrachloroethylene, trichloroethylene, dichloromethane) as well as short chain chlorinated paraffins have been declared toxic under the Canadian Environmental Protection Act (CEPA). Currently, the federal government is consulting interested parties on possible management options to reduce the use of these substances. The Montreal Protocol concerning ozone depleting chemicals explains the trend in chlorinated refrigerants. Under this protocol, manufacturing and sale of CFCs is banned as of 1996, with HCFCs expected to be phased out by 2020.

S.4 Direct Replacement Costs

The direct replacement costs are an estimate of the capital and operating costs associated with substituting the products of the chlor-alkali industry with the alternatives identified in section S-3 as of 1993. Capital costs are defined as one time changes in durable production technology, while operating costs are defined as changes in the annual cost of materials purchased and labour used. In some cases, more than one alternative was identified and quantified, generating multiple layered models or low cost and high cost alternatives.

S.4.1 Base Commodities

Table S-5 identifies the annual direct replacement costs for the base commodities category of chlor-alkali products. The low cost estimate is \$618 million/year, while the high cost estimate is \$1,495 million/year. In the base commodities category, pulp and paper was the only industry in which two substitution models were developed, one each for the distinctly different modes of chlorine free bleaching (ECF and TCF). The difference between low and high cost alternatives is based on whether chemical pulp bleaching technology changes from ECF (elemental chlorine free) to TCF (total chlorine free) bleaching. The majority of direct replacement costs for the base commodity category of chlor-alkali production are capital costs associated with changes in the production technology.

Table S-5: Direct Replacement Costs
(Base Commodity Chlor-Alkali Products)

Base Chlor-Alkali Products and Applications	Alternatives	Low Cost Alternatives (\$ millions/yr)				High Cost Alternatives (\$ millions/yr)			
		Capital (\$M)	Annual Capital	Annual Operating	Total Annual	Capital (\$M)	Annual Capital	Annual Operating	Total Annual
Electrolytic Caustic	Chemical Caustic	730	80	50	130	730	80	50	130
Elemental Chlorine									
Pulp Bleaching	ECF (Low) TCF (High)	997	109	(20)	89	3161	346	620	966
Water Treatment	Ozone	583	64	12	76	583	64	12	76
Wastewater Treatment	Ultraviolet Radiation	154	17	0	17	154	17	0	17
Titanium Dioxide	Sulphate Process	273	30	31	61	273	30	31	61
Hydrochloric Acid									
Steel Pickling	Sulphuric Acid	2	<1	46	46	2	<1	46	46
Choline Chloride	Choline Bitartrate	0	0	199	199	0	0	199	199
Total		2739	300	318	618	4903	537	958	1495

S.4.2 Polyvinyl Chloride Products

For PVC products, the direct replacement costs are primarily operating costs, where operating costs are defined as annual changes in labour and material costs, rather than changes in production technology. For example, municipalities would continue to use water pipe, but would switch from buying PVC water pipe to another type of water pipe (i.e. HDPE, ductile iron). The capital costs involved in plant investment in alternatives in order to meet the additional demand of substituting for PVC products are assumed to be incorporated in the price of the alternate materials. Table S-6 summarizes the direct replacement costs for PVC products.

**Table S-6: Direct Replacement Costs
(PVC Products)**

PVC Products	Alternatives	Low Cost Alternatives (\$ millions/yr)				High Cost Alternatives (\$ millions/yr)			
		Capital (\$M)	Annual Capital	Annual Operating	Total Annual	Capital (\$M)	Annual Capital	Annual Operating	Total Annual
Water Pipe	HDPE (low), Ductile Iron (high)	0	0	20	20	0	0	20	20
Wastewater Pipe	HDPE (low), Concrete (high)	0	0	29	29	0	0	51	51
Drainage Pipe	HDPE (low), Concrete (high)	0	0	0	0	0	0	9	9
DWV pipe	ABS (low) ABS/Copper (high)	0	0	0	0	0	0	21	21
Other Pipe	HDPE	0	0	(5)	(5)	0	0	(5)	(5)
Siding	Aluminum (low), Clay brick (high)	0	0	80	80	0	0	1253	1253
Window Profiles	Wood (low), Aluminum (high)	0	0	(118)	(118)	0	0	55	55
Flooring	Polyolefin (low) Ceramic tile/Carpet (high)	0	0	338	338	0	0	426	426
PVC Compound Wire and Cable,	PE, XLPE, TPE	70	8	173	181	70	8	173	181
Food Wrap	PE	0	0	(9)	(9)	0	0	(9)	(9)
Plastic Bottles	HDPE (low) PET (high)	10	1	(3)	(2)	14	2	2	3
Rigid Sheet, Packaging	OPS/PET	0	0	6	6	0	0	6	6
Flexible Sheet, Vehicle Trim	Fabric/TPO (low), Fabric/TPU (high)	0	0	25	25	0	0	60	60
Flexible Sheet, Pool Liners	TPE (low), Concrete (high)	0	0	8	8	0	0	100	100
Total		80	9	544	553	84	9	2162	2171

The annual low direct replacement cost estimate for PVC products is \$553 million/year. The largest costs are the direct replacement costs for PVC flooring (\$338 million/yr) and wire and cable (\$181 million/yr). PVC flooring, especially low-cost vinyl composition tile, dominates the low-cost flooring market and the recently-developed polyolefin alternative has a higher price. The alternative materials to PVC for wire and cable are expensive. The high cost estimate is \$2,171 million/yr. The magnitude of the high cost estimate for PVC products is largely due to the selection of relatively expensive clay-brick as the high cost alternative (\$1,253 million/year) in PVC siding.

S.4.3 Other Chlorinated Substances

The total direct replacement costs for other chlorinated substances is \$681 million annually. No high cost estimate was prepared for this category. These costs are dominated by the costs of replacing chlorinated refrigerants (\$481 million). Chlorinated refrigerants are being phased out under the Montreal Protocol on Ozone Depleting Substances. Some applications using chlorinated solvents (e.g., dry cleaning, degreasing) require a change in technology, and thus have primarily capital expenditures. The costs of the other chlorinated substances are primarily operating costs, or costs of material substitution. Table S-7 summarizes the direct replacement costs for the other chlorinated substances category of chlor-alkali products.

Table S-7: Direct Replacement Costs
(Other Chlorinated Substances)

Other Chlorinated Substances, Products and Applications	Alternatives	Direct Replacement Cost (\$ million/yr)			
		Capital (\$M)	Annual Capital	Annual Operating	Total Annual
Sodium hypochlorite (Household bleach)	Hydrogen Peroxide	0	0	56	56
Tetrachloroethylene (Dry Cleaning)	Hydrocarbon solvents (70%), Aqueous cleaning (30%)	231	25	18	43
Trichloroethylene (Metal Degreasing)	Aqueous cleaning	52	6	7	13
Dichloromethane (Paint Stripper, Urethane Foam)	Hydrocarbon solvents (Paint Stripper), CO2 injection (Polyurethane slab)	39	4	25	29
Chlorinated Refrigerants (CFCs, HCFCs)	HFCs	0	0	481	481
Chlorinated Flame Retardants	Aluminum trihydrate (33%) Phosphate esters (33%), Brominated organics (33%)	0	0	13	13
Short Chain Chlorinated Paraffins (Metal Working Fluids)	Over based sulfonate package	0	0	1	1
Polychloroprene	NBR (33%), EDPM (33%), High Performance Rubber Compound (33%)	0	0	45	45
Total		322	35	646	681

S.4.4 Summary of Direct Replacement Costs

The low direct replacement cost estimate is \$1.9 billion/year, with the cost fairly evenly distributed over the three categories of products. The largest single direct replacement cost estimate is the cost of substituting for the refrigerants CFC and HCFC (\$481 million/yr). The other dominant cost is the cost of substituting for PVC flooring (\$338 million/yr).

The high direct replacement cost estimate is \$4.3 billion/year. The largest direct replacement costs are those of clay-brick for PVC siding (\$1,253 million/yr) and the use of TCF pulp bleaching (\$966 million/yr), which together account for about 50% of the total. The alternatives of ceramic tile and commercial carpeting for PVC flooring (\$426 million/yr) and HFC refrigerants also have significant direct replacement costs. Table S-8 summarizes the total direct replacement costs for each category of chlor-alkali products.

Table S-8: Summary of Direct Replacement Costs

Categories	Low Cost Alternatives (\$ million/yr)				High Cost Alternatives (\$ million/yr)			
	Capital (\$M)	Annual Capital	Annual Operating	Total Annual	Capital (\$M)	Annual Capital	Annual Operating	Total Annual
Base Commodities	2739	300	318	618	4903	537	958	1495
PVC	80	9	544	553	84	9	2162	2171
Other Substances	322	35	646	681	322	35	646	681
Total	3141	344	1508	1852	5309	582	3765	4347

S.5 Direct Replacement Costs Compared to End Use Revenues

The direct replacement costs in the applications of products of the chlor-alkali industry occur at various stages in the value added chain of production which end in a product which is either bought by a domestic consumer, or exported outside of the country. In some cases the product of the chlor-alkali industry is a primary or intermediate good which is an input to the end-use product (e.g., elemental chlorine used to produce chemical pulp). In other cases the chlorinated product is a component of the final product, or end-use, which is bought by the consumer (e.g., sodium hypochlorite in household bleach, dichloromethane in paint thinner).

In order to place the direct replacement costs in context, the direct replacement costs of selected PVC products will be compared to the revenues derived from the final products either sold to the domestic consumer, or exported¹⁰. These revenues will be referred to as end-use revenues. End-use revenues are used because they are the most accessible data to place the direct replacement costs in context. The closest analogy to this ratio of cost to revenues is that of a price increase in the end-use market.

S.5.1 Base Commodities

In the industries for which comparisons were made, the direct replacement costs were 1.6% of end-use revenues using the low cost alternatives and 3.9% using the high cost alternatives. Three industries have direct replacement costs over 10% of revenues. These are: chemical pulp mills using the TCF alternative (13%), titanium dioxide (30%), and choline chloride (252%) producing industries. Both the titanium dioxide and choline chloride producing industries have one plant located in Canada. The five industries which have costs below 0.5% of end-use revenues are: steel pickling (0.5%), newsprint and mechanical papers (0.3%), metal mining (0.3%), aluminum smelting and refining (0.2%), and petrochemicals (0.1%). Table S-9 summarizes the ratios of direct replacement costs to end-use revenues for base commodities.

¹⁰ Since not all end-use revenues could be quantified, this section compares only those direct replacement costs related to the end-use revenues which could be quantified. In particular, for trichloroethylene (TCE), the direct replacement costs presented here (\$7 million) are only a portion of the total direct replacement costs (\$13 million) shown in section S.4. Therefore total direct replacement costs in Table S-12 are slightly less than figures in Table S-7 and S-8.

**Table S-9: Direct Replacement Costs Compared
to End-Use Revenues**
(Selected Applications of Base Commodities)

Base Commodity Chlor-Alkali Products and Applications	Direct Replacement Cost (Low) (\$ million/yr)	Direct Replacement Cost (High) (\$ million/yr)	End-Use Revenues (\$ million/yr)	Cost/Revenues (low) (%)	Cost/Revenues (high) (%)
Electrolytic Caustic					
Chemical pulp	70	70	7692	0.9%	0.9%
Newsprint and Mechanical papers	17	17	6006	0.3%	0.3%
Aluminum Smelting and Refining	10	10	5294	0.2%	0.2%
Soaps and Detergents	9	9	1602	0.6%	0.6%
Metal Mining (Gold)	6	6	2093	0.3%	0.3%
Petrochemicals (tar sands)	3	3	2057	0.1%	0.1%
Elemental Chlorine					
Pulp Bleaching	89	966	7692	1.2%	12.6%
Water Treatment	76	76	2297	3.3%	3.3%
Wastewater Treatment	17	17	985	1.7%	1.7%
Titanium Dioxide	61	61	177	34%	34%
Hydrochloric Acid					
Steel Pickling	46	46	10100	0.5%	0.5%
Choline Chloride	199	199	79	252%	252%
Total	604	1481	38382¹¹	1.6%	3.9%

S.5.2 Polyvinyl Chloride Products

PVC products are both intermediate and end-use goods. For example, PVC siding is an intermediate good when used in the construction of a new residential home, and an end-use good when bought by a home owner. In order to account for this two measures will be used. The first, as shown in Table S-10, is a comparison of the direct replacement cost to total

¹¹ Total does not equal the sum, since chemical pulp bleaching appears more than once and is not double-counted.

revenues generated in the markets for PVC products. For example, the direct replacement cost for PVC siding will be compared to the value of the total siding market for 1993. The second method of comparison is between the direct replacement cost and the value of end use products in which they are incorporated.

**Table S-10: Direct Replacement Costs Compared to
Total Market Value
(PVC Products)**

Product Markets	Direct Replacement Cost (Low) (\$ million/yr)	Direct Replacement Cost (High) (\$ million/yr)	Total Market Value (\$ million/yr)	Cost/Total Market Value (L) (%)	Cost/Total Market Value (H) %
Water and Sewer Pipe	49	71	1280	4%	6%
Other Pipe	(5)	25	668	(1)%	4%
Siding	80	1253	823	10%	152%
Window Profiles	(118)	55	1200	(10)%	5%
Flooring	338	426	3000	11%	14%
Wire and Cable PVC Compound	181	181	1600	11%	11%
Food Wrap	(9)	(9)	84	(11)%	(11)%
Plastic Bottles	(2)	3	225	(1)%	1%
Thermoformed Packaging	6	6	104	6%	6%
Vehicle Trim	25	60	497	5%	12%
Swimming Pool Liners	8	100	154	5%	65%
Total	553	2171	9635	6%	23%

In total, the direct replacement costs represent 6% of the value of product markets based on the low cost estimate, and 23% based on the high cost estimate. None of the low cost estimates is greater than 11% of the total market value. The three highest ratios are for substitutions with polyolefin for PVC flooring (11%), a variety of polymers for PVC in wire and cable (11%) and aluminum for PVC siding (10%). Markets exhibiting cost savings at the low cost estimate are: "Other pipe" (drainage, DWV, conduit) (1%), window profiles (10%), food wrap (11%) and plastic bottles (1%). The clay-brick alternative for siding and the concrete swimming pool alternative for pool liners have high cost ratios of 152% and 65%, respectively.

A second, and possibly more representative, comparison is between the direct replacement cost for selected PVC intermediate goods and the value of the end-use products in which they are incorporated. For example, the direct replacement costs for siding in new house construction can be compared to the total value of new residential construction. For simplicity, this measure will include the following selected end uses; water supply and sewage (water and sewer pipe), residential construction (siding, windows, wire and cable, and flooring), and transportation equipment (vehicle trim). In general, the other end-use markets for PVC products are too fragmented to assess. One example of this is all of the consumer products which incorporate PVC packaging (e.g., thermoformed rigid packaging, plastic bottles, food wrap). In the construction sector, about 60% of sales of siding, windows and flooring are associated with new residential construction, thus their direct replacement costs in Table S-11 have been reduced by 40%. Only about 10% of the PVC in wire and cable is used for residential construction.

Table S-11 summarizes the ratios of selected direct replacement costs to the revenues of end-use products which incorporate PVC products. The low cost estimate is 0.2% of revenues, while the high cost estimate is 1.1%. Using the low cost estimate the highest ratio is for pipe used in municipal water and wastewater at 1.5% of revenues. Cost savings are shown in windows used in residential construction (0.2%), where the substitute material is wood. Using the high cost estimate the highest ratio is the aggregate direct replacement costs for PVC used in construction, at 2.4% of the value of new residential construction. The largest individual ratios for PVC products used in construction are siding (1.8%) and flooring (0.6%), where the substitute materials are clay-brick and a combination of ceramic tile and commercial carpeting, respectively.

**Table S-11: Direct Replacement Costs Compared to
End-Use Revenues
(Selected PVC Products)**

End-Uses	Direct Replacement Cost (Low) (\$ million/yr)	Direct Replacement Cost (High) (\$ million/yr)	Value of End-Use Sales (\$ million/yr)	Cost/End- Use Revenue (Low) (%)	Cost/End- Use Revenue (High) (%)
Municipal Water Revenues (pipe)	49	71	3283	1.5%	2.2%
Transportation Equipment (vehicle trim)	25	60	64113	0.04%	0.1%
Residential Construction (siding)	48	752	42884	0.1%	1.8%
Residential Construction (windows)	(71)	33	42884	(0.2)%	0.1%
Residential Construction (flooring)	203	256	42884	0.5%	0.6%
Residential Construction (wire & cable compound)	10	10	42884	0.02%	0.02%
Total Residential Construction	190	1050	42884	0.4%	2.4%
Total	264	1181	110280 ¹²	0.2%	1.1%

S.5.3 Other Chlorinated Substances

In the category of other chlorinated substances, some products are end uses (bleach), some are intermediate goods (e.g., dry cleaning), and some are both. For example, refrigerants are used both to maintain existing equipment, and as part of new equipment. The direct replacement cost for refrigerants will be compared to the value of new equipment incorporating refrigeration or air conditioning units.

¹² Total does not equal the sum of the figures in the column to avoid double-counting.

**Table S-12: Direct Replacement Cost Compared to
End-Use Revenues**

(Selected Applications of Other Chlorinated Substances)

End-Uses And Chlorinated Substances	Direct Replacement Cost (\$ million/yr)	End-Use Revenues (\$ million/yr)	Cost/Revenues (%)
Household Bleach (Sodium hypochlorite)	56	94	60%
Dry Cleaning (Tetrachloroethylene)	43	740	6%
Steel Pipe And Tube (Trichloroethylene)	3	1563	0.2%
Aeronautics (Trichloroethylene)	2	4796	0.04%
Auto And Auto Parts (Trichloroethylene)	2	64113	<0.01%
Paint Stripper (Dichloromethane)	27	37	73%
Polyurethane Foam (Dichloromethane)	2	150	1.2%
Plastics (Flame Retardant)	13	1602	0.8%
Fabricated Metal Products (Short Chain Chlorinated Paraffins)	1	15404	0.01%
Commercial Refrigeration (CFC, HCFC)	66	342	19%
Domestic Appliances (CFC, HCFC)	4	917	0.4%
Transportation Equipment (CFC, HCFC)	35	64113	0.05%
Auto And Auto Parts (Polychloroprene)	24	64113	0.04%
Total	278	88195 ¹³	0.3%

For selected applications of other chlorinated substances, the direct replacement cost represents 0.3% of end-use revenues. The three end-uses with ratios of cost to revenues over 10% are: paint stripper (73%), household bleach (60%) and commercial refrigeration

¹³ The total for end-uses revenues does not equal the sum of the figures contained in the column, since steel tube is part of fabricated metal products and transportation (and auto and parts) equipment appears three times.

(19%). The paint stripper cost is high due to the high costs of commercial paint stripping alternatives. The household bleach alternative, hydrogen peroxide, currently has a low market share and a high price.

S.5.4 Summary of Selected Direct Replacement Costs Compared to End-Use Revenues

Table S-13 summarizes the ratios of direct replacement cost to end-use revenues by category, for selected products where end-use revenues could be identified and quantified. The total value of selected end-uses which could be determined and quantified is approximately \$170 billion, representing 24% of GDP in 1993 (\$712 billion). The direct replacement costs for chlor-alkali products in these end-uses ranges from 0.7% (\$1.1 billion) to 1.7% (\$2.9 billion) of end-use revenues. The category with the largest ratio is the base commodities category with a direct replacement cost of 1.6% (\$604 million) at the low cost estimate and 3.9% (\$1.5 billion) at the high cost estimate. The other chlorinated substances category has the lowest ratio at 0.3% (\$278 million) of end-use revenues.

In the context of the entire economy, the low and high direct replacement costs for all chlor-alkali products in the study represent 0.3% and 0.6% of GDP in 1993, respectively. The low and high direct replacement costs also represent 7.9% and 18.5%, respectively, of average annual growth in nominal GDP for the 5-year period 1988 to 1993.

Table S-13: Summary of Selected Direct Replacement Costs Compared to End-Use Revenues

Categories	Direct Replacement Cost (Low) (\$ million/yr)	Direct Replacement Cost (High) (\$ million/yr)	End-Use Revenues (\$ million/yr)	Cost/Revenues (Low) (%)	Cost/Revenues (High) (%)
Base Commodities	604	1481	38,382	1.6%	3.9%
PVC	264	1181	110,280	0.2%	1.1%
Other Chlorinated Substances	278	278	88,195	0.3%	0.3%
Total	1146	2940	169,461 ¹⁴	0.7%	1.7%

¹⁴Total for end-use revenues will not equal the sum of the three categories since transportation industry (\$64.1 billion), and water revenues (\$3.3 billion) appear twice within different categories.

S.6 Revenues

The revenues derived from the sale of products is another measure of the value or importance of the chlor-alkali industry and alternatives to the Canadian economy. Three measures of revenues will be used; domestic revenues, trade balance, and value of domestic sales. Domestic revenues are the sum of the value of domestic sales plus the trade balance. This section will compare revenues using two measures:

- a) domestic sales from applications compared to directly competing alternatives; and
- b) domestic revenues for chlor-alkali products compared to alternative product sectors.

S.6.1 Base Commodities

Base chlor-alkali products generate annual domestic sales of \$414 million compared to sales of alternatives of \$637 million in the applications studied. The main source of domestic sales revenues for chlor-alkali producers is caustic soda, while alternatives have the highest sales volume in the chemical pulp market, due to the on-going substitution of ECF bleaching for elemental chlorine bleaching. Chlorine use for EDC in the PVC production chain is excluded from this analysis and studied in Chapter 9 on the PVC Industry. Table S-14 presents the value of domestic sales, in specific markets, for base chlor-alkali products.

Table S-14: Domestic Sales Value
(Base Commodity Chlor-Alkali Products and Alternatives)

Base Chlor-Alkali Products And Applications	Domestic Sales of Base Commodities (\$ million/yr)	Alternatives	Domestic Sales of Alternatives (\$ million/yr)
Electrolytic Caustic	364	Lime, Soda Ash, Salt cake	248
Chemical Pulp Bleaching (Elemental Chlorine)	23	Sodium Chlorate, Hydrogen peroxide, Oxygen	374
Water And Wastewater Treatment (Elemental Chlorine)	16*	Ozone, UV Radiation Technology	8
Titanium Dioxide (Elemental Chlorine)	1	Sulphuric acid	5
Steel Pickling (Hydrochloric Acid)	8	Sulphuric Acid	2
Choline Chloride (Hydrochloric Acid)	2	Choline Bitartrate	0
Total	414		637

* Domestic sales includes packaged chlorine, not value of bulk sales (\$1.6 million) as reflected in Table S-15 and elsewhere.

Table S-15 shows the ranking of base chlor-alkali products, and alternatives, by domestic revenues in 1993. The ranking of base chlor-alkali products indicates that caustic soda has the highest market value of the chlor-alkali products, ranking third out of the 10 commodities assessed. Domestic revenues associated with caustic soda are estimated at \$386 million. Elemental chlorine and hydrochloric acid rank eighth and ninth respectively, with domestic revenues of \$70 and \$29 million. Chlorine has low domestic revenues by this measure, because only a small portion of it is sold directly to the market. As stated earlier, about 39% of chlorine is captively consumed for EDC and VCM manufacture for PVC production.

Table S-15: Ranking by Domestic Revenues
(Base Commodity Chlor-Alkali Products and Alternatives)

Rank	Base Commodities and Alternatives	Domestic Sales (\$ million/yr)	Trade Balance (\$ million/yr)	Domestic Revenues (\$ million/yr)
1	Sulphuric Acid	563	(9)	554
2	Sodium Chlorate	268	172	440
3	Caustic Soda	364	22	386
4	Oxygen	400	(100)	300
5	Hydrogen Peroxide	139	22	161
6	Soda Ash	111	(10)	101
7	Lime (calcium oxide)	91	4	95
8	Elemental Chlorine	33	37	70
9	Hydrochloric Acid	22	7	29
10	Salt cake (sodium sulphate)	13	11	24
	Total Chlor-Alkali Products	419 ¹⁵	66	485
	Total Alternatives	1585	90	1675

¹⁵ Total of \$419 million does not match Total in Table S-14 (\$414 million) since this table shows bulk value of all elemental chlorine domestic sales, and total value of hydrochloric acid (only a portion of which was covered in Table S-14).

S.6.2 Polyvinyl Chloride Products

In comparison to the base commodities which are primary goods, PVC products are intermediate and end-use goods. The production chain for polyvinyl chloride begins with ethylene dichloride (EDC) and vinyl chloride monomer (VCM). These commodities are produced at one plant in Canada, the Dow Chemical plant in Fort Saskatchewan, Alberta. PVC resin is polymerized from VCM at 3 facilities in Canada. PVC products can be produced directly from PVC resin, or indirectly with PVC compound. As these goods are precursors to PVC final products (e.g., pipe) domestic sales revenues are incorporated in the value of PVC products, but not the trade balance. Table S-16 below lists the trade balance for PVC precursors where a net annual trade deficit of \$40 million is generated by imports of PVC resin, and PVC compound.

Table S-16: Trade Balance for PVC Precursors, 1993

PVC Precursors	Trade Balance (Exports less Imports) (\$ millions)
EDC, VCM	66
Resin	(26)
Compound	(80)
Total	(40)

As PVC products are generally sold into one market, the value of domestic sales, trade balance and domestic revenues can be calculated for PVC products and alternatives in specific markets, as in table S-17 below. The total value of domestic sales of PVC products is \$1,820 million, with a trade surplus of \$45 million, and domestic revenues of \$1,865 million. This compares with domestic sales of \$2,965 million, a trade deficit of \$731 million, and domestic revenues of \$2,234 million for alternatives to PVC products competing in these specific markets. These markets account for approximately 90% of all PVC resin consumed in Canada.

Table S-17: Domestic Sales, Trade Balance, Domestic Revenues
(PVC Products and Alternatives)

PVC Products	PVC (\$ million/yr)			Alternative Product	Alternatives (\$ million/yr)		
	Domestic Sales	Trade Balance	Domestic Revenues		Domestic Sales	Trade Balance	Domestic Revenues
Pipe	329	29	358	HDPE, Duc Iron, Concrete, ABS	339	5	344
Siding	161	42	203	Aluminum, Clay brick	118	6	124
Window Profiles	463	93	556	Wood, Aluminum	786	(4)	782
Flooring	468	(108)	360	Polyolefin, Cer. tile/ Carpet	1034	(295)	739
PVC Compound in Wire & Cable ¹⁶	100	0	100	PE, XLPE, TPE	72	(58)	14
Food Wrap	68	0	68	PE	16	(5)	11
Bottles	15	0	15	HDPE, PET	210	10	220
Rigid Sheet	31	2	33	OPS, PET	73	(73)	0
Flexible Sheet	185	(13)	172	Fabric/TPO/TPU	317	(317)	0
Total Studied	1820	45	1865				
Extrapolated Total (All PVC) ¹⁷	2022	50	2072	Total	2965	(731)	2234

In order to rank the PVC industry in terms of industrial sectors which provide one or more alternatives to PVC products, estimates of domestic revenues were derived from Statistics Canada data on the value of shipments, imports and exports in 1993. The methodology used to create these industrial sectors is described in Section 9.6. In comparing the PVC industry to other sectors, the domestic revenue of the PVC industry ranks fifth out of six industry sectors which produce alternatives to PVC products. This shows that some industrial sectors producing alternatives to PVC are very broad with

¹⁶ Not a specific PVC product. The \$100 million estimate is based on 58 kT of PVC compound sold at \$1725/T for wire and cable manufacture and represents roughly 50% of domestic revenues for all PVC compound. See section 10.5.5 for details.

¹⁷ PVC sales, trade balance and revenue values in Table S-17 represent approximately 90% of all PVC resin. To estimate total PVC industry values, those totals have been multiplied by 1/0.9 (1.11) to account for PVC products which have not been assessed. The extrapolated totals are used in the rankings in Table S-18.

many different product categories, many of which do not compete in markets with PVC. Table S-18 lists the ranking of industrial sectors by domestic revenues.

Table S-18: Ranking of Industries Supplying Alternatives to PVC Products by Domestic Revenues

Rank	Industry Sectors	SIC Codes	PVC Product Alternatives	Domestic Sales (\$ million/yr)	Trade Balance (\$ million/yr)	Domestic Revenues (\$ million/yr)
1	Wood Products	25	Windows, Siding, Flooring	8776	10307	19083
2	Plastic Products other than PVC	16 (x 0.75)	Pipe, Wire & Cable, Food Wrap, Bottles, Packaging, Vehicle Trim	5434	(779)	4655
3	Aluminum Metal Products	19	Siding, Windows	4097	(390)	3707
4	Textile Products	296, 3031, 3999	Flooring, Vehicle Trim	3555	(679)	2876
5	PVC Products			2022	50	2072
6	Concrete Products	354	Sewer Pipe	817	0	817
	Total Alternatives (excluding PVC)			22679	8459	31138

S.6.3 Other Chlorinated Substances

As with the base commodities of the chlor-alkali sector, the other chlorinated substances are sold into many different markets. The value of domestic sales of the other chlorinated substances is compared to the value of domestic sales of alternatives in Table S-19. The annual value of domestic sales of chlorinated substances is \$298 million, compared to a value of \$150 million for alternatives. This reflects the dominance of many of the other chlorinated substances in their respective markets.

Table S-19: Domestic Sales Value
(Other Chlorinated Substances and Alternatives)

Other Chlorinated Substances, Products and Applications	Domestic Sales, Chlorinated Substances (\$ million/yr)	Alternatives	Domestic Sales, Alternatives (\$ million/yr)
Sodium hypochlorite (Household bleach)	70	Hydrogen Peroxide, Sodium Perborate	25
Tetrachloroethylene (Dry Cleaning)	11	Hydrocarbon solvents	1
Trichloroethylene (Metal Degreasing)	5	Hydrocarbon solvents, Aqueous cleaning	9.5
Dichloromethane (Paint Stripper, Urethane foam)	5	Hydrocarbon solvents CO2 injection	0.4
Chlorinated Refrigerants (CFCs, HCFCs)	146	HFCs	57
Chlorinated Flame Retardants	22	Aluminum trihydrate, Phosphate esters	21
Short Chain Chlorinated Paraffins (Metal Working Fluids)	1	Over based sulfonate Compound	0
Polychloroprene	39	Nitrile butadiene rubber	37
Total	298		150

Table S-20 lists the ranking of chlorinated substances and alternatives by domestic revenues. Most of the chlorinated substances have low, or zero domestic revenues, since there is little production activity in Canada and the market is supplied primarily by imports. The exception is chlorinated refrigerants, of which one product (HCFC-123) is manufactured in Canada by DuPont at their Maitland, ON site. This production generates

sufficient domestic revenues to make chlorinated refrigerants rank sixth out of 11 products¹⁸.

Table S-20: Ranking of Alternatives to Other Chlorinated Substances by Domestic Revenues

Rank	Chlorinated Substances And Alternatives	Domestic Sales (\$ millions/yr)	Trade Balance (\$ millions/yr)	Domestic Revenues (\$ millions/yr)
1	Soap And Detergent	1822	(222)	1600
2	Hydrocarbon Solvents	140	30	170
3	Hydrogen Peroxide	139	22	161
4	Nitrile Butadiene Rubber	37	75	112
5	Household Bleach	70	0	70
6	Chlorinated Refrigerants	146	(86)	60
7	Over Based Sulfonate Compounds	7	0	7
8	Phosphate Esters	15	(8.5)	6.5
9	Flame Retardants	22	(19)	3
10	Short-Chain Chlorinated Paraffins	1	(1)	0
11	Chlorinated Solvents (PERC/TCE/DCM)	21	(21)	0
12	Fluorinated Refrigerants (HFCs)	57	(57)	0
13	Polychloroprene	39	(39)	0
	Total Other Chlorinated Substances	298	(165)	133
	Total Alternatives	2217	(161)	2057

S.6.4 Summary of Revenues

In order to account for all chlor-alkali products, the ranking tables (S-15, S-18, S-20) were summed to develop estimates of the total value of chlor-alkali products, and alternatives to the Canadian economy in 1993, using the three measures of revenues. As listed in Table S-21, all chlor-alkali products have a value of domestic sales of \$2,739 million, a trade deficit of \$49 million, and domestic revenues of \$2,690 million. Domestic revenues represent 0.4% of GDP (\$712 billion). Measured by domestic revenues, the chlor-alkali product category with the highest value is the PVC category with domestic revenues of \$2.1 billion.

¹⁸ Several substances could not be ranked because of missing data. These are sodium hypochlorite, sodium perborate, and alumina trihydrate.

Industries producing alternatives to chlor-alkali products have a value of domestic sales of \$26.5 billion, a trade surplus of \$8.4 billion and domestic revenues of \$34.9 billion. Domestic revenues for alternative producing industries represent 5% of GDP. Measured by domestic revenues, the industries providing alternatives to the category of PVC products have the highest total value, with domestic revenues of \$31.1 billion.

Table S-21: Summary of Revenues

	Chlor-alkali Products			Alternatives		
	Domestic Sales	Trade Balance	Domestic Revenues	Domestic Sales	Trade Balance	Domestic Revenues
Base Commodities	419	66	485	1585	90	1675
PVC	2022	50	2072	22679	8459	31138
Other Chlorinated Substances	298	(165)	133	2217	(161)	2057
Total	2739	(49)	2690	26481	8389	34870

S.7 Employment

Employment in chlor-alkali industries can be classified into the 3 categories of base commodities, PVC products, and other chlorinated substances. A proxy for labour intensity is the ratio of employment to domestic revenues. This ratio gives the number of employees per million dollars generated in domestic revenues.

S.7.1 Base Commodities

Total employment for base chlor-alkali products refers to employment in caustic soda, elemental chlorine, hydrochloric acid, EDC and VCM production. These commodities are all produced in Canada by chlor-alkali plants, with elemental chlorine and caustic soda being joint products.

Table S-22 ranks manufacturing employment by the base commodities of the chlor-alkali industry, and alternatives to those products. The chlor-alkali base products have the second highest ranking of eight product sectors studied, with employment of 1305 people. The chlor-alkali industry is the fifth ranked of the sectors studied by labour intensity with a ratio of employment to domestic revenues of 2.7.

**Table S-22: Ranking of Base Commodities and Alternatives
by Employment**

Rank	Base Commodities and Alternatives	Manufacturing Employment	Domestic Revenues (\$ millions/yr)	Employment/ Revenues
1	Oxygen	2000	300	6.7
2	Chlor-alkali	1305	485	2.7
3	Sodium Chlorate	800	440	1.8
4	Lime (calcium oxide)	551	95	5.8
5	Hydrogen Peroxide	300	161	1.9
6	Soda Ash	280	101	2.8
7	Sulphuric Acid	250	554	0.5
8	Salt Cake (sodium sulphate)	175	24	7.3
	Total Alternatives	4356	1675	2.6

S.7.2 Polyvinyl Chloride Products

The comparison of employment for PVC products and alternatives will use the same approach as for revenues. As PVC products are generally sold into one market, employment related to production of PVC products can be compared with employment in production of alternatives to PVC products, in specific markets. A second measure will rank employment in the PVC industry with employment in comparable large integrated industrial sectors supplying alternatives to PVC products, as well as other products.

Table S-23 lists employment related to PVC products and alternatives, in specific markets. Employment related to the PVC product applications studied is estimated at approximately 5,740 people. The employment for industrial products providing alternatives to chlor-alkali products in specific markets is 13,033 people. The ratio of employment to domestic revenues for PVC products is 3.1 compared to a ratio of 5.8 for alternatives. The ratio suggests that manufacturing of alternatives to PVC is more labour intensive than PVC products manufacturing.

Table S-23: Employment in PVC Products and Alternatives
(Employment per \$ million revenues)

PVC Products	PVC		Alternative Products	Alternatives	
	Employment	Employment/ Revenues		Employment	Employment/ Revenues
Pipe	2000	5.6	HDPE, Ductile Iron, Concrete, ABS	2200	6.4
Siding	800	3.9	Aluminum, Clay brick	739	6.0
Window Profiles	800	1.4	Wood, Aluminum	5852	7.5
Flooring	700	1.9	Polyolefin, Ceramic tile/Carpet	3212	4.3
PVC Compound in Wire & Cable	200 ¹⁹	2.0	PE, XLPE, TPE	200	14.3
Food Wrap	120	1.8	PE	30	2.7
Bottles	20	1.3	HDPE, PET	800	3.6
Rigid Sheet	100	3.0	OPS, PET	0	0
Flexible Sheet	1000	5.8	Fabric/TPOs,TPUs	n.a	n.a
Total	5740	3.1	Total	13033	5.8

Table S-24 estimates that 6,908 people are employed in the total PVC industry, which includes products, merchant PVC compounding and resin production. Since the PVC products studied account for 90% of total PVC resin consumption in Canada in 1993, it is estimated that 6,378 people are employed for all PVC products, through extrapolation. Another 215 people are assumed to be employed in other merchant PVC compound manufacturing (not associated with wire and cable, which is included in the products estimate). The employment in PVC resin production is estimated to be 315 people.

¹⁹ Estimate based on proportion of merchant PVC compound manufacturing employment associated with wire and cable market (roughly half of 415 people). See section 10.5.5 for details.

Table S-24: Employment for Total PVC Sector

	Employment
Total PVC Products Studied	5740
Extrapolated Total (All PVC Products) ²⁰	6378
Add: Other Merchant PVC Compound ²¹	215
PVC Resin Production	315
Total Sector	6908
Employment/Revenues (No/\$M)	3.3

Table S-25 ranks industrial sectors supplying alternative products to PVC products by employment. The PVC sector is the fifth ranked of the six industrial sectors studied, by employment, reflecting the relatively broad nature of these other industry sectors. The PVC sector has a relatively low labour intensity (higher capital intensity) compared to other industrial sectors.

**Table S-25: Ranking of PVC and Alternative Sectors
by Employment**

Rank	Industry Sectors	SIC Codes	PVC Product Alternatives	Employment	Employment/ Revenues (empl/\$ million)
1	Wood Products	25	Windows, Siding, Flooring	92000	4.8
2	Non-PVC Plastic Products	16 (x 0.75)	Pipe, Wire and Cable, Food Wrap, Bottles, Packaging, Vehicle Trim	35086	7.5
3	Textile Products	19	Flooring, Vehicle Trim	22446	7.8
4	Aluminum Metal Products	296, 3031, 3999	Siding, Windows	18612	5.0
5	PVC Sector			6908	3.3
6	Concrete Products	354	Sewer pipe	5787	7.1
	Total Alternatives			173931	5.6

²⁰ Estimate based on employment of 5740, representing 90% of PVC resin use, multiplied by 1/0.9 (1.11).

²¹ Estimate represents a remainder, based on total merchant compound employment of 415 people and the portion for wire and cable compound of 200 people. See Table 9.6.

S.7.3 Other Chlorinated Substances

Table S-26 lists the manufacturing employment for other chlorinated substances²². As most of these products are imported, the manufacturing employment for most chlorinated substances is negligible. The largest employment figure is estimated as 400 people employed in household bleach production and distribution. The chlorinated refrigerant (HCFC-123) is produced by DuPont in Maitland, ON, which employs 70 people.

Table S-26: Ranking of Other Chlorinated Substances and Alternatives by Employment

Rank	Other Chlorinated Substances And Alternatives	Manufacturing Employment	Domestic Revenues	Employment/ Revenues
1	Soap And Detergent	3679	1600	2.2
2	Household Bleach	400	70	5.7
3	Hydrogen Peroxide	300	161	1.9
4	Hydrocarbon Solvents	100	170	0.6
5	Chlorinated Refrigerants	70	60	1.2
6	Nitrile Butadiene Rubber	5	112	0.4
7	Fluorocarbon Refrigerants	5	0	na
8	Over Based Sulfonate Compounds	5	7	0.7
9	Phosphate Esters Flame Retardants	5	6.5	0.8
10	Chlorinated Paraffin Flame Retardants (Medium and Long Chain)	5	3	1.7
	Total Chlor-Alkali Products	475	133	3.6
	Total Alternatives	4099	2057	2.0

S.7.4 Summary of Employment

In order to account for all chlor-alkali products, the ranking tables (S-22, S-25, S-26) were summed to develop estimates of the total employment in chlor-alkali product industries, and selected alternative industry sectors in 1993. As listed in Table S-27, the chlor-alkali product industries employed 8,688 people in 1993, with a ratio of employment to domestic revenues of 3.2 people per million in domestic revenues. Employment in chlor-alkali product industries represents 0.49% of total manufacturing employment in 1993 (1,787,000). Of the three chlor-alkali categories, the PVC products category has the highest number employed at an estimated 6,908 people.

²² Missing data includes sodium hypochlorite, hydrocarbon solvents, sodium perborate, alumina trihydrate.

In 1993, industry sectors producing alternatives to chlor-alkali products employed 182,386 people, with a ratio of employment to domestic revenues of 5.2 people per million in domestic revenues. This employment represents 10% of total manufacturing employment in 1993. Industry sectors producing alternatives to PVC products have the highest employment of alternatives industries at 173,931 people.

Table S-27: Summary of Employment

	Chlor-alkali Products			Alternatives		
	Employment	Domestic Revenues (\$ M/yr)	Employment/Domestic Revenues	Employment	Domestic Revenues (\$ M/yr)	Employment/Domestic Revenues
Base Commodities	1305	485	2.7	4356	1675	2.6
PVC	6908	2072	3.3	173931	31138	5.6
Other Chlorinated Substances	475	133	3.6	4099	2057	2.0
Total	8688	2690	3.2	182386	34870	5.2

S.8 Summary

The report is a socio-economic and technical evaluation of the importance of chlor-alkali products, and options (or alternatives) to these products to the Canadian economy in 1993. The report defines chlor-alkali products as all products originating in the electrolysis of sodium chloride into elemental chlorine and caustic soda. It classifies chlor-alkali products into the three categories of: base commodities (elemental chlorine, caustic soda, hydrochloric acid), PVC products, and other chlorinated substances. Three principal variables are used to compare alkali products to options; direct replacement cost, domestic revenues from the production of chlor-alkali products, and employment.

Table S-28 contains the comparative data on direct replacement costs, domestic revenues, and employment for 1993. The annual direct replacement cost for chlor-alkali products is \$1.9 billion at the low cost estimate and \$4.3 billion at the high cost estimate. Domestic revenues for chlor-alkali products were \$2.7 billion, representing 0.4% of GDP. The total revenues generated by industrial products or sectors providing alternatives to chlor-alkali products are \$34.9 billion, which represent 5% of GDP. Employment in chlor-alkali products industries was 8,688 people, representing 0.49% of total Canadian manufacturing employment (1,787,000). The total employment of industrial products or sectors providing alternatives to chlor-alkali products is 182,386, representing 10% of manufacturing employment.

Table S-28: Summary of Direct Replacement Costs, Domestic Revenues and Employment

	Direct Replacement Cost (\$ million/yr)		Domestic Revenues (\$ million/yr)		Employment	
	Low	High	Chlor-alkali	Alternatives	Chlor-alkali	Alternatives
Base Commodities	618	1495	485	1675	1305	4356
PVC	553	2171	2072	31138	6908	173931
Other Chlorinated Substances	681	681	133	2057	475	4099
Total	1852	4347	2690	34870	8688	182386

Table S-29 compares the direct replacement costs with the end-use revenues for selected chlor-alkali products where end-use revenues could be identified and quantified. End-use refers to goods which are either bought by a consumer, or exported. The total value of end-use revenues identified is approximately \$170 billion. This represents 24% of GDP in 1993 (\$712 billion). For these products, the low and high direct replacement costs ranged from 0.7% to 1.7% of end use revenues. As an alternative measure of comparison, the total direct replacement costs for all chlor-alkali products in the study range from 0.3% to 0.6% of total GDP in Canada in 1993.

Table S-29: Summary of Direct Replacement Costs Compared to End-Use Revenues

Categories	Direct Replacement Cost ²³ (\$ million/yr)		End-Use Revenues (\$ million/yr)	Cost/ End-Use Revenues (%)	
	Low	High		Low	High
Base Commodities	604	1481	38382	1.6%	3.9%
PVC	264	1181	110280	0.2%	1.1%
Other Chlorinated Substances	278	278	88195	0.3%	0.3%
Total	1146	2940	169461 ²⁴	0.7%	1.7%

²³ Costs of substitution are less than in Table S.27 as not all end-uses could be determined and quantified. Only those costs of substitution applicable to quantified end-uses are used in Table S.28.

²⁴ Total will not equal the sum of end-uses as industries appearing more than once are not double-counted.

Direct costs are not the only factor influencing product use in a dynamic economy, characterized by the continual process of development and growth of new industries and markets, and the demise of others over time. Other factors include: product and process innovation, social pressure and government influence. There have been several major trends over the last decade affecting the chlor-alkali industry that are illustrative of these other factors.

The two principal trends affecting chlor-alkali industry products are the decline in elemental chlorine use in chemical pulp production, and the growth of PVC product use in construction. In the case of chemical pulp bleaching, environmental concerns and related government regulation have driven the substitution of ECF (elemental chlorine free) bleaching for elemental chlorine bleaching. Sodium chlorate is the raw material for production of chlorine dioxide used as a substitute for elemental chlorine in ECF bleaching. This trend has led to the contraction of the chlor-alkali industry, and the growth of the sodium chlorate industry. In the case of PVC construction products, lower costs and comparable technical properties have driven the substitution of PVC products for traditional materials such as iron, aluminum, wood and concrete. The PVC industry has grown, while the market share of traditional materials industries in these markets has contracted.

In both cases, chemical pulp production and construction continue while competing industries have adjusted to supply inputs to these economic activities. The observation of a dynamic, innovative and competitive economy addressing social needs is an important perspective to be retained in considering the importance of chlor-alkali products, and options to those products, in the Canadian economy.

PART ONE

BASE COMMODITIES

1. Introduction

The report presents a technical and socio-economic comparison of products derived from the chlor-alkali industry with options to the use of these products in the Canadian economy. Chlor-alkali products are defined as products originating from the electrolysis of sodium chloride into elemental chlorine and caustic soda. The scope of chlor-alkali products investigated falls into three broad categories:

1. **base commodities** produced by the chlor-alkali industry
(e.g., elemental chlorine, caustic soda, hydrochloric acid);
2. **polyvinyl chloride (PVC) resin products**
(e.g., pipe, siding, windows, flooring, wire & cable, bottles, film & sheet); and
3. **other chlorinated substances**
(e.g., household bleach, chlorinated solvents, refrigerants, flame retardants, etc.).

The classification stems from the observation that most Canadian chlor-alkali plants which manufacture elemental chlorine and caustic soda limit production to these two basic commodities, along with some hydrochloric acid. The exception is the Dow Chemical plant located in Fort Saskatchewan, Alberta, which also manufactures ethylene dichloride and vinyl chloride monomer, the precursors necessary for the production of polyvinyl chloride (PVC) resin. Since the PVC industry is the single largest domestic use of elemental chlorine, and employs a sizeable domestic manufacturing base, it will be considered as a separate category. The other chlorinated substances category refers to various higher value-added chlorinated products which are primarily imported¹ into Canada.

Both the basic commodities and the many chlorinated substances have many and varied applications. The method employed in this study was to choose the major products and applications of the chlor-alkali industry and develop a technical description and quantitative socio-economic analysis of (1) the chlor-alkali product, and (2) the alternatives to that product, within the particular application studied. The products and applications areas studied are listed in Table S-1.

¹ The significant exceptions where other chlorinated substances are manufactured in Canada are: household bleach (sodium hypochlorite), chlorinated paraffins, and the refrigerant HCFC-123.

Table 1-1: Products and Applications Studied

Base Commodities		Polyvinyl Chloride		Other Chlorinated Substances	
Products	Applications	Products	Applications	Product	Applications
Elemental chlorine	Pulp and Paper, Water and wastewater treatment, Titanium dioxide	Pipe (Water, Sewage, etc.)	Municipal/ Industrial Construction	Sodium hypochlorite	Household bleach
		Siding	Residential Construction	Tetrachloroethylene	Dry Cleaning
Caustic soda	Pulp and paper, Alumina, Soaps and detergents, Metal mining (gold), Petrochemicals (oil sands)	Windows		Trichloroethylene	Metal Degreasing
		Flooring	Residential/ Commercial Construction	Methylene Chloride	Paint stripper, Polyurethane slab
Hydrochloric acid	Steel pickling, Choline chloride	Wire and Cable		Chlorinated Flame Retardants	Plastics
		Food Wrap	Packaging	Short Chain Chlorinated Paraffins	Metal Working
		Bottles	Packaging	Chlorinated Refrigerants	Refrigeration units, Mobile air conditioners
		Sheet, rigid	Packaging	Polychloroprene	Automobiles
		Sheet, flexible	Transportation equipment, Swimming pools		

This report does not address potential or real environmental damages or risks generated by chlor-alkali products, or alternatives. However, references to environmental regulation or environmental or public health considerations will be used where this information is appropriate in explaining market trends.

Two applications, pharmaceutical and pesticides, are not analyzed quantitatively, but qualitatively. These two industries employ a relatively small amount of chlorine to generate many products. A quantitative analysis of the products generated by these two industries is beyond the scope of a study of this nature and so the assessment was limited to a qualitative technical and socio-economic description. This description is found in Chapters 19 and 20.

The report is organized to correspond to the classification of chlor-alkali products suggested above. Part One (Chapters 2-8) covers the base commodities of the chlor-alkali industry, Part Two (Chapters 9-10) describes the polyvinyl chloride industry, and Part Three (Chapters 11-20) describes other chlorinated substances.

1.1 Study Background

In 1992, the International Joint Commission (IJC) initially recommended that the United States and Canadian governments "in consultation with industry and other affected interests, develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks and that the means of reducing or eliminating other uses be examined"². The rationale for the IJC recommendation is based on the precautionary principle, and stems from the observation that lists of persistent, bioaccumulative and toxic chemicals in both the Great Lakes and elsewhere are dominated by chlorinated substances.

In response to the IJC recommendations, the federal government developed the Chlorinated Substances Action Plan, released in October 1994, in which federal policy toward chlorine is defined as part of a broader Toxic Substances Management Policy. The Chlorinated Substances Action Plan outlines Canada's approach to the management of chlorinated substances, and indicates that the approach is to "prune the chlorine-use tree, not cut it down".

The Chlorinated Substances Action Plan has five parts, one of which is to study public health and socio-economic aspects of the chlorine and alternative sectors.³ This study fits within this part of the Chlorinated Substances Action Plan, and is referred to in the October, 1996 Progress report.

² IJC. 1992. Sixth Biennial Report on Great Lakes Water Quality.

³ The other parts are targeted action, improved scientific understanding, improved access to information and promoting and leading international efforts for global action.

1.2 Study Objectives

The purpose of this report is to provide a background document for individuals, industry groups and government departments interested in products derived from the chlor-alkali industry and options to the use of those products in Canada. The specific objectives of this study are:

- 1) to provide a description of the markets for chlor-alkali products and alternatives to those products, including market trends;
- 2) to provide a technical comparison of the production processes and technical properties related to chlor-alkali products, and alternatives to those products;
- 3) to determine the direct costs of substituting selected alternatives for chlor-alkali products, and to place these costs in context; and
- 4) to develop socio-economic profiles of both chlor-alkali products, and alternatives to those products.

1.3 Scope of Work

The range of market sectors and the number of chlorine-based products and processes currently employed in Canada is large. Time and budget constraints limited the analysis to an overview level, primarily concentrating on products either manufactured in Canada, or chlor-alkali products imported into Canada. Due to data availability considerations, the base year for the study was chosen as 1993. The scope of work for each objective is provided below.

1.3.1 Market Description

A brief evaluation of the markets for chlor-alkali products and options to those products is provided. The market description includes both a description of market share for chlor-alkali products, and alternatives to those products, and a description and analysis of market trends. Environmental and public health considerations are referred to where these considerations are appropriate in explaining market trends.

1.3.2 Technical Description

Technical descriptions and analysis of chlor-alkali products and production processes, and alternatives, are provided for the major uses in each application area, as identified in section 1.1. In general, one or more alternatives are identified for each product of the chlor-alkali industry. Where possible, only options that currently hold, or have the potential to hold, a significant portion of market share are described.

1.3.3 Direct Replacement Costs

The direct replacement cost analysis involves the development of models of substitution for primary producers, manufacturers, municipalities, household consumers or other economic entities which would directly incur the costs of adopting the various options. Only direct capital and operating costs are included in the analysis. Direct replacement costs are calculated from capital costs, annualized at a rate of 9% over 20 years, added to annual incremental operating costs.

In order to place the costs of substitution in context, these costs are compared to the end-use revenues in the applications studied. Depending on the application area, substitution for chlor-alkali products may occur at the end use, primary or intermediate good level. End-use refers to a product that is bought directly by consumers or exported, while primary or intermediate goods refer to goods used as inputs in the production process used to manufacture end-use products.

Costing data were normalized for 1993 prices, since this was the most recent year for which relatively complete cost data was available. For products in which significant annual cost variations are common, the costing data were based on five-year average (1988-93) nominal prices. Current prices may vary from the prices cited in the report.

1.3.4 Socio-economic Profiles

For each market sector, socio-economic profiles have been developed for each chlor-alkali product, and for each quantified alternative. The profiles provide basic socio-economic data for each product studied.

Socio-economic data collected for each chlor-alkali product, and quantified alternative, include:

- number and location of domestic producers
- production and capacity
- employment
- revenues
- imports and exports.

In the socio-economic section, revenues are also based on 1993 production levels, with prices for products with volatile prices based on average nominal 1988-1993 prices. Three measures of revenues are used, value of domestic sales, trade balance and domestic revenues. Domestic revenues are equal to the sum of the value of domestic sales plus the

trade balance. The trade balance is the value of exports minus the value of imports. It is used as a proxy for contribution to Gross Domestic Product (GDP)⁴.

1.4 Data Acquisition

Information and data collected for the technical, costing and socio-economic components of this study were drawn from three key sources: 1) publicly-available databases; 2) literature review; and 3) interviews with industry representatives. The methodologies employed for each source are briefly described below.

1. **Publicly-available Databases.** Much of the socio-economic data, including production, trade, domestic revenues (value of manufacturing shipments), and employment was obtained from Statistics Canada. CHEMinfo Services databases and various industry and association data were used to compile profiles.
2. **Literature Review.** Relevant studies on chlor-alkali products and their alternatives were reviewed to gather selected market, technical and socio-economic information. Other literature sources included: industry association publications, industrial journals, and reports from government and non-government organization sources.
3. **Surveys of Industry Representatives.** Direct telephone interviews with manufacturers, distributors, customers, contractors, consultants and industry associations provided much of the information on chlor-alkali products and options used in the study. Mailed surveys were also used to gather socio-economic data on market share on market share, costs, production, sales, employment and imports/exports.

It is important to appreciate that the literature review and interviews provided a number of different viewpoints and contributions for the market profiles, technical comparisons and other issues that have been combined into a summary form in this report. In summarizing

⁴ In reality GDP is based on value added throughout the production chain for goods and services in the economy. For reasons of practicality, domestic revenues, as defined above, were used as a proxy for contribution to GDP. This measure will tend to overestimate the value of goods relative to GDP by factor of two. For example in 1993 domestic revenues for plastic products industries are \$ 6.1 billion, while the value added is \$ 2.9 billion

these issues, a balanced approach was always sought. A list of literature-based references and industry sources contacted is provided at the end of each chapter of the report.

2. Base Commodities Of The Chlor-Alkali Industry

2.1 Introduction

Part One of the report consists of Chapters 2 through 8. They contain technical and socio-economic information related to the base commodities of the chlor-alkali industry: caustic soda, elemental chlorine and hydrochloric acid, and their alternatives. The specific domestic applications of the chlor-alkali products discussed in Part One are:

- a) pulp and paper, alumina, soap and detergent, mining, petroleum (caustic soda);
- b) pulp bleaching, water and wastewater treatment, titanium dioxide (elemental chlorine); and
- c) steel pickling, choline chloride (hydrochloric acid).

In order to give context for the specific applications, this chapter will provide a technical description of the production process for the base commodities, an analysis of the markets for these commodities, and a socio-economic profile. The socio-economic profile will include information on the plants, capacity, revenues and manufacturing employment associated with the base commodities of the chlor-alkali industry. In addition to the base commodities (caustic, chlorine, hydrochloric acid), this chapter will also include technical and socio-economic information on the PVC precursors ethylene dichloride (EDC) and vinyl chloride monomer (VCM). The PVC precursors are included in this section as they are integral products of the largest chlor-alkali plant in Canada, the Dow Chemical Canada plant in Fort Saskatchewan, Alberta. The other links in the PVC production chain (PVC resin, PVC compound and PVC final products) will be discussed in Part Two (Chapters 9 and 10).

The technical and socio-economic information on alternatives to the products of the chlor-alkali industry will be described in the specific chapters referring to the applications which use the base commodities of the chlor-alkali industry. The alternatives and applications are described in Chapters 3 to 8 inclusive.

2.2 Production Process

Elemental chlorine and caustic soda are commercially related in that both commodities are produced jointly, or simultaneously, through an electrolytic process. The electrolytic process involves sending an electric current through a sodium chloride, or common salt, brine solution. For every metric tonne (1000 kg) of elemental chlorine produced, there are 1,130 kg of caustic soda and 28 kg of hydrogen produced from 1,830 kilograms of

sodium chloride and 507 kg of water.¹ A combined unit of chlorine and caustic soda (i.e. 1 tonne of chlorine plus 1.13 tonnes of caustic) is referred to as an electrochemical unit, or ECU.

Elemental chlorine, caustic soda, and hydrochloric acid are produced by all of the chlor-alkali plants currently operating in Canada. Merchant hydrochloric acid is manufactured through the installation of one or several burner units within an chlor-alkali plant. A burner unit combines excess hydrogen generated by the electrolysis of sodium chloride brine, with elemental chlorine, to produce hydrochloric acid. These burner units may operate at low capacity as producers decide to either manufacture hydrochloric acid, or sell elemental chlorine, depending on market conditions.

Although there are 10 electrolysis plants in Canada which produce elemental chlorine, caustic, and hydrochloric acid, there is currently only one plant (Dow, Fort Saskatchewan, Alberta) which is integrated forward to produce the PVC precursors, EDC and VCM. EDC is manufactured by the reaction of chlorine and ethylene with a small amount of catalyst. In Canada, EDC is manufactured through a process known as oxychlorination. In the oxychlorination process, the ethylene feed is chlorinated in the liquid phase. EDC vapours are condensed, degassed and a portion is withdrawn from the oxychlorination unit. The balance of the feed is passed on to the VCM portion of the plant where hydrochloric acid and oxygen in a fluidized catalyst bed reactor produce crude EDC. The crude EDC from both streams are combined and cracked in a reactor to form VCM, with the by-product hydrochloric acid being re-cycled back to EDC production (CHEMinfo Services Inc., 1994). Merchant hydrochloric acid produced at Fort Saskatchewan comes from the attached burner unit.

EDC and VCM are precursors to the manufacture of PVC resin. There are no known alternative chemicals or chemical processes commercially available for the production of PVC, therefore a discussion of alternatives with respect to PVC production implies a discussion of alternatives to the PVC products themselves. A detailed discussion of the alternatives to PVC products is provided in Part Two of this report.

2.3 Chlor-alkali Product Markets

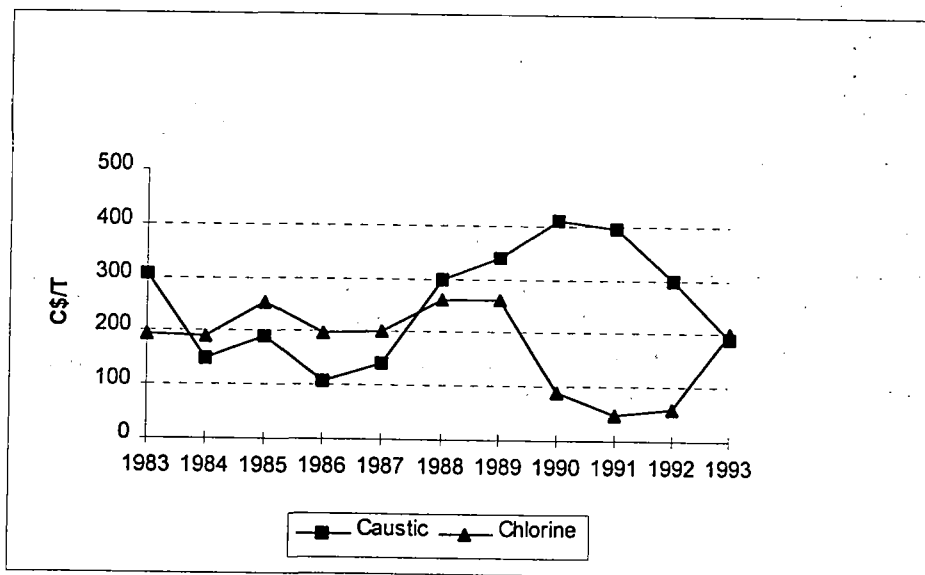
Since chlorine and caustic are produced jointly in fixed proportions, the principal market characteristic of the chlor-alkali industry is maintaining a balance between the demand and the supply of the two co-products. This balance is achieved through chlor-alkali producers finding additional markets (e.g. export sales) or increasing demand by adjusting the prices of the base commodities.

¹ Though the ratio of 1.13 is the accepted chemical mass balance ratio, the actual operating practice in Canada appears to be closer to 1.05.

Revenues and returns on capital in the chlor-alkali industry vary with swings in the economic cycles both in North America and in other nations. Historically in North America, during weak economic conditions demand for both chlorine and caustic drops. Weak economic conditions relate to subdued demands for paper, automobiles, consumer retail products and construction activity. Reduced output in these industries translates into reduced demand for PVC (chlorine derivative), aluminum as well as other metals (which relate to caustic and hydrochloric acid demands). Chlorine and caustic market areas which are influenced to a lesser degree by economic cycles include water treatment and soaps and detergents.

As Figure 2-1 shows, the price movements of chlorine and caustic soda from 1983 to 1993 can be quite extreme and neither product (caustic, chlorine) is the most valuable product at all times. Though in general caustic soda demand drives the market, as indicated by the higher prices for caustic soda, occasionally the demand for caustic soda drops, and elemental chlorine becomes more valuable, as indicated by the reversal of pricing for caustic and elemental chlorine from 1984 to 1988.

Figure 2-1: International Chlor-alkali Product Price History



A second important characteristic of the chlor-alkali market is that it is a continental market for some commodities (chlorine, caustic soda), and an international market for other commodities (EDC, VCM). These markets are dominated by a small number of multinational firms, some of which are listed in Table 2-1.

Table 2.1: Chlorine Capacity of Major U.S. Manufacturers, 1995

Producers	Capacity	% of Total Capacity
Dow Chemical	3385	30%
Occidental Chemical	2610	23%
PPG Industries	1290	11%
Other	4113	36%
Total	11398	100%

Source: Chlorine Product Profile, 1993, Camford Information Services.

The implication of chlor-alkali products being sold into continental and international markets is that a given domestic chlor-alkali market can be out of balance, with the excess commodity production being exported. This is the situation in Canada relative to elemental chlorine production. Whereas the caustic is in rough equilibrium between domestic production and consumption, the chlorine business requires a substantial export of the base commodities of elemental chlorine as well as EDC. These base commodity markets will be discussed in more detail in the following sections.

2.3.1 Electrolytic Caustic Market

In 1993, the base year of this study, the Canadian imports were roughly balanced with exports. The market for caustic is dominated by demand from the pulp and paper industry, which purchased roughly 50% of the total supply of caustic. A declining trend in domestic production of electrolytic caustic is generated by both a declining demand for caustic from pulp and paper, and more importantly, a strong declining demand for co-product elemental chlorine from pulp and paper, as discussed below. The imbalance between a slight declining demand for caustic, and a strong declining demand for elemental chlorine, generates an expected increase in imports of caustic soda by the year 2000. Table 2-2 shows the supply/demand balance for caustic soda.

Table 2.2: Electrolytic Caustic Supply/Demand Balance
(annual kilotonnes, percent of total supply)

	1988	%	1993	%	2000	%
Capacity	1850	92%	1425	94%	1150	86 %
Production	1720	86%	1225	81%	990	74 %
Imports	290	14%	308	19%	350	26 %
Total Supply	2010	100%	1507	100%	1340	100 %
Domestic Consumption:						
Pulp and Paper	980	49%	750	50%	790	59%
Alumina	90	4%	87	6%	90	7%
Soap, Detergents and Cleaners	76	4%	81	5%	85	6%
Mining, Inorganic Chemicals	57	3%	55	4%	65	5%
Petrochemicals (tar sands, crude oil)	23	1%	24	2%	30	2%
Other	311	15%	123	8%	110	8%
Total Domestic Consumption	1544	77%	1120	75%	1170	87%
Exports	466	23%	374	25%	170	13%
Total Demand	2010	100%	1507	100%	1340	100%

Source: Canadian Chlorine Supply and Applications, CHEMinfo Services, 1994.

2.3.2 Elemental Chlorine Market

Over the time period studied, the domestic production of elemental chlorine has not been in balance with the domestic demand. This imbalance has been met through the exports of elemental chlorine and EDC. The trend indicates that the domestic imbalance is increasing over time. The explanation for this trend is the collapse in elemental chlorine demand from the pulp and paper market, declining from 32% of supply in 1988, to an expected 3% by the year 2000. The principal explanation for this trend is environmental pressures and regulations at the federal and provincial levels. The environmental

regulation has generated a shift from elemental chlorine to chlorine dioxide use as an agent for pulp bleaching. This trend will be discussed in more detail in Chapter 3.

The strong declining trend in elemental chlorine use in the pulp and paper industry has had three effects on domestic elemental chlorine production: increasing exports, plant closures, and declining production. The principal demand for elemental chlorine produced in Canada is now generated by the export market. In 1993 exports of the base commodities elemental chlorine (25%) and EDC (18%) accounting for 43% of total chlorine supply. Total domestic capacity is expected to decline from 1750 kilotonnes in 1988, to 1117 by 2000, a decline of 38%. Along with the decline in capacity is a decline in domestic production, from 1700 kilotonnes in 1988 to an expected 930 kilotonnes by 2000, a decline of 43%. Table 2-3 shows the elemental chlorine supply/demand balance.

Table 2.3: Elemental Chlorine Supply/Demand Balance
(annual kilotonnes, percent of total supply)

	1988	%	1993	%	2000	%
Capacity	1750	100%	1362	115%	1117	119%
Production	1700	97%	1170	99%	930	99%
Imports	50	3%	15	1%	10	1%
Total Supply	1750	100%	1185	100%	940	100%
Domestic Consumption:						
PVC\VCM	256	15%	246	21%	248	26%
EDC Exports	135	8%	214	18%	152	16%
Pulp and paper	560	32%	175	15%	24	3%
Hydrochloric Acid	190	11%	152	13%	148	16%
Other	244	14%	105	9%	92	10%
Total Domestic Consumption	1385	79%	892	75%	664	71%
Exports	365	21%	293	25%	276	29%
Total Demand	1750	100%	1185	100%	940	100%

Source: Canadian Chlorine Supply and Applications, CHEMinfo Services, 1994.

As a result of the declining trend in elemental chlorine use in pulp and paper, PVC products are now the single largest domestic use of chlorine, accounting for 21% of domestic chlorine supply in 1993. However, the demand for chlorine through the PVC

chain has been relatively stable from 1988 to 1993, and is expected to remain so to 2000. After PVC, hydrochloric acid production is expected to be the single largest domestic use of chlorine, taking an expected 16% of chlorine supply by 2000. All other domestic applications (e.g. water treatment) represent less than 2% of domestic chlorine supply.

2.3.3 Merchant Hydrochloric Acid Market

The merchant market for hydrochloric acid refers to hydrochloric acid which is sold outside of the industries which produce hydrochloric acid. This distinction is needed in order to differentiate between industries where hydrochloric acid is produced as a by-product of another industrial process, and then re-cycled within the same plant. For example, the EDC/VCM unit of the Dow Chemical Canada plant in Fort Saskatchewan recycles the hydrochloric acid generated in VCM manufacture back into EDC manufacture. However, at the chlor-alkali plant on the same site, an attached burner unit will produce hydrochloric acid for merchant sales. Table 2-4 summarizes the hydrochloric acid supply/demand balance.

Table 2.4: Merchant Hydrochloric Acid Supply/Demand
 (annual kilotonnes, percent of total supply)

	1993	%	2000	%
Capacity ²	185	150%	162	130%
Production	113	92%	116	92%
Imports	10	8%	10	8%
Total Supply	123	100%	126	100%
Domestic Consumption:				
Steel Pickling	30	24%	35	28%
Choline Chloride	9	7%	9	7%
Sodium chlorate	12	10%	13	10%
Other	33	27%	32	25%
Total Domestic Consumption	84	68%	93	74%
Exports	39	32%	33	26%
Total Demand	123	100%	126	100%

Source: Canadian Chlorine Supply and Applications, CHEMinfo Services, 1994.

² Capacity and production refer to both burner capacity at chlor-alkali plants and other capacity. In 1993, other capacity and production refer to VCM by-product from Dow, Sarnia, ON (30 kilotonnes), by-product HFC production at Dupont, Maitland, ON (4 kilotonnes) and other by-product (3 kilotonnes). The Dow plant in Sarnia, ON shut down in 1993.

The hydrochloric acid market is projected to be relatively stable from 1993 to 2000, with the major market being the export market. The main domestic use of hydrochloric acid is steel pickling, with many other small applications.

2.3.4 Ethylene Dichloride (EDC), Vinyl Chloride Monomer (VCM) Markets

EDC and VCM are principally used as precursors in the production of PVC resin. A minor use of EDC prior to 1993 was in the production of chlorinated solvents at the Dow Chemical plant located in Sarnia, ON. The closure of this plant in 1993 explains the decline in EDC and VCM capacity from 1993 to 2000. Both of these markets are projected to be relatively stable from 1993 to 2000, with a continuing substantial export market for EDC, accounting for 26% of total supply in 1993. VCM is produced primarily to meet domestic demands for PVC resin. Table 2-5 and 2-6 summarize the EDC and VCM markets.

Table 2.5: EDC Market Supply/Demand Balance
(annual kilotonnes, percent of total supply)

	1993	%	2000	%
Capacity	1033		950	
Production	994	103%	910	100%
Imports	0	0%	0	0%
Inventory Change	- 30	3%	0	0%
Total Supply	964	100%	910	100%
Domestic Consumption:				
Solvents	4	1%	0	0%
VCM	704	73%	708	78%
Total Domestic Consumption	708	74%	708	78%
Exports	256	26%	201	22%
Total Demand	964	100%	910	100%

Source: Canadian Chlorine Supply and Applications, CHEMinfo Services, 1994.

Table 2.6: VCM Market Supply/Demand Balance
(annual kilotonnes, percent of total supply)

	1993	%	2000	%
Capacity	500		450	
Production	428	97%	427	94%
Inventory change	- 16	4%	0	
Imports	31	7%	25	6%
Total Supply	442	100%	452	100%
Domestic Consumption:				
PVC resin	419	95%	439	97%
Total Domestic Consumption	419	95%	439	97%
Exports	23	5%	13	3%
Total Demand	442	100%	452	100%

Source: Canadian Chlorine Supply and Applications, CHEMinfo Services, 1994.

2.4 Socio-Economic Profile of Chlor-Alkali Industry

2.4.1 Chlorine and Caustic Soda

As shown in Table 2-7, there were 10 chlor-alkali plants in Canada in 1993 producing elemental chlorine and caustic soda. These plants had an elemental chlorine capacity of 1,362 kilotonnes per year (caustic, 1425). As of 1995, only seven of these plants were operating due to the closure of the three plants; Avenor (Dryden, ON), ICI (Cornwall, ON), and Dow Chemical (Sarnia, ON). Currently, Dow Chemical has the largest share of capacity among the Canadian producers, accounting for close to 50% of chlorine and caustic capacity. ICI is the next largest producer, accounting for about 25% of capacity.

Table 2.7: Chlorine³ Capacities of Canadian Producers
(kilotonnes)

Plants	1987	1993	2000
Dow Chemical, Fort Saskatchewan, AB	475	550	550
ICI Canada, Becancour, PQ	270	270	270
Dow Chemical, Sarnia, ON	408	180	0
Canadian Occidental, North Vancouver, BC	145	145	145
PPG Canada, Beauharnois, PQ	70	80	80
ICI Canada, Cornwall, ON	50	50	0
Saskatoon Chemicals, Saskatoon, SK	33	33	33
ICI Canada, Dalhousie, NB	30	30	30
Avenor, Dryden, ON	15	15	0
St. Anne Chemicals, Nackawic, NB	9	9	9
Canadian Occidental, Squamish, BC	70	0	0
Canadian Occidental, Nanaimo, BC	27	0	0
Canso Chemicals, Abercrombie Pt., N.S.	25	0	0
Total Capacity	1627	1362	1117

Source: Canadian Chlorine Supply and Applications, CHEMinfo, 1994.

³ The caustic capacities are approximately equal to the chlorine capacity multiplied by 1.05.

Between 1988 and the year 2000, the chlorine capacity is expected to fall by one-third, from 1750 to 1117 kilotonnes/year (see Table 2-3). Chlorine production is expected to decline by about 45%, from 1700 to 930 kT/yr during this same period and the capacity utilization rate is expected to drop from 97% to 83%. Caustic follows the same pattern as chlorine, with capacity expected to fall from 1850 to 1150 kT/yr.

2.4.2 Hydrochloric Acid

Nine of the ten chlor-alkali plants operating in Canada in 1993 had hydrochloric acid burner capacity, as shown in Table 2-8. The total merchant hydrochloric acid capacity was 148 kT in 1993. The largest supply comes from ICI in Becancour, PQ.

The plants were operating at 78% capacity in 1993, based on a production⁴ of 115 kilotonnes. The capacity utilisation rate is expected to increase to 91% in 2000, based on an annual production of 141 kilotonnes.

Table 2.8: Hydrochloric Acid Burner Capacities
(kilotonnes annual production)

Plants	1993	2000
Dow Chemical, Fort Saskatchewan, AB	35	35
ICI Canada, Becancour, PQ	40	65
Canadian Occidental, North Vancouver, BC	11	11
PPG Canada, Beauharnois, PQ	19	21
ICI Canada, Cornwall, ON	15	0
Saskatoon Chemicals, Saskatoon, SK	16	16
ICI Canada, Dalhousie, NB	1	1
Avenor, Dryden, ON	5	0
St. Anne Chemicals, Nackawic, NB	6	6
Total Capacity	148	155

Source: Canadian Chlorine Supply and Applications, CHEMinfo, 1994.

⁴ Production refers to both hydrochloric acid for merchant markets, and production for internal use in brine treatment. Brine treatment accounted for 39 kilotonnes in 1993, and an expected 32 kilotonnes in 2000.

2.4.3 Ethylene Dichloride and Vinyl Chloride Monomer

The annual capacity of Canadian plants for EDC and VCM production was 1033, and 450 kilotonnes, respectively, in 1993, as shown in Table 2-9. The EDC capacity had declined by the end of 1993, with the 1993 closure of the Dow Chemical plant in Sarnia, ON. Dow has been considering expansion of their large Ft. Saskatchewan plant, although this is not reflected in the forecast for 2000. The imbalance between EDC capacity (1033) and VCM capacity (500) reflects the export potential for EDC, while VCM is produced primarily for the domestic PVC market.

The plant utilisation rate for EDC capacity was 96% in 1993, based on production of 994 kilotonnes. This is expected to remain the same in 2000, based on production of 910 kilotonnes. In 1993, the VCM capacity utilisation rate was 86%, based on production of 428 kilotonnes. This is expected to increase to 95% by 2000, on production of 427 kilotonnes.

Table 2-9: EDC and VCM Plant Capacities
(kilotonnes annual production)

Plants	1993		2000	
	EDC	VCM	EDC	VCM
Dow Chemical, Fort Saskatchewan, AB	950	450	950	450
Dow Chemical, Sarnia, ON	83	50	0	0
Total Capacity	1033	500	950	450

Source: Canadian Chlorine Supply and Applications, CHEMinfo, 1994.; Dow Chemical

2.4.4 Domestic Sales and Revenues

Total revenues for base chlor-alkali commodities can be estimated from production levels and market prices⁵. There is a high variability in chlorine and caustic prices. Between 1983 and 1993, chlorine prices ranged from \$50 to \$270 per tonne and caustic prices ranged from \$120 to \$400 per tonne. Five year average prices (1988-1993) were multiplied by 1993 production levels to estimate industry revenues.

⁵ Chlor-alkali producers contacted for this study regarded plant revenues as confidential.

In the following discussion, revenues will refer to the merchant value of products sold by the base commodity chlor-alkali producers to other domestic industries, or exported. Revenues will not include the value of products produced by chlor-alkali producers used internally to make other commodities. For example, chlorine used to make EDC and VCM is not included in revenues, as the value of the chlorine is incorporated in the value of EDC exported, and VCM sold to PVC resin manufacturers⁶.

Revenues will be discussed at two levels; value of domestic sales, and domestic revenues. The value of domestic sales refers to the value of sales in domestic applications, or domestic consumption. Domestic revenues is a reflection of production, including both domestic consumption and net export sales, and can be used as a proxy for contribution to GDP. In this study, domestic revenues will be estimated as: Domestic revenues = Value of Domestic sales + Trade Balance (Exports -Imports).

The estimated domestic sales of base chlor-alkali products in 1993 was \$628 million, as shown in Table 2-10. The domestic products which generate the highest proportion of domestic sales are caustic (58%), followed by the PVC precursor VCM (33%). The portion of domestic sales derived from elemental chlorine sales is relatively small (5%), due to the declining market for elemental chlorine in pulp and paper.

Table 2-10: Base Commodities Domestic Sales

Base Commodities	Domestic Sales (kilotonnes)	Price (\$/T)	Value of Domestic Sales (\$ millions)	% of Total
Caustic Soda	1120	325	364	58%
Elemental Chlorine	249	132	33	5%
Hydrochloric Acid	84	263	22	3%
EDC	0	272	0	0%
VCM	419	500	209	33%
Total			628	100%

⁶ This method will also be employed in the final summary tables where revenues from domestic VCM sales will not be included. This is because the value of VCM is incorporated in the value of PVC final products.

Total annual domestic revenues from the sale of chlor-alkali base commodities are estimated at \$760 million, based on 1993 production levels, as shown in Table 2-11. Domestic revenues are dominated by revenues from caustic soda (51%), and VCM (27%). Chlor-alkali commodities exhibit a trade surplus of \$132 million, which includes large trade surpluses in EDC (\$70 million) and elemental chlorine (\$37 million).

Table 2-11: Base Commodities Domestic Revenues
(1993, \$ million)

Base Commodities	Value of Domestic Sales	Trade Balance	Domestic Revenues	% of Total
Caustic Soda	364	22	386	51%
Elemental Chlorine	33	37	70	9%
Hydrochloric Acid	22	7	29	4%
EDC	0	70	70	9%
VCM	209	(4)	205	27%
Total	628	132	760	100%

2.4.5 Employment

Table 2-12 lists the employment levels at Canadian chlor-alkali plants. The total estimated employment in chlor-alkali production in 1993 is 1305 people. Estimates of employment in plants which are not currently operating are based on the ratio of employment of similar plants to chlorine capacity. As can be expected, declining employment in the domestic chlor-alkali industry roughly corresponds to the declining capacity, as older and smaller plants close. The decline in total employment from 1987 to 2000 is 34% over 13 years.

Table 2-12: Employment in the Production of Base Chlor-alkali Products

Plants	1987	1993	2000
Dow Chemical, Fort Saskatchewan, AB ⁷	350	350	350
ICI Canada, Becancour, PQ	225	225	225
Dow Chemical, Sarnia, ON ⁸	200	200	0
Canadian Occidental, North Vancouver, BC	150	150	150
PPG Canada, Beauharnois, PQ.	118	135	135
ICI Canada, Cornwall, ON	89	89	0
Saskatoon Chemicals, Saskatoon, SK	50	50	50
ICI Canada, Dalhousie, NB	60	60	60
Avenor, Dryden, ON	27	27	0
St. Anne Chemicals, Nackawic, NB	19	19	19
Canadian Occidental, Squamish, BC	125	0	0
Canadian Occidental, Nanaimo, BC	48	0	0
Canso Chemicals, Abercrombie Pt., NS	45	0	0
Total Employment	1506	1305	989

⁷ Dow Ft. Sask employment estimate is roughly 25% of total site employment and includes Chlor-Alkali I and II units and the EDC/VCM unit.

⁸ Dow Sarnia employment estimate is based on Ft. Sask Chlor-alkali capacity.

2.5 Summary

This chapter has described the base commodities markets of the chlor-alkali industry. The base commodities are caustic soda, elemental chlorine, hydrochloric acid. The base commodities of EDC and VCM are precursors necessary in the production of PVC. They are also described in this chapter, since the sole domestic production occurs at the largest chlor-alkali plant in Canada, the Dow Chemical plant in Fort Saskatchewan, Alberta.

The domestic market for chlor-alkali commodities exhibits an imbalance where the domestic production of caustic is roughly equivalent to domestic demand, but elemental chlorine production exceeds domestic demand, and is exported. In 1993, chlorine exports (elemental chlorine and EDC) accounted for 43% of the total domestic supply of chlorine. The trend indicates an increasing imbalance over time.

This deteriorating domestic balance results from the collapse of demand for elemental chlorine from the pulp and paper industry, which is expected to decline from 32% of chlorine supply in 1988 (560 kilotonnes) to 3% (24 kilotonnes) in 2000. The chlor-alkali industry has adjusted to this trend in three ways; increasing exports, plant closures, and decreasing production. Annual chlorine capacity is expected to decrease from 1750 kilotonnes in 1988 to 1117 in 2000, a decline of 38%. Annual chlorine production is expected to decline from 1700 kilotonnes in 1988 to 930 kilotonnes in 2000, a decline of 43%. As a result of this trend, the principal domestic use of elemental chlorine has become the production of the PVC precursors EDC and VCM, with this demand expected to be relatively stable from 1988 to 2000. In 1993, the domestic demand for elemental chlorine for VCM production accounted for 21% of total elemental chlorine supply.

Based on 1993 production levels, an estimate of the domestic sales of base chlor-alkali products was \$628 million. The domestic sales are dominated by the sales of caustic soda (58%), and the PVC precursor VCM (33%). Domestic revenues include exports and imports. Domestic revenues are estimated at \$760 million. Domestic revenues are also dominated by the sales of the same products, caustic soda (51%), and VCM (27%). Chlor-alkali commodities have a export surplus (ie. exports-imports) of \$132 million, with this export surplus dominated by the contribution of elemental chlorine (\$37 million) and EDC (\$70 million).

As of 1993, employment in the chlor-alkali industry was 1305, in ten plants located across the country. Currently, only seven plants are operating. Between 1987 and the year 2000, employment is expected to decline from 1506 to 989, a 34% decline, reflecting the plant closures caused by the declining domestic demand for elemental chlorine.

2.6 Contacts and References

2.6.1 Industry Contacts

The following organizations were contacted to provide information for this chapter. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Avenor,
- Dow Chemical,
- ICI Canada,
- PPG,
- Saskatoon Chemicals, and
- St. Anne Chemicals.

2.6.2 References

Camford Information Services. 1993. CPI Product Profile, Chlorine.

CHEMinfo Services Inc. 1994, Canadian Chlorine Supply and Applications, Environment Canada.

3. Caustic Soda

3.1 Introduction

This chapter will review the domestic market for electrolytic caustic soda, taking into consideration alternatives to electrolytic caustic. The alternatives discussed are chemical caustic (sodium hydroxide solution prepared by reacting soda ash with slaked lime), soda ash, lime, and sodium sulphate (salt cake).

This chapter will describe the production process for alternatives, as well as estimate the direct replacement costs in domestic applications based on 100% replacement with chemical caustic. In order to place the direct replacement costs in context, these costs will be compared to the revenues derived from the products of the major industries which use caustic soda; pulp and paper, alumina production, soaps and detergents, petrochemicals (tar sands), and metal mining (gold). Finally the socio-economic profile will describe the plants, capacities, production, revenues, and employment associated with alternatives to electrolytic caustic soda.

3.2 Market for Electrolytic Caustic Soda and Alternatives

Table 3-1 summarizes the domestic applications for caustic soda in Canada. In 1993, the pulp and paper industry accounted for 67% of domestic electrolytic caustic consumption, with the remaining applications including; alumina production, the production of soaps, detergents and cleaners, metal mining (principally gold), petrochemical applications (principally tar sands), and many other small volume applications, as listed in Table 3-1. A slight declining trend in caustic use in pulp and paper from 1988 to 1993 is expected to stabilize to the year 2000. All other applications are expected to stay relatively stable from 1988 to 2000.

A more detailed analysis of the different specific applications relative to alternatives is provided in the following sections on pulp and paper.

Table 3-1: Canadian Caustic Applications
(kilotonnes)

	1988	1993	2000
Pulp and Paper	980	750	790
Alumina production	90	87	90
Soaps, detergents, cleaners	76	81	85
Mining, inorganic chemicals	57	55	61
Tar sands, crude, petrochemicals	23	24	30
Other	296	123	114
Total Domestic consumption	1544	1120	1170

Source: Canadian Chlorine Supply and Applications, CHEMinfo. services, 1994.

3.2.1 Caustic Use in the Pulp and Paper Sector

As Table 3-2 indicates, caustic has many applications within the pulp and paper industry, with the principal use taking place in kraft and sulphite mills in both the pulping and bleaching stages. Kraft mills and sulphite mills use chemical pulping to produce pulp from wood fibre. These are the same mills which are switching from elemental chlorine to chlorine dioxide use in chemical pulp production, as will be discussed in chapter 4.

Table 3-2: Electrolytic Caustic Use in Pulp and Paper Mills

	1988	1993 (kilotonnes)	2000
Kraft, sulphite-based pulping	350	180	165
Kraft, sulphite-based bleaching	540	420	430
Mechanical pulping, bleaching	50	65	75
Deinking, flotation, washing	15	60	85
All other applications	25	25	35
Total	980	750	790

Source: Canadian Chlorine Supply and Applications, CHEMinfo. services, 1994.

In kraft and sulphite mills, the main uses of electrolytic caustic are: make-up for sodium values lost in the pulping and chemical recovery cycle, extraction of chlorolignins in the bleachery, and neutralization of process streams. As indicated in Table 3-2, the highest volume is used in the bleaching process.

Demand for caustic has declined in kraft and sulphite mills, particularly in the pulping stage. While some part of this decline is related to reduced production, particularly from sulphite mills, other factors are correlated with the movement from elemental chlorine to chlorine dioxide in chemical pulp bleaching. One of these correlating factors is the increasing use of oxygen delignification in chemical pulp production. As oxygen delignification reduces the chlorolignin content in the pulp emerging from the chlorination tower the demand for caustic in the bleaching stage is also reduced.

The second factor decreasing caustic use is the replacement of elemental chlorine by chlorine dioxide as a bleaching agent. In the conversion of sodium chlorate to chlorine dioxide, salt cake (sodium sulphate) is produced as a by-product. Sodium sulphate is an alternative source of sodium to electrolytic caustic. As it is available at zero cost, it has been replacing other purchased sources of sodium in the pulping process. Table 3-3 indicates the trend in use of electrolytic caustic and alternative sodium sources in the pulping stage for kraft and sulphite mills.

**Table 3-3: Estimated Sodium Sources for Kraft and Sulphite
Pulping Operations**

	Origin	1988	1993
		(kilotonnes - Na ₂ O basis) ¹	
Electrolytic caustic	Purchased	200	150
Salt cake (Sodium sulphate)	Purchased	90	50
Soda ash	Purchased	5	10
Salt cake from chlorine dioxide generators	By-product	90	210
Total sodium requirement		385	420
Total per quantity of pulping capacity (tonnes Na ₂ O/kilotonne capacity)		33	31

Source: CHEMinfo Services

¹ The Na₂O basis is commonly used to express sodium content.

Some alternatives to electrolytic caustic are currently used at kraft and sulphite mills. Major alternatives currently in use are:

- a) soda ash converted on-site to chemical caustic;
- b) salt cake (sodium sulphate). Salt cake may be purchased or obtained as a by-product from an on-site chlorine dioxide generator;
- c) various recycled spent liquors, and chemical streams containing sodium and sulphur passed through the on-site chemical recovery process; and
- d) lime used in acid stream neutralization.

Soda ash, salt cake, various spent liquors, or lime do not represent stand-alone alternatives that can replace all electrolytic caustic requirements at the mills. There are technical and equipment limitations to the adoption of these alternatives. For example, there are limitations on the amount of sulphur that can be accommodated in the pulping process, which limits the use of salt cake and other recycled chemicals containing sulphur.

Purchased chemical caustic represents one alternative that can substitute for all electrolytically derived caustic. Chemical caustic can be produced to be of similar quality and concentration to that of electrolytic caustic. Chemically derived caustic was the major source of sodium in the pulp and paper prior to the establishment of the chlor-alkali industry in the 1940s. Chemical caustic is a sodium hydroxide solution made from soda ash (sodium carbonate) reacted with slaked lime (calcium oxide). There is currently no production of merchant chemical caustic in Canada, although kraft mills use lime to make chemical caustic on-site as part of the recausticization cycle.

Mechanical pulping mills also have several uses for electrolytic caustic. One major application is in hydrogen peroxide bleaching, where caustic is required to increase pH. Caustic is also used by chemi-thermomechanical (CTMP) mills to produce sodium sulphite and sodium hydrosulfite (a bleaching agent). Deinking plants use caustic in combination with hydrogen peroxide and sodium silicate in flotation systems, and to loosen fibres and break up ink particles. In these pulp segments of the industry, the demand for caustic is expected to increase in rough proportion to production. The main alternative to electrolytic caustic would be chemical caustic.

3.2.2 Other Caustic Uses

An estimated 87 kilotonnes of caustic was used by the **alumina** industry in 1993. Alcan's facility in Jonquiere, Quebec is the only location of Canada's 11 aluminum smelting operations to have an alumina refining facility. Caustic is used as a critical reagent in the "Bayer" process, which involves the refining of bauxite ore to produce alumina (the first

of two stages in aluminum production). Alcan claims the only reasonable alternative to electrolytic caustic is chemical caustic of comparable quality and strength.

An estimated 81 kilotonnes of caustic was used by the **soaps and detergents** industry in 1993. Caustic is used mainly to carry out saponification reactions, to synthesize cation reagents and to neutralize process streams. The major users of caustic within the industry are the large soap manufacturers (e.g., Lever, Proctor & Gamble, Witco). Hundreds of smaller firms also make blended products for a large set of industrial and commercial customers.

The **mining** industry uses between 50 and 60 kilotonnes of caustic each year. Caustic is mainly used for demineralization of boiler feed water, neutralization of various process streams and treatment of tailings or other effluents. Gold refiners represent one of the largest applications within the industry. Sodium cyanide in caustic solution is used to strip gold from carbon. Within the **mining** and **soaps and detergents** industries, chemical caustic would be the principal alternative to electrolytic caustic.

The **petroleum** industry uses about 25 kilotonnes of caustic each year. Caustic is used in many applications - from drilling operations to petrochemicals. Caustic is used principally for the removal of contaminants such as hydrogen sulphide from process streams. It is also used as a neutralizing agent. The largest application of caustic in the petroleum industry is its use in the washing stage of oil sands at Syncrude and Suncor operations in Alberta.

Within the **petroleum** industry, dissolved soda ash is currently being used in selected applications (e.g. to provide alkaline solutions in oil and gas drilling activities, and in the processing of gas). Chemical caustic would be the principal alternative used to substitute for electrolytic caustic.

3.3 Alternative Production Processes

In general, caustic applications involve the requirement for an alkali, or the need for a source of sodium. Therefore, these two functions need to be preserved by alternative, non-electrolytic caustic sources in order for these alternative sources to represent technically-comparable substitutes. There are a number of non-electrolytic sources of caustic resulting in a product which is suitable for selected applications. These sources include the following:

- sodium hydroxide from the lime-soda process (i.e., chemical caustic);
- dissolved soda ash (sodium carbonate);
- dissolved lime (calcium oxide) or hydrated lime (calcium hydroxide);

- sodium sulphate converted to sodium hydroxide;
- sodium sulphide and sodium hydrosulphide;
- ammonium hydroxide;
- magnesium hydroxide; and
- potassium hydroxide.

Chemical caustic refers to caustic produced through the lime-soda process. It is the major alternative to electrolytically produced caustic soda, and for most applications is technically comparable to electrolytic caustic. Chemical caustic was used universally prior to the development of the chlor-alkali cells currently used in the production of electrolytic caustic. Chemical caustic is sodium hydroxide produced when soda ash (Na_2CO_3) is reacted with slaked lime (calcium oxide, $\text{Ca}(\text{OH})_2$) in the lime-soda process. This process generates calcium carbonate as a by-product to the caustic soda. The by-product calcium carbonate is often recycled and heated to regenerate the lime (CaO) for slaking with water.

Another non-electrolytic alternative source of caustic is dissolved soda ash. However, this alternative is limited in the degree to which it can substitute for electrolytic caustic. When soda ash is saturated in water, the ash dissociates to produce a 30-33% sodium hydroxide solution and weak carbonic acid. To a limited extent, caustic from soda ash currently competes with electrolytic caustic in a number of applications, particularly certain waste water processing, acid stream neutralization and some desulphurizing applications. Table 3-4 compares the technical factors of electrolytic caustic to these two alternatives.

Table 3-4: Technical Comparison of Caustic Substitutes

	Electrolytic Caustic	Chemical Caustic	Dissolved Soda Ash
Ease of handling	Easy to handle 50% bulk solution Truck, railcar to storage tank	Easy to handle 50% bulk solution Truck, railcar to storage tank	Hard to handle 33% solution Fine, dry powder Hopper cars; solids handling equipment; mixing tank and heater
Strength	77% Na_2O	77% Na_2O	55% Na_2O
Energy	Common steam tracing	Common steam tracing	Extra steam heating
Purity	Chlorides - diaphragm: 1% - membrane: 40-100 ppm Metals - low No organics	Chlorides - 0.15-0.35% Metals high Organics - odour, colour	Chlorides very low Organics - odour, colour

Soda ash is shipped either as a slurry or in dry form, which makes handling more difficult compared to (liquid) electrolytic caustic. Soda ash may also cost more, since volumetrically to obtain the same amount of sodium ions requires 60-70% more material. In certain applications (i.e., those requiring high purity caustic), the use of soda ash can result in minor constituents in the mineral which can cause undesirable chemical side-reactions. In many chemical reactions involving soda ash carbon dioxide is generated, which can cause foaming problems in the process.

3.4 Direct Replacement Cost

The following section estimates the direct replacement cost of electrolytic caustic soda, based on 100% substitution using chemical caustic. A comparison of the costs of chemical caustic relative to electrolytic caustic is complicated by the difficulty in valuing electrolytic caustic due to the wide price swings needed to bring the chlor-alkali market into balance, as discussed in Chapter 2.

The direct replacement cost analysis makes the following assumptions:

- Lime is produced regionally, and soda ash is imported from natural deposits in Wyoming and shipped to Canada where it is processed in regional lime-soda process plants distributed across Canada. Industry sources suggest a more probable scenario may be that plants would locate near Wyoming (rather than in regions across Canada). Capital investment costs to construct lime-soda process plants in Canada, based on recent Wyoming plant estimates, total \$730 million to produce 1,120 kilotonnes of caustic per year. Average freight costs to ship soda ash are assumed to be \$65/tonne, and chemical caustic is shipped as 50% bulk solution short distances to customers.
- The lime-soda process produces 1.0 tonne of caustic from 1.4 tonnes of soda ash and 0.7 tonnes of lime. In addition, a fine precipitate of solid calcium carbonate is produced, which entails additional capital and operating costs in order to reprocess it back to lime for slaking. The caustic produced is a 15% solution, which must be concentrated to bring it up to the commercial standard of 50% using an evaporation process which consumes additional energy.
- Chemical caustic can be substituted for all electrolytic caustic consumed in Canada. This assumption is conservative, in that the cost of chemical caustic substitution is higher than substitution with dissolved soda ash. Also, it is more realistic since chemical caustic can be made to the same strength and purity. Dissolved soda ash can only be used in a minority of applications where electrolytic caustic is used.

- All chemical prices represent a five-year average for the period ending 1993. For mature commodities like soda ash and lime prices are relatively stable, however electrolytic caustic prices are volatile and ranged from a high of just over \$400 a tonne to a low of \$200 a tonne from 1988-1993. The average price for caustic soda over this period was \$325.

Using these assumptions, the total unit operating cost of producing chemical caustic is \$370/tonne, before inclusion of capital investment. The price of chemical caustic represents an additional cost relative to electrolytic caustic of \$45/tonne, given an average price of \$325/tonne for electrolytic caustic. The volume of electrolytic caustic used in Canada in 1993 was 1120 kT. The additional capital cost of \$730 million for conversion to chemical caustic, amortized at an 9% interest rate over a twenty year life, amounts to an additional annualized capital cost of \$80 million/year. The total direct replacement cost, including both annual capital and operating costs, is \$130 million/year, roughly one-third higher than the current cost of electrolytic caustic. The direct replacement costs calculations are summarized in Table 3-5.

Table 3-5: Direct Replacement Cost of Chemical Caustic

	Electrolytic Caustic	Chemical Caustic	Difference
Material Costs Soda Ash (C\$/T)		270	
Lime (C\$/T)		35	
Utilities (C\$/T)		15	
Overhead (C\$/T)		50	
Total Cost (C\$/T)	325	370	45
Volume (kT/yr)	1120	1120	
Total Value (\$ millions/yr)	364	414	50
Capital (\$ million)		730	
Annual Capital (\$ million/yr)		80	80
Total Annual Cost (\$million/yr)			130

Source: CHEMinfo Services.

Small reductions in the cost impact are possible by changing certain assumptions. For example, the chemical caustic business could locate close to the soda ash supply source in

Wyoming, and then all caustic would be shipped into Canada. Total capital investment would likely be less than the \$730 million assumed in the above calculation due to economies of scale (e.g., a few larger plants, rather than a large number of small plants distributed regionally). Operating costs would be reduced by lower raw material shipping costs, but increased by finished product shipping costs. Overall, it is estimated that the market price for chemical caustic would not change by more than 10%.

3.5 Direct Replacement Cost Compared to End Use Revenues

In order to place the direct replacement costs in context, they can be compared to the end use revenues from the main industries which use caustic soda: pulp and paper, alumina production, soaps and detergents, petrochemicals industry (tar sands), and the mining industry (gold). In order to be more precise, the end-use revenues used for the pulp and paper sector will be the value of domestic chemical pulps, and the value of newsprint and mechanical papers. These end-use values will be used as chemical pulp is principally exported as market pulp, while mechanical pulps are primarily used in integrated pulp and paper mills to produce newsprint and mechanical papers.

As shown in Table 3-6, the direct replacement costs for electrolytic caustic for all applications would be less than 1% of the value of the end use product.

**Table 3-6: Direct Replacement Costs compared
to End Use Revenues**

Application	Caustic Use (1993, kilotonne)	Additional Cost (\$ million)	End-Use Revenues (\$ million)	Cost/ Revenues (%)
Chemical pulp	600	70	7692	0.9%
Newsprint and Mechanical Papers	150	17	6006	0.3%
Primary aluminum smelting and refining	87	10	5294	0.2%
Soaps and Detergents	81	9	1602	0.6%
Metal mining (gold)	55	6	2093	0.3%
Petrochemicals (Oil sands)	24	3	2057	0.1%

Sources: Statscan, 1993, 31-203.

3.6 Socio-Economic Profile of Alternatives to Electrolytic Caustic

This section will profile industries which produce alternatives to electrolytic caustic. These alternative industries are: chemical caustic, soda ash, lime and salt cake.

The socio-economic profile of chlor-alkali production was provided in Chapter 2. In 1993, total capacity for caustic production was 1425 kilotonnes, while production was 1225 kilotonnes, in ten plants located across the country. The value of domestic sales is estimated at \$364 million, while domestic revenues are estimated at \$386 million. Total employment in chlor-alkali production is estimated at 1305 in 1993. Assuming that 40% of all employment in chlor-alkali production is related to caustic soda generates an estimate of 522 people employed in electrolytic caustic production.

3.6.1 Chemical Caustic

There are no commercial facilities in Canada producing chemical caustic. There are three facilities in the United States, all located at trona mine sites in Green River, Wyoming. Table 3-7 provides the capacities of the three plants. These plants were constructed in response to the rising prices of commercial electrolytic caustic during the 1980s. TG Soda Ash Inc., the largest of the three facilities, has taken its plant (or at least portions of the plant) on and off production, depending on electrolytic caustic prices.

Table 3-7: Chemical Caustic Plants

	1993 (kilotonnes)
TG Soda Ash Inc., Green River, WY	135
Solvay Minerals, Green River, WY	68
FMC Corp., Green River, WY	58
Total Trona-based Capacity	261

Source: CHEMinfo Services

The Wyoming plants compete mainly in regional markets and do not represent major players in the North American commercial caustic markets because trona-based caustic operations are at a competitive disadvantage when chlorine prices swing upward (and hence electrolytic caustic prices swing downward). Nonetheless, the raw material base at

the Wyoming plants can support expanded plant capacities in the event that caustic prices reach and remain at levels making chemical caustic a competitive alternative.

3.6.2 Soda Ash

There is one soda ash producer in Canada - General Chemicals (located in Amherstburg, Ontario) - which produced about 375 kilotonnes in 1993. Table 3-8 provides a summary of soda ash supply and demand. General Chemicals serves the traditional and higher-end markets in Canada, particularly the glass industry, and also exports a large portion of its production to the U.S., South America and Europe. General Chemicals uses the "Solvay" process to produce a high-quality soda ash, and currently operates the only plant on the continent that uses this process. Additional annual capacity of 100 kilotonnes has been added to this plant in the past year, in anticipation of a growing demand for soda ash.

Table 3-8: Canadian Soda Ash Supply/Demand

	1993 (kilotonnes)
Capacity	400
Production	375
Imports	120
Total supply	495
Domestic demand	410
Exports	85
Total demand	495

Source: CHEMinfo Services

Soda ash imports, which were 120 kilotonnes in 1993, satisfy close to 30% of current domestic demand. In particular, imported soda ash serves the pulp and paper sector and other lower value application areas. Exports, which were 85 kilotonnes in 1993, accounted for over 20% of current domestic production.

The single Canadian soda ash manufacturing plant currently plays a minor role in the North American market, accounting for under 5% of North American soda ash capacity (see Table 3-9). The U.S. is the world's largest producer and exporter of soda ash, due to the large trona deposits in Wyoming and California.

Table 3-9: North American Producers of Soda Ash

	(kilotonnes)
Canada	
General Chemical Canada, Amherstburg, Ontario	400
U.S.A.	
FMC Corp., Green River, WY	2,565
General Chemical, Green River, WY	2,160
Rhone-Poulenc, Green River, WY	2,070
Solvay Minerals, Green River, WY	1,800
North American, Argus, CA	1,170
Tg Soda Ash, Green River, WY	1,170
Total Capacity	11,335

Source: CHEMinfo Services

Soda ash capacity in North America is continuing to grow. While Canadian-based General Chemicals has added marginal capacity, U.S.-based FMC Corp. is planning an additional 450 kilotonnes and Solvay Minerals has just completed an expansion which has resulted in a capacity increase of 80%. North American is also increasing its capacity by 450 kilotonnes this year. New producers are also planning soda ash plant investment within the next three years. For example, Lake Minerals and Vulcan Materials (subsidiaries of Cominco American) are planning a 540 kilotonne operation and Owens Lake, California, and World Trona are planning to construct a 1,000 kilotonne/year plant in 1997 in Wyoming which will produce semi-pure soda ash.

Revenues: Based on a price of \$270 a tonne, domestic revenues are \$101 million. The trade deficit is \$9 million. The value of domestic sales are \$111 million.

Employment: General Chemical Canada employees approximately 280 people at the Amherstburg, ON facility which makes soda ash as well as calcium chloride. Approximately 50 people are attributed to the production of soda ash.

3.6.3 Lime

There are 19 plants (about 15 companies) supplying lime in Canada, as listed in Table 3-10. Some plants, accounting for about 15% of total lime production, are

dedicated to serving captive, on-site requirements (e.g., sugar, steel and wood pulp production). Table 3-10 provides a list of the Canadian lime supply plants, excluding lime produced at pulp and paper mills.

Table 3-10: Canadian Lime Plants

Merchant Suppliers	Location	Province	Capacity (kilotonne/yr)
Algoma Steel	Sault Ste. Marie	ON	275
BC Sugar	Taber	AB	60
Beachvilime	Beachville	ON	700
Continental Lime	Faulkner	MB	120
Continental Lime	Exshaw	AB	160
Continental Lime	Kamloops	BC	235
Dymond Clay Products	Haileybury	ON	40
General Chemicals	Amerherstburg	ON	290
Global Stone	Ingersoll	ON	225
Graybec	Joliette	PQ	300
Graybec	Marbleton	PQ	300
Guelph DoLime	Guelph	ON	120
Havelock Processing	Havelock	NB	175
Koch Minerals	Spragge	ON	200
Manitoba Sugar	Winnipeg	MB	15
Steetley Industries	Dundas	ON	350
Summit Lime Works	Hazell	AB	50
Texada Lime	Fort Langley	BC	170
Timminco Inc.	Haley	ON	50
Total Operating Capacity			3,835
Estimated Idle Capacity			700
Total Capacity Available			4,535

Source: Camford Information Services.

There is sufficient lime capacity in Canada to accommodate any requirements from new lime-soda caustic plant additions. The lime industry currently operates with a substantial amount of idle capacity, estimated at about 15% of current capacity levels. Furthermore, the amount of lime required to satisfy caustic production requirements is estimated at less than 100 kilotonnes per year, or about 2% of current capacity levels in Canada (assuming that all lime-soda capacity includes capture of calcium carbonate and recycling to an on-site lime kiln).

Production of lime is estimated at 2700 kilotonnes, with exports of 172 kilotonnes and imports of 46 kilotonnes.

Revenues: Based on a price of lime of \$35 per tonne, domestic revenues are \$95 million. The trade surplus is \$4 million and the value of domestic sales is \$91 million.

Employment: In 1993 manufacturing employment in lime production was 551.

3.6.4 Salt Cake

As shown in Table 3-11, there are six plants supplying salt cake in Canada, with the two Saskatchewan Minerals plants accounting for over 50% of current capacity. The number of salt cake manufacturing facilities has decreased over the past decade, mainly due to the installation of on-site chlorine dioxide generators (which produce salt cake as a by-product) at pulp and paper mills. Capacity in 1993 was 530 kilotonnes per year, down from the 830 kilotonnes produced in 1981.

Table 3-11: Canadian Salt Cake Plants

Company	Location	Capacity (ktonne/yr)
Saskatchewan Minerals	Chaplin, SK	100
Saskatchewan Minerals	Fox Valley, SK	170
Millar Western	Edmonton, AB	107
Soteck	Capri, SK	55
Ormiston Mining	Ormiston, SK	90
Tonelli (recycling)	Mississauga, ON	8
Total capacity (1993)		530
Total capacity (1981)		830

Source: Camford Information Services

Domestic demand for salt cake has been mainly from pulp and paper mills, with only minor amounts being exported or used for the domestic manufacture of glass, detergents and other applications. Imported salt cake currently accounts for about 5% of domestic demand. Exports are significant, accounting for over 50% of production in 1993. The industry operated at 60% capacity in 1993. Therefore, current facilities appear to be capable of satisfying any increased demand arising from the need for substitution of electrolytic caustic.

Revenues: Domestic revenues are estimated at \$24 million calculated from a production of 300 kilotonnes and a price for salt cake of \$80 per tonne.

Employment: Based on estimates obtained from company representatives, approximately 175 employees are attributed to the production and sales of salt cake in Canada.

3.7 Summary

Alternatives to electrolytic caustic described in this section are chemical caustic (produced using the lime-soda process), soda ash, lime and salt cake. Table 3-12 summarizes the socio-economic profiles of caustic soda and these 3 alternatives. Currently electrolytic caustic dominates the merchant market for alkali, though there are minor uses of chemical caustic (produced on-site), dissolved soda ash, sodium sulphate, and lime. Currently there are no facilities in Canada producing merchant chemical caustic.

The principal market for alkali products is in the chemical pulp producing segment of the pulp and paper industry. In this market segment, demand for merchant sources of sodium (ex. electrolytic caustic, salt cake) exhibits a slight decline. This slight decline results from decreased production of chemical pulp, increased use of oxygen delignification, and substitution of sodium sulphate produced on-site. The sodium sulphate (or salt cake) is produced as a by-product of chlorine dioxide generation. All other market segments (mechanical pulp production, alumina production, soaps and detergents, metal mining, petrochemicals) exhibit a relatively stable demand for alkali products.

The direct replacement cost for electrolytic caustic is estimated based on 100% substitution with chemical caustic. Chemical caustic is sodium hydroxide produced through the lime soda process, where soda ash is reacted with slaked lime. The direct replacement costs are estimated at \$50 million in annual operating costs, and \$730 million in capital costs (\$80 million annualized), resulting in an estimated annual cost of \$130 million.

In order to place the direct replacement costs in context, they can be compared to the total revenues generated by the industries which use electrolytic caustic. In all electrolytic caustic using industries the direct replacement costs would be 1%, or less, of total annual end use revenues.

Table 3-12: Summary of Socio-Economic Data of Electrolytic Caustic and Alternatives (1993)

	Electrolytic Caustic	Soda Ash	Lime	Salt cake
Value of Domestic Sales (\$ million)	364	111	91	n.a.
Trade Balance (\$ million)	22	(9)	4	n.a.
Domestic Revenues (\$ million)	386	101	95	42
Employment	522	n.a.	551	n.a.
Employment/Domestic Revenues	1.4	n.a.	5.8	n.a.

3.8 Contacts and References

3.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Albchem,
- Alcan Aluminum,
- Avenor,
- BC Chemicals,
- Chemprox,
- CXY Chemicals,
- Dow Chemical,
- Dupont Canada,
- Eka-Nobel,
- FMC Chemical Products,
- General Chemical Canada,

- General Chemical Corp,
- ICI Canada,
- PPG,
- Saskatoon Chemicals,
- Solvay Minerals Inc.,
- St. Anne Chemicals, and
- Sterling Chemicals.

3.8.2 References

Camford Information Services. 1993. Lime, Salt cake Product Profiles.

CHEMinfo Services. 1993. North American Bleaching Chemicals, Outlook to 2000,

Statistics Canada. 1993. Manufacturing Industries of Canada, 31-203

Statistics Canada. 1993. Imports by commodity (65-007), Exports by commodity (65-004)

4. Chlorine in the Pulp and Paper Industry

4.1 Introduction

This chapter reviews elemental chlorine use and alternatives to chlorine within the pulp and paper industry. The focus will be on chlorine use within the kraft, sulphite and semi-chemical pulp mills which produce chemical pulp. These are the same mills which are the major users of caustic soda, as identified in Chapter 3.

This chapter begins by describing the market for elemental chlorine and alternatives within the pulp and paper industry. A description of the production processes for two alternatives to elemental chlorine pulp, namely: elemental chlorine free pulp (ECF); and total chlorine free pulp (TCF) follows. The term ECF pulp refers to the elimination of elemental chlorine from the bleach sequence through substitution by chlorine dioxide and other technologies. The term TCF pulp refers to a collection of alternative technologies, including extended cooking, oxygen and ozone delignification, and hydrogen peroxide bleaching. The two alternatives are not mutually exclusive, with many of the process changes involved in production of TCF pulp (e.g. oxygen delignification, extended cooking) being compatible with production of ECF pulp.

The direct replacement cost will be estimated for the two alternatives (ECF, TCF) based on 1993 production levels. These costs will be compared to the revenues from the sale of chemical pulps. Finally the socio-economic profile will describe and compare the industries which supply alternatives to elemental chlorine. The variables used in the socio-economic profile will be plants, capacity, production, revenues and employment.

4.2 Market for Elemental Chlorine and Alternatives

In 1993, the Canadian pulp and paper industry produced 22,896 kilotonnes of wood pulp, of which 12,308 kilotonnes (54%) was chemical pulp and 10,588 kilotonnes (46%) mechanical pulp. Manufactured paper products from integrated pulp and paper mills accounted for 5,300 kilotonnes of chemical pulp production, while 7,008 kilotonnes of chemical pulp were sold as market pulp. The majority of chemical market pulp was exported. In contrast, only 1,124 kilotonnes of mechanical pulp was market pulp, with 9,464 kilotonnes used to manufacture paper products (CPPA, 1994).

Almost all of the elemental chlorine used in the pulp and paper industry has traditionally been used to bleach or brighten chemical pulp. Some elemental chlorine is used in de-

inking operations. Chemical pulps are produced by 44 kraft, sulfite and semi-chemical mills in Canada. Table 4-1 indicates the distribution of chlorine and chlorine dioxide use in the pulp producing segment of the Canadian pulp and paper industry.

Mechanical pulps are generally not considered an alternative to bleached chemical pulp since they are unable to achieve equivalent strength and brightness properties. However, since the early 1980's, an increasing quantity of bleached chemi-thermomechanical (CTMP) pulps have become available which can replace bleached sulfite and kraft pulp in some paper products. These CTMP pulps are chlorine-free. Canada is the world leader in production of these type of pulps.

Table 4-1: Bleaching in the Pulp and Paper Industry, 1993

	Chlorine and Chlorine Dioxide Based Bleaching	Non-chlorine Based Bleaching	Nominal Bleaching Capacity (1993) (kilotonne/day pulp)
Chemical pulps	99%	1%	37
Deinked paper	20%	80%	4
Mechanical pulps	0%	100%	32
Overall	51%	49%	73

Source: CHEMinfo Services

The major trend in chemical pulp bleaching has been the substitution of chlorine dioxide for elemental chlorine as a bleaching agent, as illustrated in Table 4-2. Another trend has been the increased use of oxygen delignification. Both of these trends were influenced by federal environmental regulation of dioxin and furan discharges and regulations in various provincial jurisdictions of absorbable organic halides (AOX) discharges.

**Table 4-2: Elemental Chlorine and its Alternatives
in Chemical Pulp Brightening**

	Percent of Brightening Requirement		
	1988	1993	2000
Elemental chlorine	61%	15%	1%
Chlorine dioxide	35%	73%	80%
Oxygen delignification	1%	6%	15%
Hydrogen peroxide, other chemicals	3%	6%	4%
Total brightening/bleaching chemical requirement	100%	100%	100%

Source: CHEMinfo Services

These trends have led to a collapse in demand for elemental chlorine from the pulp and paper industry, as shown in Table 4-3, with an expected 96% decline in demand from 1988 to 2000. The largest use of elemental chlorine in 2000 within the pulp and paper industry is expected to be the generation of chlorine dioxide at one mill.

Table 4-3: Elemental Chlorine Use in the Pulp & Paper Industry

	Kilotonne		
	1988	1993	2000
Direct application	520	155	10
Sodium hypochlorite production	40	10	2
Chlorine dioxide generation (one mill)	0	10	12
Total demand	560	175	24

Source: CHEMinfo Services

The other alternative (TCF pulp production) is not used to a large extent in Canada. As of 1993, the proportion of TCF pulp in Canada was less than 1% of total chemical pulp production, with only a few Canadian mills accounting for TCF pulp production. Howe Sound Pulp and Paper (Port Mellon, B.C.) was responsible for most of Canada's TCF bleached kraft pulp produced in 1993. Another mill producing TCF pulp in 1993 was Stora Forest Industries (Port Hawkesbury, N.S.), which can produce TCF sulphite pulp.

However, world wide production of ECF and TCF pulp has been increasing. As shown in Table 4-4, TCF technology development has been strongly promoted by some European mills, particularly in Scandinavian countries. ECF and TCF pulp demand in Europe is being driven both by government environmental regulations, and by customer demands for totally elemental chlorine free pulp and paper. During 1993, TCF pulps in the European market commanded a premium of US\$40 to \$100 per tonne (Mullins and Roberts, 1995), though this premium has eroded since 1993^{1, 2}.

Table 4-4: Scandinavian and European Production of Elemental Chlorine, ECF and TCF Pulps

	Production in 1994 (million tonnes)			Estimated Production in 2000 (million tonnes)		
	Cl	ECF	TCF	Cl	ECF	TCF
Scandinavia	0.0	7.2	2.3	0.0	4.3	6.4
Continental Europe	1.6	3.2	0.3	0.0	4.8	0.5
Total	1.6	10.4	2.6	0.0	9.1	6.9
Total (%)	11.0	71.2	17.8	0.0	56.9	43.1

Source: Mullin and Roberts, 1995

TCF has been considered to be at a disadvantage for customers that do not discriminate between bleach processes, since it has been difficult, or impossible for some mills, to achieve the same degree of strength and brightness in TCF paper as with chlorine bleached or ECF paper. Technical improvements continue to address the strength and brightness achievable with TCF pulp.

4.3 Pulp Production Processes

This section will discuss the bleaching processes for elemental chlorine, and for the two alternatives to elemental chlorine, ECF and TCF chemical pulp production. ECF refers to

¹ Paper purchasing personnel contacted at two major Canadian paper distributors in March 1997 state for the few grades of TCF papers they sell, there are no price premiums for TCF grades versus elemental chlorine free papers.

² Sodra Cell, Why Totally Chlorine Free Market Pulp?, Graph Titled, "Pulp Price Development- TCF vs. ECF Bleached Softwood Kraft Pulp, 1993 to 1996. .

chemical pulps produced without elemental chlorine using chlorine dioxide. TCF refers to chemical pulps produced without the use of chlorine or chlorine dioxide. While these three classifications of bleaching technology are commonly used they are not mutually exclusive. For example, some Canadian mills combine elemental chlorine, chlorine dioxide, and oxygen delignification in their operations.

Chemical pulp is produced by mills which cook raw wood chips in an alkaline chemical solution within a digester, in order to separate the wood fibre from the lignins and extractives. Lignin is a dark-coloured polymeric substance which serves as a cementing agent for individual wood fibres. Extractives are resins, oils, alcohols and fatty acids contained in the pulp. Following the pulping stage, the raw pulp, or brownstock, is sent to the bleachery, where the principal use of elemental chlorine occurs.

There are numerous chemical process configurations that can be used to bleach the pulp and separate the lignins and extractives. Table 4-5 lists some of the different chemicals and processes, and serves as the key to understanding the bleaching sequences which will be discussed for the different methods of pulp bleaching described.

Table 4-5: Legend for Bleaching Sequences

Symbol	Description of chemical application
C	- elemental chlorine (upper case "C" refers to less than 50% chlorine dioxide substitution in first stage)
c	- elemental chlorine (lower case "c" refers to greater than 50% chlorine dioxide substitution in first stage)
D	- chlorine dioxide (upper case "D" refers to greater than 50% chlorine dioxide substitution in first stage)
d	- chlorine dioxide (lower case "d" refers to less than 50% chlorine dioxide substitution in first stage)
E	- caustic extraction stage
H	- sodium hypochlorite stage
O	- oxygen delignification stage
o	- oxygen in caustic extraction stage
P	- hydrogen peroxide bleaching stage
p	- hydrogen peroxide in caustic extraction stage
()	- no washing between stages, or shows optional stage
Z	- ozone delignification
n	- neutralization
A	- acid treatment
Y	- sodium hydrosulfite
Q	- chelation of metal ions

The chemical pulp bleaching process typically involves three different stages. The first is the application of an agent (e.g. elemental chlorine) designed to bleach and further

separate the lignins and extractives from the brownstock. The second involves the application of an alkali (e.g. caustic) to extract the now chlorinated lignins and extractives from the brownstock. The final action is the use of an agent (e.g. chlorine dioxide) to further bleach the pulp to the necessary level of brightness.

4.3.1 Elemental Chlorine Bleaching

The major use of elemental chlorine is the direct application to the brownstock. A secondary use is the manufacture of sodium hypochlorite, used in the final stage to brighten the pulp. One example of an elemental chlorine pulp bleaching sequence is CEH (chlorine, caustic extraction, sodium hypochlorite), for semi-bleached pulp.

Both the use of elemental chlorine, and sodium hypochlorite, may generate unacceptable levels of dioxins and furans, and AOX, in effluent. Thus, chlorine dioxide substitution for both sodium hypochlorite, and elemental chlorine has taken place in Canada. By 2000, the major use of elemental chlorine in the pulp and paper industry is expected to be for the production of chlorine dioxide, at one mill in Canada.

4.3.2 ECF Pulp

Chlorine dioxide (ClO_2) is generally manufactured on-site from purchased sodium chlorate (NaClO_3). As with the chlor-alkali process, sodium chlorate is manufactured from sodium chloride (common salt) brine through electrolysis in a different electrolytic reaction than that required to produce elemental chlorine and caustic. Sodium chlorate is shipped as either a crystal, a dissolved crystal or a generator feed solution (5:1 salt to sodium chlorate), depending on the type of chlorine generator used on site to produce chlorine dioxide (Bradley, 1995).

Table 4-6 lists the major production processes and generators used to generate chlorine dioxide gas from sodium chlorate. The major by-products of chlorine dioxide generation are sodium sulphate (saltcake, Na_2SO_4), and sulphuric acid (H_2SO_4). As discussed in Chapter 3, saltcake is displacing some caustic use in mills. Despite this and other by-product uses within the mill, at the current time, the by-products are in excess of what can be used. Thus, in most mills, unused by-products are discharged with the effluents, and may require some alkali to neutralize the acid.

Table 4-6: Processes for Chlorine Dioxide Generation
(kilograms per kilogram of chlorine dioxide)

Process	Inputs							Credits		
	NaClO ₂	NaCl	SO ₂	H ₂ SO ₄	HCl	CH ₃ OH	Cl ₂	Cl ₂	Na ₂ SO ₄	H ₂ SO ₄
Mathieson	1.80		0.75	1.30					1.20	1.60
Mathieson	1.75	0.18	0.65	1.75				0.12	1.38	1.80
Mathieson	1.70	0.34	0.54	2.50				0.20	1.54	2.20
Solvay	2.00			3.00		0.3			1.80	2.40
R2	1.66	0.95		4.80				0.57	2.26	3.20
R3	1.66	0.95		1.60				0.57	2.26	
R3H SVP HCl	1.66			0.75	.60			0.60	1.10	
R5	1.70				1.3			0.7		**
R7	1.66	0.2	0.5	0.2				0.1	1.40	
R8	1.64			1.3		0.2			1.50	
R8 SVP-LITE	1.64			1.0		0.2			1.10	0.25
SVP-HP	1.60			0.74		0.26			1.04	0.23#
R10	1.62			0.79		0.15		0.01	1.45	
Integrated							0.6	0.1		

Source: CHEMinfo Services

** Plus 1.0 kg NaCl. # Oxygen

The use of chlorine dioxide reduces the chemical load in the bleaching sequence, compared to using elemental chlorine. Chlorine dioxide has a molecular weight of 67.5 (chlorine, 71), but has approximately 2.63 times the oxidizing power of chlorine, and is thus more effective on an equivalent mass basis. This results in less chlorine dioxide being applied compared to elemental chlorine. Elemental chlorine demand for typical softwood pulp can run 5-6% by weight of the pulp production (approximately half for hardwood), whereas only 2-3% by weight chlorine dioxide is required.

In the 1970s, chlorine dioxide was used primarily for downstream treatment of the chlorine/caustic delignified pulp to achieve the final points of brightness. A traditional five-stage bleaching process using chlorine dioxide to brighten the pulp would be: CEDED. Today, as shown in Table 4-7, most chemical pulp producing mills have made the transition from elemental chlorine to relying on chlorine dioxide in the first bleaching stage. Thus, a typical bleaching sequence in Canadian mills is now: DcEoDED, DEopDED or DEopD.

Table 4-7: Mills Bleaching Sequence Status for 1993

Company	Location	Province	1993 Capacity (tonne/day)	1993 Bleach Sequence	1993 Chlorine Dioxide Substitution Rate (percent)
Mills Using Oxygen Delignification					
Weldwood of Canada Ltd.	Hinton	AB	1100	ODcEopDED	80
Peace River Pulp	Peace River	AB	950	ODcEoDED	50
Celgar Pulp Co.	Castlegar	BC	1200	ODEopDnD	100
Howe Sound Pulp & Paper	Port Mellon	BC	1100	ODcEoDnD, OPP	60
Cariboo Pulp & Paper Co.	Quesnel	BC	1150	ODcEo(p)DED	60
Eddy, E B Forest Products Ltd.	Espanola	ON	990	ODcEoHD	65
Malette Kraft Pulp and Power	Smth. Rock Falls	ON	470	ODEopDEpD	100
Total Oxygen Delignification Capacity			6960		
Mills Without Oxygen Delignification					
Weyerhaeuser Canada Ltd.	Grande Prairie	AB	800	DEopDED	100
Weyerhaeuser Canada Ltd.	Kamloops	BC	1200	DEopWDD	100
Avenor Inc.	Gold River	BC	755	DcEoHD, DEopPD	75
Crestbrook Forest Industries	Skookumchuck	BC	800	DEopDED	100
Fletcher Challenge Canada Ltd.	Mackenzie	BC	1200	DcEoDED(P)	85
Fletcher Challenge Canada Ltd.	Campbell River	BC	1130	DcEDED, DcEoDED	70
Fletcher Challenge Canada Ltd.	Crofton	BC	1020	D(Cd)EoPDED	60
Intercontinental Pulp Co.	Prince George	BC	685	DcEopDEpD	75
MacMillan Bloedel Ltd.	Nanaimo	BC	1120	DcEopDED	70
MacMillan Bloedel Ltd.	Powell River	BC	575	DcEoHH	80
Northwood Pulp Ltd.	Prince George	BC	1500	DEopDEpD	100
Prince George Pulp & Paper	Prince George	BC	540	DcEopDEpD	80
Skeena Cellulose	Prince Rupert	BC	1300	DcEopDED	70
Western Pulp Ltd. Partnership	Squamish	BC	700	DcWEopDD	55
Fraser Inc.	Edmundston	NB	500	DcEopDH	65
Irving Pulp & Paper Ltd	Saint John	NB	825	DcEopDEpD, DEoDEpD	75
Miramichi Pulp & Paper Inc	Newcastle	NB	600	CdEopDEpD	18
St Anne Nackawic Pulp	Nackawic	NB	750	CdEopDEhpD	60
Scott Maritimes Ltd	Abercrombie Pt	NS	675	CdEopDED, DEopDED	60
Stora Forest Industries	Port Hawkesbury	NS	450	CdEDED	40
James River Marathon Ltd	Marathon	ON	600	DEopDED	100
Kimberly Clark of Canada	Terrace Bay	ON	1240	DcPcEoDED, DcEDED	70
Avenor Inc.	Dryden	ON	800	DcEoWHDED	50
Boise Cascade Canada Ltd	Fort Frances	ON	550	DcEoHD	65
Avenor Inc.	Thunder Bay	ON	1260	DcEHDED, DcEoDED	70
Domtar Inc	Cornwall	ON	400	CdEoDED	40
James MacLaren Industries Inc.	Thurso	PQ	900	DcEopDED	60
Domtar Inc	Lebel Sur Quevillon	PQ	1000	DcEoHDED	30

Company	Location	Province	1993 Capacity (tonne/day)	1993 Bleach Sequence	1993 Chlorine Dioxide Substitution Rate (percent)
Avenor Inc.	La Tuque	PQ	1000	DcEoDED, DcEoD	60
Donohue Inc	St Felicien	PQ	1000	D(c)EopDED	80
Stone Consolidated Inc	Portage du Forge	PQ	600	CdEoHDED	10
Domtar Inc	Windsor	PQ	850	CdEoEoHD	45
Weyerhaeuser Canada Ltd	Prince Albert	SK	1000	DcWEoDED	80
Total full brightness without oxygen delignification			28325		
Semi-Bleached Mills					
MacMillan Bloedel Ltd	Port Alberni	BC	350	CEpH	0
Stone Consolidated Inc	Trois Rivieres	PQ	240	CEH	0
Total semi-bleached capacity with no oxygen delignification			590		
Dissolving Grade Sulphite (Fully Bleached)					
Western Pulp Ltd Partnership	Port Alice	BC	470	CCEcH(D)	0
Tembec Inc	Temiscaming	PQ	600	CEDH	0
Total Capacity with Dissolving Grade Sulphite			1070		

Source: CHEMinfo Services Inc. Information gathered by CHEMinfo survey of mills during middle and second half of 1993.

Since 1993, ECF technology has become the dominant method of chemical pulp bleaching in Canada. However, in 1993, the base year for this study, only 7 of the 44 chemical pulp mills had completely eliminated the use of elemental chlorine by converting to 100% chlorine dioxide substitution. These 7 mills represented the only completely ECF pulp-producing facilities in Canada, with a total capacity of 6,570 tonnes/day. The remaining 37 mills still used some elemental chlorine in the bleaching process, with some mills still relying heavily on elemental chlorine as the primary bleaching agent - e.g., Miramichi Pulp & Paper Inc. in New Brunswick, with 18% chlorine dioxide substitution, and Stone Consolidated Inc., with 10% chlorine dioxide substitution.

In 1993, the pulp production weighted-average chlorine substitution rate was 66%.³ Canadian mills have been quickly moving towards ECF pulp production, such that by 1995, the pulp production weighted-average chlorine dioxide substitution rate was 85%.⁴ The expectation is that, by the year 2000, the weighted average (first stage) substitution rate will be at least 95% in Canada, with most mills operating routinely at 100% chlorine

³ CHEMinfo Services, North American Bleaching Chemicals Study

⁴ Doug Pryke, Executive Director, Alliance for Environmental Technology, Comments on Draft Interim Report, Sept. 20/95.

substitution. The experience with 100% chlorine dioxide substitution is that product quality in terms of strength and brightness can be maintained.

4.3.3 TCF Pulps

Industry sources generally agree that the production of TCF pulp currently requires a combination of process technologies and alternative bleaching agents to achieve TCF high brightness grades (88-92 ISO). Achieving very high brightness TCF pulps (i.e., ISO 93) may require continued developments in TCF pulping and bleaching technology. Commonly recognized technologies and bleaching agents for producing TCF pulp include: extended cooking, ozone delignification, oxygen delignification and hydrogen peroxide bleaching. Some of the TCF sequences adopted to date are listed in Table 4-8 and provide an indication of the unique bleaching sequences adopted by mills.

**Table 4-8: Identified Bleach Sequences to Achieve 90+ ISO
Brightness**

(all sequences preceded by modified cooking)

Sequence	Source
OZ(Eo)PY	Libergott, N., <i>et al.</i> , Methods to Decrease and Eliminate AOX in the Bleach Plant - Part II: Lowering AOX Levels in the Bleach Plant, Pulp & Paper Canada, Southam Business Communications, 94:11 (1993)
(OAO)ZEopPAP	H.A. Simons Ltd., Assessment of Industry Costs to Meet British Columbia's New AOX Regulations, Prepared for Ministry of Environment, Lands and Parks, June 1992
OQPZP	Paprican: personal conversation
OQZPZP	Paprican: personal conversation

In addition to the above bleach sequences, there are others which can yield TCF pulp of 90+ brightness. For example, there are alternate possible sequences involving ozone and peroxide, with the particular sequence adopted being specific to each mill. Major factors that can influence the bleaching sequence include: whether hardwood or softwood is being processed; the quality of the wood; existing equipment capability; final brightness targets; and pulp strength requirements. Control of trace metals, particularly iron and manganese is a key feature of TCF processes and may present process problems.

The following sections will discuss some of the components of TCF processes, beginning with those which precede a traditional bleaching sequence. These TCF processes are also

used in combination with elemental chlorine, or chlorine dioxide bleaching, particularly extended cooking and oxygen delignification.

4.3.3.1 Extended Cooking (Modified Continuous Cooking- MCC)

Extended cooking refers to addition of alkaline solution progressively as the wood chips are cooked in the digester, rather than all at the start of the cook, as is done in conventional cooking (McCubbin, 1988). Extended cooking reduces the lignin content of pulp entering the bleach plant, which lowers the chemical charge required to brighten the pulp.

These extended delignification systems can, by themselves, decrease the lignin content of the brownstock by 20 to 70% compared to traditional cooking, but normally achieve a range of 25% to 40% lignin reduction.

Continuous digesters can be retrofitted for extended delignification. The ease and cost of modifications may vary (and in some cases may not be feasible) depending on the age, capacity utilization and other factors specific to each continuous digester. Most older models of batch digesters are not retrofitted for extended delignification. However, there are new designs of batch digesters (i.e., RDH, Superbatch[®]) which can be modified to yield pulp with low kappa number, comparable to the output from a continuous digester with extended modified cooking.

4.3.3.2 Oxygen Delignification

Oxygen delignification refers to an additional stage between the pulp digesters, and the bleachery. In the oxygen delignification process, the unbleached pulp from the digesters is washed and de-watered to high (25-35%) or medium consistency (8-15%) pulp. The de-watered pulp is then introduced into a retention tower where oxygen (1-3% of pulp volume) is introduced to the de-watered pulp under alkaline conditions (0.5-2% caustic).

The application of oxygen to the pulp prior to bleaching reduces the lignin content by 40-50%, thus lowering total bleaching agents required by about the same amount. Combined with extended cooking, oxygen delignification can reduce the lignin content to between 50-70%. The 50% reduction in lignin content from oxygen delignification is the maximum possible level which can be achieved without impairing pulp strength.

Oxygen is commercially made by separating air into its constituents, largely nitrogen and oxygen. Either pressure swing adsorption (PSA) units or cryogenic plants can be used. PSA units are designed to handle lower production requirements. They are typically installed at sites requiring less than 60 tonnes/day of oxygen. Oxygen can either be shipped to mills or

produced on-site. Much of the oxygen used by the pulp and paper industry is currently produced at the mill site. Mills may choose to install air separation equipment which they can operate themselves. However, most elect to purchase oxygen from major gas suppliers who build and operate a PSA unit on the mill site.

There were 7 mills in Canada that operated oxygen delignification stages in 1993. Their cumulative capacity was 6,960 tonnes/day. Since 1993, the number of mills and tonnage using oxygen delignification has increased. One estimate shows 14 mills using oxygen delignification by 1996. Most oxygen delignification installations are relatively new. Only E.B. Eddy at Espanola had installed a unit prior to 1989. All new greenfield mills installed after 1989 incorporated extended cooking processes as well as oxygen delignification.

4.3.3.3 Ozone Delignification

Ozone is an aggressive oxidizing agent that can be used to delignify pulp. While theoretically TCF chemical pulp can be produced without ozone, most of the currently operating TCF chemical pulp mills use ozone. The main problem in producing TCF pulp without ozone is that of insufficient brightness of the pulp. Without ozone, the industry standard chemical pulp requirements of 88-90+ ISO cannot be readily achieved through extended cooking, oxygen delignification and hydrogen peroxide bleaching alone.

As with oxygen delignification, ozone delignification refers to an additional stage between the digesters, and the bleachery. In this case, a retention tower applies ozone to the pulp as a 6-15% mixture in oxygen, where the ozone dosage ranges from 0.2 to 0.6% of the total weight of pulp. Ozone treatment can be combined with extended cooking and oxygen delignification to reduce the lignin content of the pulp by 70 to 80%. A major problem with ozone delignification is fibre degradation, where pulp viscosity (the resistance offered by the pulp to shear stress - an indication of fibre length and strength) can be reduced by as much as 10%.

Ozone is produced from industrial grades of oxygen, or from air. It is produced through the installation of an ozone generator (ozonator) where an electrical discharge converts oxygen into ozone. Mills adopting oxygen and ozone delignification may have the need for on-site cryogenic oxygen production if they plan to use oxygen for effluent treatment and lime kiln enrichment in addition to delignification and bleaching (Eo stages). Cryogenic facilities require closer supervision and maintenance.

No mills in Canada operated with ozone in 1993. Some Canadian mill operators have considered ozone delignification as an option, but those contacted in this study during 1994-1995 indicated no definite commitment to moving in that direction. More recently, E.B.

Eddy, at Espanola, ON has announced an intention to install an ozone delignification system.

Ozone delignification systems are installed in at least 17 full-scale chemical pulp mills world wide, eight of them in Scandinavia. As the application of ozone is generally considered to reduce pulp strength, the mills using ozone can be assumed to have developed operating techniques allowing them to compete with mills using traditional processes. Table 4-9 lists 13 installations where ozone is used.

Table 4-9: Ozone Installations Around the World
 (as of June 1995)¹

Company	Location	Country	Capacity (tonne/day)	Sequence	Pulp Process
All TCF Production					
Lenzing AG	Lenzing	Austria	400	EopZP	Hwd, Mg sulphite
Sodra Cell	Monsteras	Sweden	1,000	OQZP	Swd, Hwd Kraft
Peterson Saffle	Saffle	Sweden	132	ZEP	Sulphite
SCA Ostrand	Timra	Sweden	915	OPZEP	Swd, Hwd Kraft
Wisaforest	Pietarsaari	Finland	1,000	OQZEopAEpA	Swd, Hwd Kraft
ECF and Some TCF With Ozone					
SAPPI	Ngodwana	S. Africa	585	OZD	Swd, Hwd Kraft
Stora Billerud ⁵	Skoghall	Sweden	450	OAZEopDEpD OA(ZQ)EopP	Swd Kraft
MoDo Paper	Husum	Sweden	860	OQPZP, OQPZD	Hwd, Kraft
Union Camp	Franklin, VA	USA	900	OZEoD	Swd Kraft
Consolidated Paper ¹	Wisconsin Rapids, WI	USA	750	OZDED	Swd, Hwd Kraft
Metsa-Botnia	Raumo	Finland	1,600	OZD	Swd Kraft
Metsa-Botnia	Kaskinen	Finland	1,450	OOZPD00ZP	Swd, Hwd Kraft
Ponderosa Fibres	Memphis, TN	USA	180	Proprietary	Recycled papers

Source: Pulp and Paper Research Institute of Canada.

¹ Operational in 1996, unknown as to start date.

⁵ Stora Billerud is reported to have discontinued use of ozone due to pulp quality problems. Comment by Douglas Pryke, Alliance for Environmental Technology, 1996

4.3.3.4 Enzymes

An additional means of maximizing the rate and extent of delignification in the pulping process is the incorporation of enzymes. Enzymes (e.g. xylanase enzymes) are applied to the brownstock prior to the bleaching process, typically immediately after the digesters. Residence time for the enzymatic reaction to occur typically requires between one and two hours. Some mills report that enzymes provide a one-point improvement in pulp brightness.

The xylanase enzyme, has the function of modifying the hemicellulose content of the brownstock so that the chlorine (or chlorine dioxide) applied in the bleachery is more effective in further separating the lignin from the wood fibre. This leads to more efficient extraction of lignin in the extraction stage.

However, problems with enzymes include pH control, and the temperature sensitivity of the enzymes. Sulphite mill operators who have considered enzymatic delignification, have concluded that it does not work in sulphite pulping. Enzymes are not used by most Canadian mills on a continuing basis.

4.3.3.5 Hydrogen Peroxide Pulp Bleaching

Hydrogen peroxide has been used commercially as a pulp bleaching agent since 1940, when the first plant was installed to brighten mechanical pulp. Since then, hydrogen peroxide bleaching has been extended to CTMP, semichemical and chemical pulps. While hydrogen peroxide has been used extensively to bleach mechanical and deinked pulps, this agent is sparingly used on chemical pulps. Relatively large dosages of hydrogen peroxide are required by kraft mills in order to produce a TCF pulp of high brightness.

In combination with an extended cooking, oxygen and ozone delignification, two separate peroxide stages can render a kraft softwood pulp of 90 ISO brightness. Approximately 3-5% peroxide as a percentage of final pulp weight is required to achieve the necessary increase in brightness. Currently, there are no mills in Canada operating in this manner.

Without ozone, peroxide can be used in combination with oxygen to achieve brightness approaching 85-87 ISO. In 1993, the Howe Sound Pulp & Paper mill at Port Mellon, BC produced such pulp with an OPP bleach sequence, although this was a small portion of its total production. Also in 1993, Stora (Pt. Hawkesbury, NS) used high doses of hydrogen peroxide to make TCF sulphite pulp for 40% of its production. Currently, only 15% of its output is TCF.

Many mills in Canada use peroxide as part of the caustic extraction stages. Mills are more likely to apply peroxide if there is a production constraint on chlorine dioxide generation. Peroxide is an option even if the kraft mill operator wants only a small improvement in pulp brightness.

4.3.3.6 Chelating Metallic Ions

Hydrogen peroxide is normally applied to pulp in an alkaline solution containing buffering and stabilizing agents. Chelants are stabilizing agents that tie up trace metallic ions, notably iron and manganese, which serve to catalyze the degradation of hydrogen peroxide. The degradation of hydrogen peroxide can lead to high demand for bleaching agent resulting in poor production economics. The presence of these metallic ions can vary on a seasonal basis for some mills. Spring run-off can result in a greater concentration in the process water. Chelating agents are therefore sometimes used on an intermittent basis. Iron, even in very small amounts, is harmful to the brightening sequence because it reacts with lignin degradation products in the pulp to produce dark-coloured compounds.

With hydrogen peroxide bleaching, the chelating agent of choice is usually DTPA (diethylenediamine pentaacetic acid), which provides better performance than does EDTA (ethylenediamine tetraacetic acid) and also provides more chelating sites- 5, versus that of EDTA - 4.

4.4 Direct Replacement Cost for ECF and TCF Chemical Pulp

This section provides an estimate of the costs of converting Canadian chemical pulp mills to ECF and TCF chemical pulp, given bleaching sequences as of 1993. These costs should be regarded as rough estimates of actual costs, due to the necessary simplifying assumptions used in generating the cost estimates. A more accurate cost estimate would involve detailed engineering studies of all Canadian chemical pulp mills, a level of detail beyond the scope of this study.

4.4.1 Methodology Used to Estimate ECF Conversion Costs

The methodology employed to calculate the direct replacement costs for ECF technology is taken from Vice et al. (1994). This study combines cost data from a comprehensive U.S. EPA study (U.S. EPA, 1993a, 1993b) with data from European mills. The U.S. EPA study is based on a nation-wide survey of actual capital, operating and maintenance costs experienced by pulp mills.

Vice et al. (1994) present the capital and operating costs for converting a variety of typical U.S. bleached kraft pulp mill bleach lines to an ECF bleach sequence involving oxygen delignification and chlorine dioxide substitution. In choosing this sequence, weight was placed on the actual trend in use of oxygen delignification within the Canadian pulp and paper industry. Although oxygen delignification is not technically necessary to make ECF pulp, some mills in Canada had already adopted this process for various reasons. These reasons are often mill specific and may include, but not be limited to: a need to meet provincial effluent quality permits, guidelines or regulations (or any anticipation of possible changes to these over time); production rates and other microeconomic factors; capacity constraints on chlorine dioxide generation or pulp quality considerations.

In the Vice study, bleached kraft mills are grouped into the following six categories for capital and operating cost analysis.

- Basecase 1: traditional pulping, no first stage chlorine dioxide substitution (CEH);
- Basecase 2: traditional pulping, some first stage chlorine dioxide substitution <30%, some hypochlorite used (i.e., CdEHD);
- Basecase 3: traditional pulping, chlorine substitution 70% to 99%, no hypochlorite used (i.e., DcEoDED);
- Basecase 4: with oxygen delignification used (i.e., ODoEoDD);
- Basecase 5: with extended cooking used (no oxygen delignification); and
- Basecase 6: both oxygen delignification and extended cooking used (OCdEoD).

The Vice study used bleach line configurations data collected during the U.S. EPA study to select a typical bleach line to represent each of the above six groups (shown in brackets above) and assumed that all bleach lines used softwood furnish. The study provides the additional capital and operating costs that a typical mill would incur in substituting the suggested ECF (ODEopD) bleaching sequence for the existing base case bleaching sequences.

In this study, the methodology to derive operating costs involves allocating the 44 Canadian chemical pulp mills to the six base case categories used in the Vice study, and then applying the same incremental costs per tonne of production used in the Vice study, converted to Canadian dollars.

There were a few mills which did not clearly fit into one of the above base cases defined by Vice et al. These were mills that already had high chlorine dioxide substitution levels and/or used sodium hypochlorite. These mills were nonetheless classified as Basecase 3 mills for the purposes of conducting the costing analysis.

For the purposes of estimating capital costs to achieve ECF pulp for the Canadian mills, the six categories defined in the Vice study were collapsed into three groups, A, B and C, defined as follows:

- A) Mills without oxygen delignification: 33 mills**
 - average annual capacity of 828 tonnes per day.
 - chlorine dioxide generator capacity already installed.
 - no oxygen delignification.
 - average capital cost of conversion to ECF: \$25 million.
- B) Mills with oxygen delignification: 7 bleach mills**
 - average annual capacity of 1,010 tonnes per day.
 - chlorine dioxide generator capacity already installed.
 - oxygen delignification in place.
 - average capital cost of conversion to ECF: \$5 million.
- C) Semi-bleached mills: 4 mills**
 - average annual capacity of 415 tonnes per day.
 - no or low chlorine dioxide generator capacity.
 - no oxygen delignification.
 - average capital cost of conversion to ECF: \$34 million.

For each of these groups, capital costs from the Vice study were applied, suitably indexed for the average capacity of the Canadian mills groups. The major cost is installation of oxygen delignification at the Group A and C mills. Group C mills also require upgrades to chlorine dioxide capacity.

4.4.2 Direct Replacement Cost for ECF Pulping

The total costs of converting to oxygen delignification and 100% chlorine dioxide bleaching using an ODEopD process is estimated at \$997 million in capital costs with annual operating savings of \$20 million. The annualized additional capital cost at an 9% discount rate and 20-year equipment life is \$109 million. Total additional annual costs, including operating cost savings are estimated at \$89 million. The highest costs are borne by mills heavily reliant on elemental chlorine bleaching, without oxygen delignification and no or low chlorine dioxide generator capacities. Table 4-10 summarizes the direct replacement cost calculation for conversion to ECF pulping.

Table 4-10: Direct Replacement Costs for ECF Pulping
(\$ million)

Basecase Bleach Sequence	No. of Mills	Capital	Annualized Capital	Annual Operating	Total Annualized
Group A Mills	33	\$828	\$91	(\$28)	\$63
Group B Mills	7	\$34	\$4	\$11	\$15
Group C Mills	4	\$135	\$15	(\$3)	\$12
Total	44	\$997	\$109	(\$20)	\$89

Source: Beak Consultants Limited, CHEMinfo Services based on Vice et al. (1994). Totals have been rounded.

Excluded from this cost analysis are the savings in effluent discharge permit fees mills would realize by reducing chlorine and AOX levels in their effluent. These fees apply to mills in British Columbia, but are difficult to quantify without knowing the quantity of discharges for mills in a reference year, and the reduction achieved with ECF bleaching regimes. An order-of-magnitude estimate is that a savings of \$0.2 to \$2 million per year may be realized among all the BC mills if they went to ECF.

4.4.3 Direct Replacement Cost for TCF Pulping

This section provides the costs for the pulp and paper industry to make the transition to TCF pulp. Operating costs are based largely on estimates generated by H.A. Simons (1992) in their report for the B.C. government on the costs of meeting the province's AOX regulations. The capital costs contained in the H.A. Simons report were considerably reduced⁶. These capital costs were re-worked as some pulp and paper producers, as well as other industry sources (personal conversations, Neil McCubbin, private consultant) claim the realized actual capital costs to install a pulping process and bleaching sequence to make TCF pulp has turned out to be significantly lower than published reports indicate. Several explanations for this discrepancy include:

- early reports estimating theoretical costs to install TCF equipment and make process changes did not have the knowledge gained through actual installations and plant operational experience;
- conservative cost approaches were taken for new, unproved technology;
- mills' ability to minimize cost by adopting innovative operational changes were underestimated;

⁶ The capital costs used in the H.A. Simons report, if translated to all Canadian chemical pulp mills, would be approximately 10 billion dollars.

- minor operation changes can reduce capital requirements; and
- minor, inconsequential throughput debits were absorbed to reduce capital costs (i.e. no need for recovery boilers).

To achieve pulp of comparable strength and brightness, it was assumed mills would have to adopt the following processes in various possible combinations:

- extended delignification;
- oxygen delignification;
- ozone delignification; and
- chelation and two stage peroxide bleaching.

In order to estimate the costs of converting to TCF pulp production, Canadian mills were grouped into the following categories which related to additional pulping and bleaching equipment requirements:

- 1) mills already with oxygen delignification;
- 2) mills without oxygen delignification;
- 3) semi-chemical pulps;
- 4) mills which did not already have modified continuous cooking processes; and
- 5) mills which had batch digester capacity and therefore required new continuous digesters to undertake MCC.

The estimated capital cost of converting existing facilities to produce TCF pulp is approximately \$3.2 billion. See Table 4-11 for the calculation of capital costs. On an annualized basis (over 20 years at 9% interest), this capital cost is \$346 million/yr.

Table 4-11: TCF Capital Cost Assumptions

Component	Capital Costs	# Mills Requiring	Total Capital
	(\$million/mill)		(\$million)
Oxygen delignification system (includes housing)	25	37	\$925
Ozone stage and other bleach plant changes	35	44	\$1,540
Extended delignification modifications on continuous digester	2	22	\$44
Replacement of batch digesters with continuous digesters	34	19	\$652
Total			\$3,161

Source: CHEMinfo Services

The capital cost of installing only oxygen (at facilities without such stages) and ozone delignification stages for all mills in Canada totalled \$2.5 billion. The majority of these costs are associated with ozone delignification stages. Table 4-12 details the capital costs of oxygen and ozone delignification installations required for TCF pulping.

Table 4-12: Capital Costs for Oxygen and Ozone Only
(\$ million)

	# of Mills	Oxygen Delignification	Ozone Delignification	Total Capital Costs
Mills with O ₂ delig.	7	0	\$245	\$245
Mills without O ₂ delig.	33	\$825	\$1,155	\$1,980
Semi-bleached pulps	4	\$100	\$140	\$240
Total	44	\$925	\$1,540	\$2,465

Source: CHEMinfo Services

To achieve pulp with comparable strength and brightness, it was assumed that extended modified continuous cooking (EMCC) would need to be undertaken prior to oxygen and ozone delignification, and subsequent hydrogen peroxide bleaching. Conventional continuous cooking can render a softwood pulp to 20 kappa. However, if ozone and/or oxygen delignification stages follow, the strength of the pulp can be significantly compromised if the kappa is reduced to this level. When ozone and oxygen stages are

installed, the preference is to have the pulp exiting the digesters at higher kappa (i.e., 24 to 30) to maintain pulp strength.

EMCC can reduce the kappa number of the pulp leaving the digester but at the same time maintain pulp strength. This is accomplished by increasing the intimacy of fibre and white liquor chemical mixing while operating at lower temperature in an extended "cooking" zone within the digester.

The capital cost to retrofit a conventional continuous digester for EMCC are typically less than C\$2 million per digester, according to industry suppliers which have carried out retrofits. In 1993, it is estimated there were 3 mills which already operated MCC processes and did not require retrofit. It is assumed that the 41 remaining would require either new continuous digesters or MCC retrofits on existing continuous digesters. The assumption is that for 22 mills which have continuous digesters but are not equipped with MCC, the capital cost to retrofit is C\$2 million per mill, or \$44 million in total. It is also assumed that batch digesters (except newer models) cannot not be retrofitted.

Additional annual operating costs for the total industry are estimated at \$620 million/yr. Therefore the total annual cost in converting to TCF pulp production is estimated at \$966 million/yr. Table 4-13 summarizes the direct replacement costs for TCF pulping.

Table 4-13: Direct Replacement Cost of TCF Chemical Pulp
(\$ million)

	# of Mills	Capital	Annualized Capital	Annual Operating	Total Annualized
Mills with oxygen delignification	7	\$245	\$27	\$100	\$127
Mills without oxygen delignification	33	\$1980	\$217	\$500	\$717
Semi-bleached pulps	4	\$240	\$26	\$20	\$46
Retrofit for EMCC	22	\$44	\$5		\$5
New digesters	19	\$652	\$71		\$71
Total		\$3,161	\$346	\$620	\$966

Source: CHEMinfo Services

There were approximately 19 mills in Canada in 1993 with batch digester capacity. The total capacity of nearly 150 to 160 batch digesters was 12,400 tonnes of pulp per day. The average batch digester capacity works out to approximately 650 tonnes/day per mill or 80 tonnes/day per digester (average of 8 batch digesters per mill). By comparison, modern

continuous digesters typically have capacities greater than 500 tonnes/day and can range up to 1,500 tonnes per day. Even greater capacities are available according to suppliers. The assumption in this study is that one 650 tonne/day continuous digester (equipped with EMCC capability) would be installed at each of the 19 mills with batch capacity. The capital turnkey cost of one new 650 tonne/day continuous digester is approximately C\$ 34.3 million⁷. Therefore, the total capital cost to the Canadian industry is \$652 million.

Excluded from this cost analysis are the savings in effluent discharge permit fees mills would realize by reducing chlorine and AOX levels in their effluent. These fees apply to mills in British Columbia, but are difficult to quantify without knowing the quantity of discharges for mills in a reference year, and the reduction achieved with ECF bleaching regimes. An order-of-magnitude estimate is that a savings of \$0.4 to \$3 million per year may be realized among all the BC mills if they converted to TCF pulp.

4.5 Direct Replacement Cost Compared to End Use Revenues

In order to put the direct replacement costs in context, they can be compared to the value of annual domestic production of chemical pulp. Given 1993 production of 12,308 kilotonnes of chemical pulp, and a price per tonne of \$625⁸, generates an estimate of the value of chemical pulp of approximately \$7.7 billion dollars. As shown in Table 4-14, the direct replacement costs for ECF pulp are 1.2% of the annual value of chemical pulp production, while the costs for TCF are 12.6% of the value of chemical pulp production.

**Table 4-14: Direct Replacement Cost Compared to
End Use Revenues**

(\$ million/yr)

	Value of Chemical Pulp Production	Direct Replacement Cost	% of End Use Value
ECF	\$7,692	89	1.2%
TCF	\$7,692	966	12.6%

Source: CPPA, 1994

⁷ Based on information provided by Ahlstrom Machinery Inc., Glen Falls, NY

⁸ The price of \$625 a tonne is calculated as the total value of pulp exports in 1993 (\$4,615 million) over the total quantity of pulp exports (7386 kilotonnes).

It is also important to recognize that chemical pulp mills are the primary users of electrolytic caustic as discussed in Chapter 3. The annual direct replacement cost of electrolytic caustic allocated to the chemical pulp market (\$70 million) represents approximately 0.9% of the value of domestic chemical pulp production.

4.6 Socio-Economic Profile

This section provides a socio-economic profile of Canadian industries which provide alternatives to elemental chlorine in the pulp and paper sector. Currently existing alternatives to elemental chlorine are sodium chlorate (used to produce chlorine dioxide), oxygen used in oxygen delignification, and hydrogen peroxide. As ozone is not currently used in the Canadian pulp and paper industry, a profile of ozonator suppliers will not be included in this chapter. However, interested readers may find information on industry suppliers of ozonators in the following chapter on water treatment, Chapter 5. For reference, some socio-economic information is provided for the chlor-alkali industry as it relates to the pulp and paper sector.

4.6.1 Chlor-alkali Industry

The profile of chlor-alkali producers of elemental chlorine was provided in Chapter 2. In 1993, there were ten plants producing elemental chlorine, with a capacity of 1362 kilotonnes and production of 1,170 kilotonnes. Total employment in chlor-alkali production was estimated at 1305. Assuming that 40% of these employees are associated with elemental chlorine production generates an estimate 522 people employed in elemental chlorine production. Total annual merchant domestic revenues from elemental chlorine sales are estimated at \$70 million.

Based on an estimated use of 175 kilotonnes (15% of production) kilotonnes of elemental chlorine in the pulp and paper industry as of 1993, and using a price of \$132 per kilotonne total domestic revenues associated with elemental chlorine sales to pulp and paper mills are \$23 million.

4.6.2 Sodium Chlorate

The major bleaching agent in ECF pulp is chlorine dioxide. The majority of chlorine dioxide used in bleaching chemical pulps is produced from sodium chlorate.

Plants and Plant Locations: Table 4-15 lists the 17 sodium chlorate plants across Canada. Major manufacturers include: Sterling Chemicals (four plants, 32% of total capacity), Canadian Occidental (five plants, 21% of total capacity), and Eka-Nobel Canada (two plants, 22% of total capacity).

Table 4-15: Sodium Chlorate Plants in Canada

Company	Location		1993 Capacity (kilotonnes)
Albchem Industries	Bruiderheim	AB	50
BC Chemicals	Prince George	BC	80
CXY Chemicals	Amherstburg	ON	50
CXY Chemicals	Brandon	MB	80
CXY Chemicals	Bruiderheim	AB	50
CXY Chemicals	Nanaimo	BC	16
CXY Chemicals	Squamish	BC	11
Eka-Nobel Canada	Magog	PQ	120
Eka-Nobel Canada	Valleyfield	PQ	100
ICI Canada	Dalhousie	NB	22
PPG Canada	Beauharnois	PQ	50
Saskatoon Chemicals	Saskatoon	SK	45
St. Anne Chemical	Nackawic	NB	10
Sterling Chemicals	Buckingham	PQ	132
Sterling Chemicals	Grand Prairie	AB	45
Sterling Chemicals	N. Vancouver	BC	92
Sterling Chemicals	Thunder Bay	ON	55
Total capacity			1008

Source: CHEMinfo Services

Capacity and Production Levels: Canada has nearly 60% of North American sodium chlorate capacity, with 1993 capacity levels estimated at just over 1,000 kilotonnes, as shown in Table 4-16. Production for 1993 is estimated at 830 kilotonnes. The plants responding to our survey (10 of the 17 plants) indicated that over 95% of their product was sold to the pulp and paper sector. Therefore, virtually all of the 830 kilotonnes of sodium chlorate produced in Canada is used by the pulp and paper sector. Sodium chlorate production has been growing rapidly for the last decade in response to the collapsing demand for elemental chlorine. Growth in production is expected to slow once chlorine dioxide substitution is complete, and may even be reversed as mills adopt oxygen delignification and thereby reduce the chlorine demand of the brownstock pumped into the bleach plant.

Table 4-16: Sodium Chlorate Supply/Demand (1993)

	1993 (kT)
Capacity	1008
Production	830
Imports	9
Inventory Changes	10
Total Supply	858
Domestic Demand	518
Exports	340
Total Demand	858

Source: Statistics Canada for production, imports, exports (imports and exports figures from Statistics Canada adjusted to reflect 100% sodium chlorate content)

Exports and Imports: As shown in Table 4-16, a large percentage (40%, 340 kilotonnes) of Canada's sodium chlorate production is exported to the United States, and imports are minor. Nine of the ten companies responding to our survey confirm the high level of exports, with five plants reporting that roughly two-thirds of production is exported and another four plants reporting that 46% of production is exported.

Revenues: The average sales price calculated from the revenue data provided, is about \$518/tonne. This is within the range of sodium chlorate prices of \$450 to \$550/tonne between 1988 and 1993.

Domestic sales, at approximately 60% of production, are an estimated \$268 million. Domestic revenues, including net imports and exports, are estimated at \$440 million. Virtually all of these revenues arise from sales to the pulp and paper sector.

Employment: Employment in the sodium chlorate industry is estimated at 800 people. Virtually all people employed in the industry are dedicated to producing sodium chlorate for the pulp and paper sector.

4.6.3 Oxygen Supply

Oxygen is often supplied by units installed on-site to produce the gas. Production units are normally leased to the user (e.g. pulp and paper mill), with a flat fee charged to the user based on the capacity of the unit. Direct sales to the pulp and paper industry of oxygen are rare due to high cost of transportation of liquid oxygen, often produced at

centralized cryogenic plants. Due to the presence of many small regional oxygen producing facilities, capacity for the "industry" is not well defined.

For 1993, it is assumed that the 7 pulp and paper plants using oxygen delignification were leasing oxygen units. Apart from the pulp and paper sector, major users of these units (or buyers of oxygen) include the primary metals sectors, the food, and the mining industry. Table 4-17 lists the 3 major suppliers of industrial gases in Canada.

**Table 4-17: Major Suppliers of Oxygen and Air Separation Units
for Pulp and Paper Production**

Company	Location
Praxair Canada	Mississauga, Ontario
Air Liquide	Brampton, Ontario
Air Products Canada	Brampton, Ontario

Source: CHEMinfo Services

Imports and Exports: Exports of oxygen supply units are negligible. Some units are imported from fabrication firms in the United States. Air Products Canada principally imports units, while Praxair, and Air Liquide contract for the domestic manufacture of units, but also have the option of importing. For the purposes of this study, it is assumed that one-third of all units are imported.

Revenues: The estimated annual domestic sales revenues from the lease of oxygen units, or the sale of oxygen is \$400 million. These revenues come predominantly from the primary metals sector, the mining sector, and the food industry. Assuming that exports are negligible and imports represent approximately one third of domestic sales generates an estimate for domestic revenues of approximately \$300 million.

In 1993, annual domestic sales revenues associated with unit leases to the pulp and paper industry are estimated at approximately \$4 million. This is based on 7 plants using oxygen delignification, with the lease for a 50 tonne/day oxygen PSA unit being \$50,000 a month.

Employment: Total employment in the industrial gases supply sector is estimated at 2000 people. This estimate will be used for employment associated with oxygen production, since oxygen is the key gas produced at most cryogenic plants. The largest supplier (Air Liquide) employs approximately 1100 people.

4.6.4 Hydrogen Peroxide Supply

Hydrogen peroxide for the North America market is supplied by six companies, three of which operate in Canada. Table 4-18 lists 4 plants operated by these 3 companies.

Table 4-18: Canadian Hydrogen Peroxide Capacity

		1993 Capacity (kilotonnes)
Chemprox	Becancour, PQ	40
FMC	Prince George, BC	41
DuPont Canada	Maitland, ON	40
DuPont Canada	Gibbons, AB	36
Total Capacity		157

Source: CHEMinfo Services

Capacity and Production Levels: In 1993, the four Canadian plants had a total capacity of 157 kilotonnes. The two Du Pont plants together account for close to 50% of Canada's total hydrogen peroxide capacity. Much of Canada's capacity has been installed within the last five years, including Du Pont's Gibbons plant, FMC's plant and half of Chemprox's capacity. As shown in Table 4-19, production is estimated at 128 kilotonnes, which represents about 82% of capacity. It is assumed that about 75% of production volumes are sold to the pulp and paper sector (about 100 kilotonnes), with most hydrogen peroxide being sold to mechanical pulp mills and lesser volumes to deinking and kraft mills. The non-pulp uses are textiles, food manufacturers, environmental firms and chemical manufacturers.

Table 4-19: Hydrogen Peroxide Supply/Demand

	1993 (kilotonnes)
Capacity	157
Production	128
Imports	12
Inventory Changes	5
Total Supply	145
Domestics Consumption	115
Exports	30
Total Demand	145

Source: Statistics Canada production, imports, exports, imports and exports figures adjusted to reflect 100% hydrogen peroxide content.

Exports and Imports: Canadian plants exported 30 kilotonnes in 1993, representing over 20% of production levels. Imports are minor, constituting less than 10% of domestic consumption. One company indicates it exported 52% of its production to the United States.

Revenues: Domestic sales revenues are estimated at \$139 million, based on domestic consumption of 115 kilotonnes, and a price of \$1,212 per tonne. Total domestic revenues are estimated at \$161 million. About \$102 million of revenues are associated with domestic sales to the pulp and paper sector.

Employment: Total employment is estimated at 300 people. It is estimated between 150 and 220 employees are associated with the domestic pulp and paper sector.

4.7 Summary

The preceding chapter has described two alternatives to the use of elemental chlorine as a bleaching agent in the production of chemical pulp. The two alternatives are elemental chlorine free (ECF) pulp, and total chlorine free pulp (TCF). ECF refers to pulp bleached with chlorine dioxide, while TCF pulp is normally produced using a mixture of processes. These processes include extended cooking, ozone and oxygen delignification, and hydrogen peroxide bleaching. The different processes are not mutually exclusive, with

many Canadian mills combining elemental chlorine, chlorine dioxide, and oxygen delignification.

In 1993, 7 of 44 chemical pulp mills were producing totally ECF pulp. This number had increased to 20 by 1995. Based on comparable weights of chlorine and chlorine dioxide, 66% of chemical pulp was produced by chlorine dioxide bleaching in 1993, increasing to 85% in 1995. By 2000, it is expected that almost all pulp produced in Canada will be ECF pulp. The main reason for this rapidly collapsing demand for elemental chlorine is federal environmental regulation of dioxins and furans and the regulation of absorbable organic halides (AOX) by various provincial jurisdictions.

TCF pulp has a very low market share in Canada, both in 1993, and currently. However TCF pulp is becoming more common internationally, particularly in Europe.

The costs of total substitution to ECF pulp using the base year are estimated at \$20 million in annual operating cost savings, and an additional \$997 million in capital costs. Converting capital to annual costs generates an estimated annual direct replacement cost to ECF pulp of \$89 million/year. This represents approximately 1.2% of the value of domestic chemical pulp production (\$7.7 billion).

The costs of total substitution to TCF pulp using the base year are estimated at \$620 million in annual operating costs, and \$3.2 billion in capital costs. Converting capital costs to annual costs results in annual direct replacement costs of \$966 million to switch to TCF pulping. This represents 12.6% of the value of domestic chemical pulp production (\$7.7 billion).

Using the measure of domestic revenues, elemental chlorine is the product with the lowest value of the four commodities profiled and summarized in Table 4-20.

Table 4-20: Socio-Economic Data of Elemental Chlorine, and Alternatives Used in the Chemical Pulp Market (1993)

	Elemental Chlorine	Sodium Chlorate	Oxygen	Hydrogen Peroxide
Value of Domestic Sales (\$ million)	33	268	400	139
Trade Balance (\$ million)	37	172	100	22
Domestic Revenues (\$ million)	70	440	300	161
Employment	522	800	2000	300
Employment/Domestic Revenues	7.5	1.8	6.7	1.9

4.8 Contacts and References

4.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each organization.

- Alcell Inc.
- Alliance for Environmental Technology, Doug Pryke, Executive Director,
- Coast Papers
- Consolidated Papers Inc.
- Crestbrook Pulp & Paper
- Fraser Inc.
- H.A. Simons
- Irving Pulp & Paper
- Liebergott & Associates Consulting Inc.
- Malette Pulp & Paper
- Miramichi Pulp
- N. McCubbin Consultants Inc.
- Paprican
- Prince George Pulp & Paper
- Scott Paper
- Skeena Cellulose
- Sodra Cell
- St. Anne Nackawic
- Stora Forest Industries Ltd.
- Sunds Defibrator
- TAPPI
- Union Camp
- Unisource Canada Ltd.

4.8.2 Association Contacts

- Canadian Pulp and Paper Association

4.8.3 References

- Bradley, R., A. Leder and N. Takei. 1995. Sodium Chlorate: Chemical Economics Handbook, SRI.
- Canadian Pulp and Paper Association (CPPA). 1994. Reference Tables: 1994. Published by the Department of Economics and Statistics, CPPA.
- CHEMinfo Services, 1993, North American Bleaching Chemicals, Outlook to 2000.
- McCubbin, N. 1988. Kraft Mill Effluents in Ontario, for Environment Ontario.
- Mullins, R. and M. Roberts. 1995. Process conversions continue as paper markets rebound. Chemical Week (January 4/11, 1995): 28-30.
- Simons Ltd. 1992. Assessment of Industry Costs to Meet British Columbia's New AOX Regulations, Prepared for the Ministry of Environment, Lands and Parks, June 1992.
- U.S. EPA. 1993a. Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Point Source Category. Engineering and Analysis Division, Office of Science and Technology, Office of Water, Washington, D.C.
- U.S. EPA. 1993b. Economic Impact and Regulatory Flexibility Analysis of the Proposed Effluent Guidelines and NESHAP for the Pulp, Paper and Paperboard Industry. Engineering and Analysis Division, Office of Water, Washington, D.C.
- Vice, K.M., R.E. Sieber and B. Bicknell. 1994. Costs of Upgrading Bleach Plants to Minimize COD Discharges. Non-Chlorine Bleaching Conference Proceedings, 1995.

5. Chlorine in Water and Wastewater Treatment

5.1 Introduction

This chapter describes the use of elemental chlorine, and alternatives, in municipal water and wastewater treatment. The two alternatives assessed are ozonation for water supply, and ultraviolet radiation for wastewater treatment.

Initially, the market for elemental chlorine and alternatives in municipal water and wastewater treatment will be described. Then, the various water treatment technologies will be reviewed. The direct replacement costs between elemental chlorine and alternatives will be estimated, and these costs will be compared to the revenues received by municipal water utilities. Finally, the socio-economic profile will describe the industries providing packaged elemental chlorine, and alternatives to elemental chlorine, using the variables of plants, production, revenues, and employment.

5.2 Market for Chlorine and Alternatives in Water Treatment

Elemental chlorine has been the primary disinfectant for water since the advent of public water supply. Approximately 16.5 kilotonnes of elemental chlorine were used in water treatment in Canada in 1993. As shown in Table 5-1, the major uses of elemental chlorine in water treatment are for municipal water supply, municipal wastewater, and self-supplied industrial water treatment. Chlorine is also used in treating the water in municipal and private swimming pools. This analysis will focus on the major chlorine uses, municipal water supply and wastewater treatment.

Table 5-1: Chlorine Use for Water Treatment

Segment	1993 (kilotonnes)
Municipal Water Treatment	8.5
Municipal Sewage Treatment	7.0
Industrial Water Treatment	1.0
Total	16.5

Source: CHEMinfo Services

5.2.1 Water Treatment

Elemental chlorine dominates the market for water disinfection in Canadian water supply. In 1993, there were an estimated 2,900 water treatment plants in Canada. See Table 5-2 for a breakdown of water treatment types. Roughly 70% of these plants used chlorine gas or chlorine compounds for water treatment. Most other plants used a simple physical separation process (e.g. filtration) or nothing at all.

The number of plants using alternate water treatment technology is small, but growing. Ozone treatment is the most common new technology, used in about 30 plants in Canada. Most of the plants using ozone technology are located in Quebec, where ozone technology transferred from France is preferred by the provincial government. Large ozonation facilities are installed in Montreal, Sherbrooke, Laval and Quebec City. A growing number of small and medium size plants have recently converted to ozone technology in Ontario. Western Canada has yet to use ozone significantly.

Table 5-2: Water Treatment Plants

Treatment	Number of Plants (1993)	%
Chlorine and Chlorinated Compounds	1960	69
No treatment	870	30
Ozone	30	1
Total	2860	100

Source: National Inventory of Municipal Waterworks & Wastewater Systems in Canada (1986); CHEMinfo Services interviews with industry

Some of the diseases that are controlled through chlorination and other treatment methods include those caused by bacteria, viruses or protozoa. Related illnesses are many and include: cholera, hepatitis A, giardiasis, to mention a few.

Potential health concerns related to the formation of chlorine by-products of oxidation, notably trihalomethanes (THMs) has been the main reason for the slight trend towards the adoption of ozone. These THMs include chloroform (CHCl_3), bromoform (CHBr_3), and their intermediates (CHCl_2Br , CHClBr_2).

5.2.2 Wastewater Treatment

In 1993, there were just over 2000 wastewater plants operating in Canada. As Table 5-3 shows, about two-thirds of these are simple lagoon or communal septic tank systems where natural biological processes take place on small wastewater volumes without the use of chemical treatment. The remaining 700 treatment plants used either primary or secondary treatment, or both, to clean the effluent.

Elemental chlorine is used as a tertiary disinfectant in about 75% of the plants using some form of primary or secondary treatment. UV radiation has displaced chlorine in a small but growing number of plants, 40 plants in 1993, growing to 70 plants in 1995. Industry sources indicate that most new plants in Quebec, and many in Ontario are being installed with UV systems, while this trend is less evident in Western¹ and Atlantic Canada.

Table 5-3: Wastewater Treatment Plants

Treatment	Number of Plants
Lagoon or Communal Septic Tank	1300
Primary & Secondary Treatment (with Chlorine)	516
Primary & Secondary Treatment (no Chlorine)	109
Primary Treatment Only	75
UV Radiation	40
Treatment Plants Subtotal	740
TOTAL	2040

Source: National Inventory of Municipal Waterworks and Wastewater Systems in Canada (1986); CHEMinfo Services industry interviews

The principal explanation for the trend towards the increased use of UV radiation are the environmental concerns related to the toxicity of chlorinated effluent. Chlorinated effluent has been declared toxic under the Canadian Environmental Protection Act (CEPA).

¹ Nevertheless the largest UV wastewater treatment plant in the world (Bonnybrook) is located in Calgary, Alberta.

5.3 Technical Description of Chlorine and Alternatives in Water Treatment

5.3.1 Elemental Chlorine in Water Treatment

The treatment of water for municipal use involves the cleaning and disinfection of raw water to produce potable water. Cleaning typically encompasses techniques such as filtration, coagulation, sedimentation, and carbon absorption used to separate solids and fine impurities from the raw water. Once the solids are removed, chemical disinfection takes place in two stages. The first disinfection stage involves the direct application of chlorine gas to the raw water. The dosage and residence time in the holding tank will vary according to many factors, notably the raw water quality, and the temperature. Chlorine dosage rates can double from winter to summer.

The second stage (post-chlorination) involves adding an additional dose of chlorine to the water leaving the treatment plant into the distribution system. A 0.5 mg/L minimum residual level of chlorine is a typical target to ensure control throughout the distribution system. Similar compounds such as chlorine dioxide, hypochlorite, and chloramine have also been used in this stage. The purpose of this residual treatment is to control bacterial regrowth in reservoirs and holding systems.

5.3.2 Alternatives to Elemental Chlorine in Water Treatment

Some of the water treatment technologies that represent alternatives to the use of chlorine gas include:

- similar compounds such as chlorine dioxide, hypochlorite and chloramine;
- bromination;
- ozone treatment;
- UV radiation;
- ultrasonics; and
- induced magnetic fields.

Ozonation is the first non-chlorine treatment technology to have been installed in water treatment plants across Canada. Ozonation involves 3 stages. The first stage involves sending a feed gas of air or purchased oxygen through a dielectric unit in an ozone generator, where an electrical discharge converts oxygen to unstable ozone (O_3). In the second stage, ozone is bubbled through the raw water stream in a large contact chamber, where the oxidation of pathogens and organic compounds takes place quickly. Typical dosage rates range from 0.5 to 3.0 mg/L. The final step involves the capture and destruction of the remaining ozone in the offgas in a separate thermocatalytic unit.

Ozone is equally or more effective than chlorine as a biocide against bacteria, viruses or protozoa in surface or ground waters. Ozone is highly effective against common water parasites such as Giardia Lamblia and Cryptosporidium which have been responsible for many reported human digestive illnesses. It can be applied in lower concentrations and requires shorter contact times to achieve a 99% pathogen removal. Unlike chlorine, ozone is equally effective in disinfection control throughout the pH range of 6.5 to 8.5 typically encountered in water treatment. Its greater oxidizing power removes more organic compounds, especially chlorophenols, which give odour and taste to water. It is more effective in removing organic colouration of water than chlorine. Another advantage of ozone is that it does not generate chlorinated organic by-products such as THMs.

The main problem with ozone is the lack of residual chemicals left to prevent regrowth of micro-organisms throughout the water distribution system. With the use of ozone, additional chemical treatment is generally applied to stop the regrowth of organisms throughout the pipes and outlets of the water distribution system. Although fine sand filtration or biological carbon filtration may be used as a finishing step, complete removal of micro-organisms is not assured.

Residual chlorination (the application of chloramine) as a secondary disinfectant has been suggested as an alternative to provide a residual biocide in water systems, although there are some concerns about its toxicity to fish. Ammonia and chlorine are added together to a raw water stream to produce monochloramine (NH_2Cl). Ammonia is added in a slight excess over chlorine to suppress the formation of di- and tri-chloramines, which have distinctive taste and odour. Table 5-4 summarizes the comparison of chlorine and ozone.

Table 5-4: Comparison of Water Treatment Technologies

Characteristic	Chlorination	Ozone
Performance (reliability)	Very good	Very good
Effectiveness (degree of reduction)	Fair	Good
Flexibility (adaptation to changes)	Good	Good
Ease of Implementation	Fair	Fair
Energy Use	Low	High
Maintenance	Low	Moderate
Water Quality	Fair	Good
Residual Effect	Good	Poor
Air Emissions Hazard	Low	Low
Storage & Handling Risk	Medium	Low

Source: CHEMinfo Services Inc.

5.3.3 Elemental Chlorine in Wastewater Treatment

The addition of chlorine to wastewater is used to ensure that waters contaminated through residential, commercial and industrial use are returned to the natural environment without significantly affecting the receiving water quality and aquatic habitats. Elemental chlorine may be used to meet the water quality control limits issued by provincial environment ministries, notably those related to the discharge of fecal coliform bacteria.

Wastewater treatment plants use physical, biological and chemical processes to clean waste from water. Primary treatment involves the removal of grit and sediment through screening and clarification. Secondary treatment uses bacteria (activated sludge) to convert pathogens and organic compounds to inorganic forms. Chlorine is typically applied in small doses as a final (tertiary) treatment measure to ensure final removal of organics and micro-organisms from the effluent streams. Typically, dosage rates of 3-7 mg/L are applied to secondary treatment effluent. Higher levels of 10-20 mg/L are usually used for wet weather flows which receive primary solids removal treatment, but by-pass secondary treatment.

5.3.4 Alternatives to Elemental Chlorine in Wastewater Treatment

Some of the common alternatives to the use of chlorine in wastewater treatment include:

- similar chemicals, such as chlorine dioxide, hypochlorite or bromine chloride, and
- processes (ozonation, UV radiation, gamma radiation, solar aquatics and wetlands).

Of the commercial process change technologies, ozone and UV radiation are commercially established, with UV radiation being preferred for wastewater treatment. Although the biocidal properties of UV have been known for over 100 years, this technology has only become commercialized in the last 10 years.

As with chlorine, ultraviolet radiation is also used as a tertiary treatment. Ultraviolet radiation uses an intense light to purify the wastewater. The wastewater flows through hydraulic channels parallel to submerged banks of mercury-vapour lamps typically spaced about 3 inches apart. The lamps are similar to standard fluorescent lamps without the phosphor coating, but are protected by quartz sleeves. The effectiveness of UV radiation treatment is proportional to the intensity of radiation and the exposure time. UV has been reported to be effective against a wide variety of bacteria, viruses and protozoa. As microbial size and complexity increases, there is increased resistance to UV radiation. For example, the destruction of algae requires up to 100 times the dosage required to inactivate most bacteria and viruses. Table 5-5 summarizes the comparison of chlorine and UV.

Table 5-5: Comparison of Wastewater Treatment Technologies

Characteristic	Chlorination	UV Radiation
Performance (reliability)	Very good	Good
Effectiveness (degree of reduction)	Good	Good
Flexibility (adaptation to changes)	Fair	Good
Ease of implementation	Fair	Fair
Energy Use	Low	High
Maintenance	Low	High
Water Quality	Fair	Good
Air Emissions Hazard	Low	Very low
Storage & Handling Risk	Medium	Low
Exposure Risk	Low	Low

Source: CHEMinfo Services

Since UV disinfection operates through light transmission, the physical characteristics of the source waters determine the ultimate effectiveness of the treatment. High turbidity, colour, organic content and iron salts can adversely affect the transmission of UV light through water. The minimum UV dosage must be calculated based on the characteristics of the source water and the target effluent levels. Since UV light is not an oxidant like chlorine or ozone, it has almost no effect on organic chemicals present.

5.4 Direct Replacement Cost of Non-Chlorine Technologies

The basic model of substitution for chlorine in municipal water treatment is to assume complete replacement of chlorine facilities by ozone treatment systems. For municipal wastewater treatment, the model assumes substitution by UV radiation systems. This substitution takes place only at the number of plants identified as using chlorine in Canada. The cost of chlorine used in water and wastewater treatment is estimated by multiplying the 1993 estimated volume by the 1988-1993 weighted average market price for elemental chlorine sold to municipalities. This price (\$1025 per tonne) differs significantly from the bulk price for elemental chlorine assessed in chapter 2 (\$132 per tonne). These prices differ as municipalities typically purchase elemental chlorine in 50-100 lb. containers from firms specializing in packaged chlorine. These firms re-process and package elemental chlorine bought in bulk from chlor-alkali manufacturers.

To provide realistic cost estimates, a variety of plant sizes had to be considered. The number of treatment plants was segmented into three categories and cost estimates were obtained from literature and major technology suppliers.

Category	Volume Range (ML/d)	Representative Plant Size (ML/d) (MUSG/d)		Population
Small	0-5	1	0.25	2,500
Medium ²	5-50	10	2.5	25,000
Large	50+	100	25	250,000

5.4.1 Substitution of Ozone Treatment in Water Treatment

For ozone treatment systems, capital and operating costs for three plant sizes were obtained from a Beak Consultants Ontario ozone study³. These cost levels were confirmed by contacting a major ozone equipment supplier. Costs included direct (equipment, tanks, piping, control systems) and indirect costs (design, engineering and building construction). An average dosage of 2 mg/L of 10% concentration ozone was assumed as a midpoint of the typical range. This assumes a mild treatment in relatively unpolluted waters. The model assumes no residual chemical biocidal treatment for bacteria control in the distribution system. At a 0.5 mg/L chlorine level, the post-chlorination costs would be negligible compared to the capital and operating costs of the ozonation.

Table 5-6 provides the calculation of direct replacement costs for ozonation. Capital costs are estimated at \$583 million, with an operating cost difference of \$12 million/year. Annualized capital costs, assuming an 9% interest rate and plant life of twenty years amount to \$64 million per year. Total additional annual costs, including operating costs are \$76 million.

² includes installation costs, assumed equal to equipment costs.

³ Robertson, J.L., BEAK Consultants Ltd., Combined Application of Ozone and Chlorine or Chloramine to Reduce Production of Chlorinated Organics in Disinfection of High DOC Drinking Water., 1983 (Costs were interpolated from cost data for plants with sizes 0.5, 5.0, and 50 MUSG/d.)

Table 5-6: Direct Replacement Cost for Ozonation

	Small (0-5 MLD) ⁴	Medium (5-50 MLD)	Large (50+ MLD)	Total
OZONATION				
Number of Plants	1549	323	88	1960
Capital Cost per Plant (\$x000/plant) ⁵	190	430	1700	
Operating Costs per Plant (\$x000/plant/yr)	10	17	63	
Total Capital Cost (\$millions)	294	139	150	583
Total Operating Costs (\$millions/yr)	15	5	6	21
CHLORINATION				
Volume (kilotonne/yr)				8.5
Price (C\$/tonne)				1025
Total Operating Cost (\$millions/yr)				9
DIFFERENCE				
Total Capital Costs (\$millions)				583
Annualized Capital Costs (\$million/yr)				64
Total Operating Costs (\$millions/yr)				12

5.4.2 Substitution of UV Radiation Treatment in Wastewater Treatment

With UV radiation treatment equipment, the critical factor is the number of lamps to be installed for a particular flow rate. Detailed capital equipment cost estimates were obtained from the leading Canadian manufacturer of UV systems for the 3 different size plants. The cost estimates were based on wastewater having a total suspended solids content of 30 mg/L and a target disinfection level of less than 200 fecal coliform per 100 mL (geometric mean measurement). No additional costs were assumed for any solids removal processes such as sedimentation, flocculation, or filtration. This assumes fairly high quality wastewater with low total suspended solids to prevent the shielding of bacteria. Since design, engineering and construction costs were not provided, installation costs have been assumed as equal to equipment costs. Energy costs were calculated based on 50 watt lamps at a rate of \$0.05 per kilowatt-hour. Lamp replacement costs were calculated based on an average life of 2 years and \$100 per lamp. Cleaning costs, including labour and acid cleaning solution, were estimated at \$6 per lamp.

⁴ Millions of litres per day

⁵ includes installation costs, assumed equal to equipment costs.

As summarized in Table 5-7, capital costs are estimated at \$154 million, and operating costs are virtually the same as with chlorine. Annualized capital costs, assuming an 9% interest rate and plant life of twenty years, amount to an additional \$17 million per year.

Table 5-7: Direct Replacement Cost for UV Radiation

	Small (0-5 MLD)	Medium (5-50 MLD)	Large (50+ MLD)	Total
UV RADIATION				
Number of Plants	393	96	27	516
Number of Lamps	24	224	2176	
Capital Equipment Cost (\$x000/plant)	46	176	1575	
Installation (assumed equal to equip.)	46	176	1575	
Total Capital Cost (\$x000/plant)	92	352	3150	
Operating Costs (\$x000/plant/yr)	2	18	170	
Total Capital Costs (\$millions)	36	34	84	154
Total Operating Costs (\$millions/yr)	1	2	5	7
CHLORINATION				
Volume (kilotonnes/yr)				7
Price (C\$/tonne)				1025
Total Cost (\$millions/yr)				7
DIFFERENCE				
Total Capital Costs (\$millions)				154
Annualized Capital Costs (\$millions/yr)				17
Total Operating Costs (\$millions/yr)				0

Source: CHEMinfo Services

5.5 Direct Replacement Cost Compared to End Use Revenues

Total water rate revenues for 1993 are estimated at \$3.3 billion, consisting of \$2.3 billion for water supply, and \$1.0 billion for sewer surcharges. As shown in Table 5-8, the direct replacement cost represents 3% of water supply, and 2% of wastewater revenues. These percentages should be seen as conservative estimates as water rates in Canada commonly do not recover the full costs of providing these services to the consumer (Env. Canada, 1995)

Water revenues were estimated using average monthly water prices for residential and commercial customers, multiplying these prices by the number of connections to the system, pro-rating the monthly figures to annual figures, and aggregating the results.

Industrial revenues were assumed to be equal to commercial revenues, since no data were available on industrial revenues. Both water supply and wastewater charges are commonly charged on the same water bill where the sewer proportion of the rate is commonly calculated as a percentage of the water supply rate. In 1991 the percentage of revenues corresponding to sewer surcharges was estimated at approximately 30% of total revenues.

**Table 5-8: Direct Replacement Costs Compared to End Use
Revenues**
(\$ million, 1993)

	Direct Replacement Cost	Annual Water Revenues	%
Water	76	2297	3.3
Wastewater	17	985	1.7
Total	93	3282	3.5

Source: Environment Canada (1995)

5.6 Socio-Economic Profile of Chlorine and Alternatives for Water Treatment

This section will provide a socio-economic profile of elemental chlorine, and alternatives, provided to the water treatment industry. In contrast to the previous chapters, a socio-economic profile of the firms that package and provide the majority of elemental chlorine to the municipal market will be provided. These firms are distinct from the chlor-alkali producers, and act to take bulk chlorine deliveries from the chlor-alkali producers and re-package the elemental chlorine for resale to the municipal treatment market.

A profile of chlor-alkali producers is provided in Chapter Two. In 1993, elemental chlorine production was 1170 kilotonnes. Of this total, 15.5 kilotonnes (1.3%) was sold to the domestic market for municipal water/wastewater treatment, 1.5 kilotonnes directly, and 14 tonnes indirectly through elemental chlorine packaging firms. Total domestic sales revenues associated with the sales of elemental chlorine to the municipal treatment market by chlor-alkali producers were \$2.0 million, consisting of \$0.2 million in direct sales and \$1.8 million in sales to chlorine packaging firms. The socio-economic profile of packaged chlorine is provided in the following section.

5.6.1 Packaged Chlorine Supply Industry

Plants and Locations: Chlorine is supplied to municipalities largely through distributors who purchase wholesale from the major chlorine producers. The packaged chlorine market consists of about 7 plants across Canada, as listed in Table 5-9. Stanchem operates four plants, with facilities in Cornwall, Winnipeg, Vancouver and Fort Saskatchewan, thereby dominating the market with national coverage.

Table 5-9: Major Packaged Chlorine Plants in Canada

Company	Location
Canadian Miraclean	Vancouver, BC
PrairieChem	Saskatoon, SK
Stanchem	Cornwall, ON
Stanchem	Vancouver, BC
Stanchem	Winnipeg, MB
Stanchem	Fort Saskatchewan, AB
Welland Chemical	Sarnia, ON

Source: CHEMinfo Services

Production and Capacity Levels: The bulk of chlorine supplied to municipalities is packaged in one tonne or 50-100 pound steel cylinders. Only a couple of larger municipalities, such as Toronto, purchase chlorine in bulk (50 tonne tank cars) from chlor-alkali manufacturers. Out of an estimated 15.5 kilotonnes of elemental chlorine used in the municipal water treatment sector, 14 kilotonnes are supplied by packaging firms. An estimate of the amount of elemental chlorine supplied in one tonne cylinders is 5 kilotonnes, while 9 kilotonnes are estimated to be provided in 50-100 pound steel cylinders.

Imports and Exports: Imports and exports of packaged elemental chlorine are negligible.

Revenues: Given an estimated average 1988-1993 price of \$639 for a one tonne container, and \$1389 (per tonne) for 50-100 pound cylinders, excluding deposit, an estimate of annual domestic sales revenues associated with elemental chlorine sales by packaging firms is \$15.7 million.

Employment: Based on estimates obtained from industry suppliers, approximately 125 employees are involved in the production and sale of packaged chlorine in Canada.

5.6.2 Ozone Technology Industry

Plants and Location: There are three principal suppliers of ozone technology in Canada; Emery Trailgaz Inc., Ozonia/Degremont Infilco Ltd. and Hankin Atlas Ozone systems. Hankin Atlas is the only Canadian manufacturer/supplier of large ozone systems. The two other firms are French based multinational firms with continental head offices located in the United States.

Production/Capacity: The capacity to supply ozonation equipment and generate ozone is not rate limited by processing equipment.

Imports/Exports: The machinery provided by Emery Trailgaz and Ozonia/Degremont is imported, while approximately 60% of the machinery produced by Hankin Atlas is exported.

Revenues: Revenues are estimated at approximately \$5 million per year.

Employment: Employment is estimated at 37 people in total, with Hankin Atlas employing 17 full time and part time staff.

5.6.3 UV Radiation Technology Industry

Plants and Locations: The UV radiation technology market is dominated by a Canadian firm, Trojan Technologies Inc. of London Ont. A rapidly growing company addressing a global market, Trojan has supplied about 80% of the UV systems in Ontario and one plant in Manitoba. The second major UV company is Fischer and Porter (Canada) Ltd. of Downsview, Ont. Known for its process control instrumentation, Fischer and Porter supplies gas dispensers, UV water treatment systems and chemical feed pumps. Fischer and Porter has installed about 10% of the UV systems in Ontario and has a larger presence in Western Canada. It was the main supplier to the Bonnybrook, Calgary Wastewater Plant. Degremont Infilco Ltd is also a UV radiation equipment manufacturer and supplier, supplying approximately 10% of the UV systems in Ontario.

Production: Based on information obtained from industry suppliers, it is estimated that at least 80% of UV radiation disinfection equipment is supplied to the wastewater treatment sector. Likewise, a similar level of revenues is generated by sales to that sector as well.

Export and Import: In general, the domestic market for UV radiation disinfection technology is limited and accounts for a little over 10% of supply. The remaining 90% is directed towards the export market, mostly to the United States.

Revenues: Revenues in 1993 for the sector as a whole are estimated to be around \$28 million, with the majority of revenues (> 80%) arising from the wastewater treatment sector.

Employment: It is estimated approximately 120 people were employed in the manufacture of UV technology in Canada in 1993.

5.7 Summary

The preceding chapter has described the use of elemental chlorine in water and wastewater treatment, and two alternative technologies for water and wastewater treatment - ozonation and UV disinfection. Elemental chlorine supply for water treatment comprises two distinct industries, bulk chlor-alkali producers as profiled in Chapter Two, and elemental chlorine packaging firms which package bulk chlorine for shipment to the water treatment sector.

In the base year for the study (1993), approximately 30 water treatment plants (1% of the total) were using ozonation technology, while 40 wastewater treatment plants (2%) were using UV disinfection technology. The number of plants using UV increased to 70 by 1995. The remainder of plants were using elemental chlorine. A slight trend towards increasing use of both ozone and ultraviolet radiation is explained primarily by potential health and environmental concerns; specifically the formation of trihalomethanes (THMs) in water supply, and the toxicity of chlorinated effluent.

The direct replacement costs for ozonation technology in water treatment using the 1993 base year data are estimated at \$12 million in additional annual operating costs, and \$583 million in capital costs. Converting these capital costs to annual costs generates a total annual cost of \$76 million. This represents approximately 3% of total annual revenues derived from water supply rates.

The direct replacement costs of UV disinfection technology in wastewater treatment are estimated at \$154 million in capital costs, with no change in operating costs. Converting these capital costs to annual costs generates an annual capital cost of \$17 million. This represents approximately 2% of total annual revenues derived from wastewater treatment.

A summary of socio-economic information for elemental chlorine, packaged chlorine sold to the municipal sector, ozone and UV radiation is presented in Table 5-10. Using the indicator of domestic revenues indicates that bulk elemental chlorine manufactured by chlor-alkali producers is the largest of the industries profiled. Given that the water treatment sector accounts for only 1-2% of elemental chlorine supply however, a more accurate comparison may be between packaged chlorine, and alternatives. Using this measure, the

ultraviolet radiation supply industry has higher domestic revenues than the industry supplying packaged chlorine.

Table 5-10: Socio-economic Summary for Chlorine and Alternatives in Water Treatment

	Bulk Chlorine	Packaged Chlorine	Ozone	UV Radiation
Value of Domestic Sales (\$ million)	33	16	5	3
Trade Balance (\$ million)	37	0	(3)	25
Domestic Revenues (\$ millions)	70	16	2	28
Employment	653	125	37	120
Employment/ Domestic Revenues	9.3	7.8	18.5	4.3

5.8 Contacts and References

5.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Beak Consultants Ltd.
- Control and Metering Environmental
- Degremont Infilco ltd.
- Degremont (Ozonix)
- Emery Trailgaz (Henkel)
- Fischer and Porter Ltd.
- Lacelle, D. (Environment Canada)
- Metcon Sales and Engineering
- Trojan Technologies
- Welland Chemical

5.8.2 Association Contacts

- Canadian Water and Wastewater Association

5.8.3 References

Environment Canada. 1995. Municipal Water Rates in Canada: Current Practice and Prices, 1991. Water and Habitat Conservation Branch, Environment Canada. 32 pp.

Environment Canada, National Inventory of Municipal Waterworks and Wastewater Systems in Canada (1986);

Robertson, J.L., BEAK Consultants Ltd., Combined Application of Ozone and Chlorine or Chloramine to Reduce Production of Chlorinated Organics in Disinfection of High DOC Drinking Water., 1983

6. Chlorine in Titanium Dioxide Production

6.1 Introduction

This chapter examines the use of elemental chlorine, and alternatives, in the production of titanium dioxide (TiO_2). Titanium dioxide is a white inorganic mineral pigment used in paints and protective coatings (50%), plastics (20%), paper (15%) and a range of smaller products (15%). The alternative to the use of chlorine is the older sulphate process. The chloride process uses elemental chlorine, while the sulphate process uses sulphuric acid, in order to produce titanium dioxide.

This chapter describes the industry structure, elemental chlorine use, and alternatives in titanium dioxide production. The direct replacement cost of the sulphate process for the chloride process will be assessed, and these costs compared to the annual revenues derived from titanium dioxide production. A socio-economic profile of the alternative to elemental chlorine, sulphuric acid, will be provided in the following chapter, hydrochloric acid used in steel pickling.

6.2 Chlorine and Alternatives in TiO_2 Production

Table 6-1 shows the 2 titanium dioxide plants in Canada. In Canada, the chloride process is the dominant process for producing titanium dioxide. The one firm in Canada producing titanium dioxide from ore (Kronos Canada) has 50 kilotonnes of chloride based production, and 20 kilotonnes of sulphate based production. The prevalence of the chloride process in Canadian TiO_2 manufacturing is similar to the North American situation, while the sulphate process is more prevalent in Europe and less developed countries. In 1993, the chloride process accounted for 54% of world-wide process capacity.

Tioxide Canada's plant located in Tracy, Quebec is currently used as a finishing plant for finishing 52 kT/yr of imported TiO_2 . Finishing refers to adding silica, alumina or zirconium (depending on the final application) to slurried TiO_2 to add a molecular abrasion resistant coating and extend the UV stability. Previously, this plant location produced titanium dioxide using the sulphate process.

Table 6-1: Canadian Titanium Dioxide Producers

Company	Location	Process	Capacity (kT/yr)
Kronos Canada Inc.	Varennes, PQ	Chloride	50
		Sulphate	20
Tioxide Canada Inc.	Tracy, PQ	finishing	52
TOTAL			122

Source: Chemical Marketing Reporter/Camford Information Services

The chloride process uses chlorine as an intermediate chemical. Supply of the chlorine required by titanium dioxide production in Canada is expected to come from a regional manufacturer, likely ICI in Becancour, PQ. In 1993, approximately 10 kilotonnes of chlorine (or 1% of Canadian chlorine production) was sold for use in titanium dioxide production. It is estimated that chlorine sales to the titanium dioxide industry generated revenues of about \$1.3 million in 1993 based on an elemental chlorine price of \$132/tonne.

Trends in elemental chlorine demand in the titanium dioxide industry exhibit a slight increase as Kronos Canada plans a potential 20% expansion of capacity for its chloride process plant. The Tioxide Canada plant in Tracy, Quebec closed its sulphate plant in 1992, primarily due to environmental concerns related to effluent, notably waste sulphuric acid.

The chloride process was first developed in response to environmental concerns about the sulphate process. The rutile ore used in the chloride process typically has a higher titanium dioxide content than ilmenite ore used in the sulphate process, thus reducing overall treatment requirements. The gaseous chlorine used in the chloride process can also be reprocessed more easily than the sulphuric acid in the sulphate process. The chloride washing process is also somewhat cleaner and requires less makeup. Hydrochloric acid can be produced as a by-product from the chloride process, but the quantities are much lower than the spent sulphuric acid from the sulphate process.

In the sulphate process, almost 3 tonnes of sulphuric acid are required for every tonne of product. Disposal opportunities for the spent sulphuric acid are determined by the markets that exist for the by-products. In Germany and the U.S., the acid is recycled and the iron sulphate salts are isolated and sold to wastewater chemical markets. In Canada, the wastewater treatment chemical market is small. Therefore, at the Kronos Canada

sulphate plant limestone is used to neutralize the waste sulphuric acid to produce gypsum (calcium sulphate). This is then sold to a Montreal wallboard manufacturer.

6.3 Titanium Dioxide Production Processes

The two processes used in making TiO_2 - the chloride process and the sulphate process - result in products having different properties and unique markets. In the chloride process, black rutile ore (containing from 70 to 95% titanium dioxide) is chlorinated and the resulting titanium chloride vapours are oxidized to titanium dioxide. Chlorine is recycled within the system. Rutile ore is naturally occurring titanium dioxide, which may contain up to 10% iron. It is a reddish-brown mineral that occurs in large deposits in the eastern US, Brazil and Australia. The rutile form of TiO_2 can be made from the sulphate process by seeding the titanium hydrate solution with rutile crystals and conditioning agents, but this extra process is rarely used.

The sulphate process produces a TiO_2 , known as anatase titanium dioxide, which is softer than that produced by the chloride process. In the sulphate process, ilmenite ore is digested with sulphuric acid to form titanium sulphate and ferrous sulphate as intermediate products. Ilmenite ore is an iron-black mineral consisting of a combination of titanium and iron oxides known as ferrous titanate ($\text{FeO} \cdot \text{TiO}_2$). Ilmenite contains roughly 50 to 85% titanium and can also contain manganese or magnesium and many trace heavy metals. It occurs widely throughout the US, Canada, Sweden, Russia and India. After separating the ferrous sulphate, the titanium sulphate is hydrolyzed and then calcined to produce titanium dioxide. Titanium slag, having a high TiO_2 content, can also be used. The refining process utilizes water-based, wet-batch chemistry which includes a number of processing steps, including dissolution, clarification, vacuum crystallization and filtration.

The titanium dioxide powder produced from either process is coated with an inert silica or alumina layer which is deposited on the surface of the TiO_2 powder in a slurry tank in the final processing stage. Performance properties such as dispersion, gloss, UV absorbency, tinting strength, and tones can be adjusted by varying the amount and composition of coatings.

Rutile TiO_2 from the chloride process is generally preferred for paints, plastics and coatings because of its durability and non-chalking properties. In most paper applications, a mixture of anatase and rutile TiO_2 is preferred since the softer material is less erosive on fine machinery.

TiO_2 produced by the sulphate process is relatively soft and has chalking properties. The ilmenite ore used in the sulphate process is typically lower in titanium dioxide content than the rutile ore used in the chloride process, but is generally cheaper and more widely

available. TiO_2 produced by the chloride process has a higher density and is slightly more durable. Table 6-2 summarizes the comparison of the 2 titanium dioxide processes.

Table 6-2: Technical Comparison of TiO_2 From Chloride and Sulphate Processes

Characteristic	Chloride Process	Sulphate Process
Raw Material Availability	Rutile; Low	Ilmenite; High
Product Grade	Higher	Lower
Product Hardness	Hard	Soft
Disposal Problems	Low	High
Substitutability	Low	Low

Source: CHEMinfo Services

6.4 Direct Replacement Costs

The alternative for chlorine use in TiO_2 production is the sulphate production process. Since the sulphate and chloride processes involve different technologies, a complete plant conversion would be required to substitute the sulphate process for the chloride process. The direct replacement cost model assumes installation of a new 50 kilotonne per year facility using the sulphate process. One critical assumption is that the rutile form of TiO_2 can be produced from the sulphate process. In addition, the chloride and sulphate processes require different water effluent treatment, the costs of which have been estimated.

The sulphate process is almost twice as capital intensive as the chloride process, but has fewer off-site requirements. SRI (1989) estimated that, at US \$160 million, the sulphate process had a 30% higher overall capital cost than the chloride process for a 45 kilotonne plant. Capital costs for sulphate TiO_2 plants range from \$3,300 to \$4,300 per tonne of finished product, depending on the size. Since plant capacities range from 37 kilotonnes to 295 kilotonnes, a 50 kilotonne facility is considered a small plant, and would cost about \$4,300 per tonne, or C\$213 million. An industry producer confirms this estimate as reasonable. Of this, \$173 million is for direct costs and \$100 million is for off-sites. These costs include approximately \$60 million for a sulfuric acid neutralization required to handle effluent for the 50 kT/year facility. This estimated capital cost is confirmed by one industry source which recently installed a neutralization facility.

Additional costs must be incurred for removal of the old facility. Industry sources suggest that an extra \$1,200 per tonne is required for standard demolition and removal. This could add another \$60 million to the cost, although it has not been included in the calculation. Environmental site remediation costs were not considered in this scenario. Process design literature shows that the sulphate process is about 25% more costly to operate than the chloride process (SRI, 1989). One producer contacted for this study, confirms this differential and adds that nearly 80% of the differential operating costs can be attributed to waste treatment and other "environmental" costs.

Major potential waste streams typically generated from titanium dioxide production facilities using the sulphate process include¹:

- digester sludge which includes impurities such as silica, alumina, unreacted iron and sulfuric acid;
- ferrous sulphate;
- strong sulfuric acid waste and metal salts, generated as filtrate after formation of the titanium dioxide;
- weak sulfuric acid waste stream and metal salts, generated from washing titanium dioxide hydrate precipitate; and
- vapour scrubber wastewater containing titanium, generated from scrubbing of ore drying, digestion, and kiln drying.

Treatment of strong sulfuric acid waste and contained metal salts presents a major requirement for sulphate plants. Neutralization of sulfuric acid containing streams is required before discharge. Neutralization can be carried out with a variety of alkali sources including calcium or sodium based. In Canada, Kronos neutralizes its waste stream with calcium carbonate. Calcium and sulphate in aqueous form react to form a precipitate of calcium sulphate. Calcium sulphate is also referred to as gypsum, and has application in gypsum wallboard construction and other uses. However, the value of gypsum is generally very low, such that revenues from selling gypsum derived from this process do not come close in offsetting the costs of operating the neutralization process. Mined and other sources of gypsum are low cost alternatives for gypsum customers.

The total additional capital and operating costs associated with a 50 kilotonnes-TiO₂ per year sulphate plant are estimated at \$273 million and \$31 million/year, respectively. Annualized additional capital costs are estimated at \$30 million/year, assuming an 9% interest rate and twenty year plant life period. Total additional annual costs, including operating costs, are estimated at \$61 million/year. Costs are summarized in Table 6-3.

¹ Pollution Prevention Technology Handbook, Robert Noyes, Noyes Publication, Park Ridge, NJ, USA, 1993, Page 160 - 162.

Table 6-3: Direct Replacement of Chlorine in Titanium Dioxide Production

	Chloride Process	Plant Process	Sulphate Process Waste Disposal	Total Costs	Difference
Capacity (kilotonnes)	50	50	50		
Capital Costs (\$M)					
• Battery Limits		173		173	173
• Off-sites		40		40	40
• Waste Disposal			60	60	60
Total Capital Cost (\$M)		213	60	273	273
Operating Costs (\$M/yr)					
Raw material, utilities	54	57	12	69	15
Labour, Maintenance	20	21	4	25	5
Overhead	41	43	9	52	11
Total Operating Cost (\$M/yr)	115	121	25	146	31

Source: CHEMinfo Services Inc., Industry producers.

6.5 Direct Replacement Costs Compared to End Use Revenues

Canadian titanium dioxide 1993 production at Kronos Canada is estimated to be 65 kilotonnes. Assuming a price for titanium dioxide of \$2722/tonne generates an estimated annual revenues from Titanium Dioxide production of approximately \$177 million. The costs of substitution (\$61 million) represent approximately 34% of total revenues from the sale of titanium dioxide.

6.6 Summary

The preceding chapter has described two processes utilized to produce the white pigment titanium dioxide. The chloride process involves chlorinating black rutile ore and oxidizing the resulting titanium chloride vapours. The alternative sulphate process involves digesting ilmenite ore with sulphuric acid to form titanium sulphate.

In the base year for the study (1993), only one plant in Canada was refining titanium dioxide from ore (using both chloride and sulphate processes). There also was one finishing plant coating imported titanium dioxide from Europe, but this process does not require chlorine. In 1993, approximately 70% of the titanium dioxide manufactured in Canada was produced using the chloride process. The sole Canadian manufacturer is considering expanding chloride production by 20%, reflecting an increasing market for chloride-process titanium dioxide. The increasing market share of chloride based titanium dioxide manufacture is principally in response to environmental concerns regarding the sulphate process.

The direct replacement costs from chloride-process to sulphate-process titanium dioxide production, using 1993 production, are estimated at \$273 million in capital costs and an additional \$31 million in annual operating costs. Converting these capital costs to annual costs generates a total annual cost of \$61 million. This represents 34% of revenues derived from domestic titanium dioxide production (approximately \$177 million).

6.7 Contacts and References

6.7.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Kronos Canada
- Tioxide Inc.

6.7.2 References

Camford Information Services. Profile: Titanium Dioxide. Toronto, Ontario.

Chemical Marketing Reporter. Schnell Publishing, New York, New York.

7. Hydrochloric Acid in Steel Pickling

7.1 Introduction

This chapter discusses the largest single use of hydrochloric acid in Canada, steel and iron pickling (surface cleaning). The alternative to hydrochloric acid analyzed will be sulphuric acid. Hydrochloric acid is produced through burner units attached to chlor-alkali plants where excess hydrogen generated by the electrolytic process is combined with elemental chlorine. For any given chlor-alkali producer, the production of hydrochloric acid can vary depending on the difference in merchant prices between the acid and elemental chlorine. In 1993, the net total production of hydrochloric acid used approximately 13% of total domestic elemental chlorine production. After captive by-product uses (such as chlor-alkali brine treatment) are excluded, a total of 113 kilotonnes of hydrochloric acid was produced for the merchant market.

Initially this chapter will review the market for hydrochloric acid, and alternatives, in steel pickling (surface cleaning). A technical description of the production process for steel pickling is followed by an estimate of the direct replacement cost of sulphuric acid for hydrochloric acid, including costs for disposal of wastes. Finally the socio-economic profile of the alternative to hydrochloric acid - sulphuric acid - will be provided, including a description of plants, production, revenues and employment.

7.2 Use of Hydrochloric Acid and Alternatives in Steel Pickling

The largest single merchant end use application of hydrochloric acid (HCl) in Canada is in pickling within the iron and steel industry. The industry began to switch to hydrochloric acid and away from sulphuric acid over 30 years ago. Table 7-1 shows that steel pickling uses a total of 30 kT annually of HCl, representing approximately 26% of total domestic merchant hydrochloric acid production (113 kilotonnes).

Table 7-1: Hydrochloric Acid Pickling Applications

	1993 (kilotonnes)
Galvanized sheet steel	12
Other steel	10
Wire shapes	8
Total pickling demand	30

Source: CHEMinfo Services Inc.

The largest use of HCl is in the production of galvanized sheet. Stelco and Dofasco are the major galvanized sheet manufacturers in Canada. Other large steel mills such as Sidbec-Dosco and Algoma Steel also use HCl for their steel shapes and other products. Wire shapes use HCl for cleaning prior to drawing, as well as in the finishing operations. Fastener plants use both hydrochloric acid and sulphuric acid for pickling. Many of the merchant galvanizers also have pickling tanks or lines so they can clean their customers' products prior to painting or galvanizing. However, some facilities continue to operate sulphuric acid pickling baths.

The alternative to the use of HCl in pickling is sulphuric acid, which was used exclusively in the early days of steelmaking. Today, the steel industry in North America is turning away from sulphuric acid because of higher energy costs, an inability to regenerate the acid and potentially higher waste disposal costs associated with sulphuric acid pickling. Several industry sources agree that although some old pickling plants continue to use sulphuric acid, no new sulphuric acid pickling lines are being installed. Total annual domestic use of sulphuric acid in steel pickling is estimated at 20 kilotonnes.

7.3 Technical Comparison of Hydrochloric Acid, Sulphuric Acid

Steel is pickled in both primary production prior to cold rolling and in secondary production. The second pickling is done prior to being drawn into shapes for further surface finishing, such as zinc galvanizing or coating. Some non-coated steels are pickled prior to shipment to customers. The use of pickling acid removes iron oxide from the surface, leaving bare metal. The pickling process can also provide an etch that allows zinc or other coatings to be smoothly coated onto the steel. Both hydrochloric acid and sulphuric acid are able to remove rust and scale from iron and steel. Table 7.2 provides a comparison of the technical properties of hydrochloric acid and sulphuric acid in iron and steel pickling.

Hydrochloric acid generates fumes that are significantly more corrosive and toxic than those generated by sulphuric acid. Facilities must be specifically designed taking into consideration the more corrosive nature of hydrochloric acid. Sulphuric acid can be safely raised to a higher temperature for more effective use, since it does not generate extensive fumes. However, hydrochloric acid is not usually heated for pickling, since the acid fumes generated at higher temperatures are toxic and highly corrosive and would require containment.

Hydrochloric acid has a greater ability to dissolve ferric oxide, the higher oxidative state of iron. The mechanism of hydrochloric acid pickling is a dissolution of oxidized scale from the outer surface (where ferric oxide is in highest concentration) inwards. Sulphuric acid has a propensity to react with the reduced state, low-oxygen rust next to the "mother metal" surface. Sulphuric acid tends to work underneath, dislodging rather than dissolving scale and rust flakes, and producing a more insoluble rust by-product than hydrochloric acid. Table 7-2 summarizes the comparison between acids.

Table 7-2: Technical Comparison of Pickling Acids

Characteristic	Hydrochloric Acid	Sulphuric Acid
Operating temperature range	ambient (25) - 70°C	generally higher
Concentration	14%	11%
Pickling time (depends on concentration)	continuous is faster batch is slower	continuous slower batch is faster
Pickling capacity (tonnes/day)	lower	higher
Product quality	higher	potentially lower (requires greater operator care)
Surface consistency	uniform	variable
Disposal products	soluble ferrous oxide	insoluble ferrous sulphate
Solubility of rust	higher	lower
Regeneration	common	not feasible

Source: CHEMinfo Services Inc.

Hot sulphuric acid attacks metal more aggressively than hydrochloric acid which is "more forgiving". Since HCl is less aggressive on the metal surface than sulphuric acid, parts can be left in the pickling bath for a greater length of time, without concern for corrosion. For example, in batch operations, parts pickled in HCl can be left over-night without damaging the base metal. When using sulphuric acid, operators need to be trained to ensure parts are removed soon after they are cleaned. The nature of sulphuric acid pickling can also lead to uneven metal surfaces. One result is that the surface area of the part may be increased such that a greater amount of protective coating (i.e., zinc in galvanizing) is required.

Another major advantage of hydrochloric acid is that it can be regenerated from ferrous chloride (FeCl_2) in spent pickling acid solutions. Most major steel products companies purchase HCl as a make-up stream to replenish losses and their stock of regenerated acid.

Larger companies can reclaim up to 98% of HCl acid solution. In smaller plants, roughly 35% of the ferrous chloride is recoverable as HCl, and the remainder is sent for either conversion to ferric chloride (FeCl_3) or used directly by municipal water treatment, industrial water treatment and other applications. It is assumed that, on average, 60% of recoverable HCl is reclaimed.

Sulphuric acid pickling liquors contain ferrous sulphate in spent solution. Fresh sulphuric acid must be continuously added to a pickling bath to maintain the acid strength. It is not possible to regenerate this acid so that it must be replaced over time. Companies either pay to have their acid removed and disposed at in a waste processing facility, or give it away to chemical distributors which can sell it. Some companies sell waste hydrochloric acid pickling liquor directly to municipalities which use it for water treatment.

At waste processing facilities hydrochloric or sulphuric acid pickling liquors are usually first neutralized with caustic. A flocculant is typically added to precipitate metals. The water is conditioned to meet municipal sewer standards and the solid sludge is sent to landfill.

7.4 Direct Replacement Cost for HCl in Steel Pickling

7.4.1 Capital and Operating Costs

The direct replacement cost assumes that hydrochloric acid is replaced by sulphuric acid through the use of an equivalent volume of pickling solution. Hydrochloric acid regeneration requires that more sulphuric acid be purchased in order to generate an equivalent pickling solution. This is partially offset by the slightly lower average concentration of sulphuric acid. Some additional capital may be required to install steam heating coils, but the pickling baths are assumed to remain unchanged. The amount of energy required to raise the bath solutions to a higher operating temperature was calculated and found to be negligible.

Average prices for hydrochloric acid and sulphuric acid were used in the cost analysis. Prices for each acid have remained reasonably steady in the five-year period from 1988 to 1993. The price of hydrochloric acid used was \$263/kilotonne, while the price for sulphuric acid used was \$99/tonne. Table 7-3 summarizes the direct replacement costs.

Table 7-3: Direct Replacement Cost for HCl in Steel Pickling

	Hydrochloric Acid	Sulphuric Acid
Quantity required (kilotonne)	30	59
Concentration (%)	14%	11%
Recycle rate (%)	60%	0%
Pickling solution applied (kilotonne)	536	536
Average price (\$/tonne)	263	99
Total material cost (\$millions)	7.8	5.8
Difference		(2)
No. of pickling baths		100
Cost per steam coil (\$000's)		20
Capital cost (\$millions)		2

Source: CHEMinfo Services Inc.

7.4.2 Waste Disposal Costs

The effectiveness of sulphuric acid pickling liquor is reduced as iron and other metal salts are formed. Fresh, concentrated acid is added to restore the activity of the pickling solution as more and more metal products are cleaned. Over time, the activity of the pickling liquor becomes weak such that it needs to be totally replaced with fresh acid. (The same happens with hydrochloric acid based pickling liquors.) The spent liquor can either be sent for waste disposal or transferred to chemical distributors which sell the product. Some pickling facilities sell waste liquor directly to major end-users such as municipalities. The contents of the spent acid solution determine whether the product is sent for waste treatment and solids disposal, or has commercial chemical value.

A portion of the pickling acid solution is lost through drag-out and rinsing of the metal. Rinsing is usually carried out with water (or steam) which cleans the part and generates a dilute liquor stream from which it is not economically feasible to recover the chemicals contained. If the rinse solution is sufficiently dilute (i.e., meeting municipal regulatory standards), it may be sent directly into the sewer system. In other cases, neutralization or other chemical treatment may be necessary.

Any ferrous sulphate recovered from acid recycling needs to be sold or disposed. The economics of neutralizing, recovering, concentrating and drying ferrous sulphate from

acid pickling liquors have not been favourable given the low value of the chemicals generated and the costs of transporting spent acids with low concentration of potentially commercial chemicals.

Ferrous sulphate is used in pigments production, coatings, inks, animal feeds, water and sewage treatment, catalysts and fertilizers. However, these applications require unique grades (i.e., different iron content, monohydrate, heptahydrate, etc.), with different purities. The demand for low-grade ferrous sulphate produced from, or contained in, spent acid pickling baths is limited to such applications as water and sewage treatment, and other applications which can accommodate low quality (and low priced) product. Philip Environmental, Laidlaw, BWA and Fanchem are firms taking away spent pickling baths.

The cost of pick-up and disposal for picklers varies between 0 and 22¢/litre. Some pickling operations can sell the iron content of their pickling solution, such that there is a cost savings associated with disposing the "waste". The value of commercial product can range considerably (i.e., 0-10 ¢/litre of solution). One waste handling firm states that the cost of pick-up and disposal can range from 14 to 22 ¢/litre for waste pickling liquors (includes transportation). There is no cost difference between hydrochloric and sulphuric acid liquors. For higher volume generators of waste, discounts are available. However, if hazardous metals (i.e., lead, nickel, cadmium, hexavalent chromium) are contained in the waste, the disposal cost can be much higher. Most pickling liquors do not contain these metals in high enough concentration to increase the cost of disposal. Another waste handling firm claims to pick up spent liquors which have commercial chemical value free of charge. This company sells the waste pickling liquor to municipal water treatment facilities for their iron content. (Iron contained as ferrous chloride is used to treat for phosphorus content). One large steel operation generates "a high quality" spent hydrochloric acid pickling liquor that it sold directly to a large Ontario municipality.

An estimated 214 kT of spent hydrochloric acid currently requires sale or disposal. According to one chemical distributor, roughly one-third of this quantity is absorbed into the market, largely being sold to municipalities for waste water treatment. The same distributor needs to import liquors from the United States to meet Canadian demand. The average value in the wastewater treatment market is about \$50/T. Another one-third portion of the spent hydrochloric acid has a low commercial value and is sold at no cost. The remaining one-third needs to be sent for waste treatment. The average cost of disposal is estimated at \$150/T. The substitution of sulphuric acid for hydrochloric acid would result in an estimated 536 kT of spent sulphuric acid pickling solution in Canada, 322 kT more than the spent hydrochloric acid volume. It is assumed that the municipalities would continue to purchase the same volume for water treatment at the same price, and that the same volume of low value spent sulphuric acid would continue to

be sent to market at no cost. The additional cost is incurred in disposing of the additional 322 kT of spent sulphuric acid at \$150/T, as shown in Table 7-4.

Table 7-4: Disposal Cost Model Assumptions and Calculations

Waste Pickling Solution Portions	Hydrochloric Acid			Sulphuric Acid			Difference (\$M)
	Volume (kT)	Cost (\$/T)	Cost (\$M)	Volume (kT)	Cost (\$/T)	Cost (\$M)	
33% sold to market	71	-50	-3.6	71	-50	-3.6	0
33% transferred free	71	0	0	71	0	0	0
33% sent for disposal	72	150	10.8	394	150	59.1	48
Total waste solution	214		7.2	536		55.5	48

7.4.3 Direct Replacement Cost Summary

Direct replacement of sulphuric acid for hydrochloric acid would result in an estimated additional capital expenditure of \$2 million and an additional annual operating costs of \$46 million. This annual cost includes an estimated \$48 million per year for disposal of greater quantities of spent sulphuric acid pickling.

Annualized capital costs, assuming an 9% interest rate and a 20-year equipment life, are \$0.2 million. The substitution of sulphuric acid for hydrochloric acid would result in a cost of approximately \$46.2 million dollars a year to iron and steel manufacturers, and other pickling operators, including the costs of waste disposal for sulphuric acid.

7.5 Direct Replacement Cost Compared to End Use Revenues

Environment Canada (1995) estimated revenues for the Canadian steel industry in 1994 at \$10.1 billion. The direct replacement costs of switching to sulphuric acid (\$46.2 million annually) represent less than 0.5% of revenues from domestic steel manufacturing.

7.6 Socio-Economic Profile

The socio-economic profile concentrates on sulphuric acid only. The profile for hydrochloric acid production was provided in Chapter 2, and is summarized here. In 1993, total production of hydrochloric acid for merchant sale was 113 kilotonnes, with 30 kilotonnes (26%) used in steel pickling. Domestic revenues from hydrochloric acid production are estimated at \$29 million, with domestic sales to steel manufacturers valued at approximately \$8 million. Assuming that 10% of employment in chlor-alkali production is related to hydrochloric acid production generates estimated employment of 131 people in hydrochloric acid production.

7.6.1 Sulphuric Acid

The majority of companies producing sulphuric acid are involved in metals mining and smelting (e.g. Noranda, Inco, Falconbridge). These companies produce sulphuric acid as a by-product of smelting operations. The primary metals involved include: copper, lead, zinc, nickel, cobalt, silver, gold and cadmium.

Number and Location of Producers: Ten companies produce sulphuric acid in Canada, as listed in Table 7-5. They are spread geographically from Trail, British Columbia to Belladune, New Brunswick.

Table 7-5: Sulphuric Acid Producers In Canada

COMPANY	LOCATION
Border Chemical	Transcona, Winnipeg, MB
Brunswick Mining & Smelting Corp. Ltd.	Belledune, NB
Canada Colours & Chemicals Ltd.	Elmira, ON
Cominco	Trail, BC
Falconbridge Limited	Toronto, ON (head office)
Inco Limited	Sudbury, ON
Marsulex Inc.	North York, ON (head office)
Noranda	Toronto, ON (head office)
Sherritt Inc.	Fort Saskatchewan, AB
Zinc Electrolytique Du Canada	Valleyfield, PQ

Source: CHEMinfo Services Inc., 1994

Production Levels: Approximately 5,600 kilotonnes of sulphuric acid were produced in Canada in 1994 (excluding Border Chemical and Canada Colours & Chemicals). Four companies, Falconbridge, Marsulex, Noranda and Sherritt Inc. accounted for 78% of Canadian sulphuric acid production.

Imports and Exports: Imports in 1993 were 96 kilotonnes, while exports were 6 kilotonnes.

Revenues: Assuming a price of \$99 dollars per tonne, the value of annual domestic sulphuric acid production is approximately \$563 million. The trade deficit was \$9 million and therefore domestic revenues were \$554 million.

Number of Employees: The number of employees directly involved in sulphuric acid production is small in relation to total employment by companies in the industry. Based on estimates obtained from company representatives 250 employees can be attributed to the production of sulphuric acid in Canada.

7.7 Summary

The preceding chapter has described the use of sulphuric acid as an alternative to the use of hydrochloric acid (HCl) in steel pickling. In 1993, 30 kilotonnes of hydrochloric acid were used in steel pickling, as compared to 20 kilotonnes of sulphuric acid. The trend is towards an increasing use of hydrochloric acid, due to waste disposal problems with sulphuric acid, and an inability to regenerate the acid. In contrast to sulphuric acid up to 98% of hydrochloric acid can be re-generated, although 60% recovery is reflective of the industry as a whole.

The substitution model for HCl in steel pickling assumes that it is replaced by sulphuric acid. The cost savings from substitution are \$2 million in annual operating costs, while the direct replacement costs are \$2 million in additional capital costs. An additional \$48 million are required to dispose of a greater amount of spent sulphuric acid liquor, that would not be regenerated. Converting capital costs to annual costs generates total annual cost savings of \$46.2 million. This represents less than 0.5% of total revenues from steel production (\$10.1 billion).

Using the measure of domestic revenues indicates that sulphuric acid is a larger part of the economy than hydrochloric acid. Table 7-6 summarizes the socio-economic profiles.

Table 7-6: Socio-economic Profiles for Acids

	Hydrochloric Acid	Sulphuric Acid
Domestic Sales (\$ million)	22	563
Trade Balance (\$ million)	7	(9)
Domestic Revenues (\$ M)	29	554
Employment	131	250
Employment/ Domestic Revenues	4.5	0.4

7.8 Contacts and References

7.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Brunswick Mining and Smelting
- Canada Colours and Chemicals
- Cominco Ltd.
- Falconbridge and Kidd Creek Mines
- Inco Ltd.
- Marsulex Inc.
- Noranda
- Sherritt Inc.
- Stelco Inc.
- Zinc Electrolitique du Canada

7.8.2 References

Environment Canada. 1995. Steel Manufacturing Sector Strategic Options Process Plan. Document Prepared for the Steel Issue Table. Steel Section of the Mining, Minerals and Metals Division, Industrial Sectors Branch. Pollution Prevention Directorate, Environment Canada, Hull.

8. Hydrochloric Acid Used In Choline Chloride Production

8.1 Introduction

One of the largest uses of hydrochloric acid is in the production of choline chloride. Choline chloride production accounts for approximately 9 of the 84 kilotonnes of merchant hydrochloric acid used in Canada in 1993.

Choline chloride is the most common form of commercially available choline for the animal feed industry. Choline is an essential component in building plant and animal cell membranes and as such is used as an important dietary supplement for poultry and some livestock. A small amount is also used for human nutrient supplements. Chickens, turkeys, game birds, swine and other non-ruminative livestock require feeds containing choline in levels ranging from 0.05% to 0.2% of feed weight to achieve optimum growth, particularly in the early growth phase. Choline is a necessary requirement to maintain current day commercial production levels of poultry and swine. The absence of choline would lead to drastically reduced growth rates, longer growth periods, smaller animals, and lower yields.

Three alternative commercial chemicals providing the same choline vitamin nutrient are: choline bitartrate (CBT), choline dihydrogen citrate (CDC) and cytodine diphosphate choline (CYDC). Only the first two alternatives have US certification as feed ingredients. All of these alternatives are produced in small quantities in food grade form for human vitamin and medicinal uses. Of these three alternatives, choline bitartrate is the only chemical with a significant commercial volume. It will be considered as the best currently available alternative to choline chloride.

This chapter will assess choline chloride through five sections; market analysis, technical description, cost of substitution, cost of substitution compared to end-use revenues, and socio-economic profile. The socio-economic profile will contain information on production, imports and exports, revenues and manufacturing employment.

8.2 Market Analysis

Over 95% of choline chloride is sold as unrefined feed grade which is combined in pre-mixes and animal feeds. About two-thirds of this choline chloride is used for poultry feed with swine feed making up the bulk of the remainder. The remaining 5% of choline chloride

is refined further to the higher purity food grade (pharmaceutical grade) which is used for preparation of vitamins, nutrient supplements and infant formula. Choline chloride also has minor uses as a catalyst, a curing agent and neutralizing agent. Demand in these applications is very low.

Choline chloride dominates the market for choline sources in animal feed. Commercially available alternatives (CBT, CDC, CYDC) are produced in small quantities, primarily for human food and vitamin supplements.

8.3 Technical Comparison

Choline chloride is manufactured by the reaction of hydrochloric acid with trimethylamine and ethylene oxide to form the hydrochloride of choline. Since the product is deliquescent (absorbs water readily), it is commonly produced in a 70% liquid solution. Many large feed plants have liquid solution choline chloride delivered by truck. A slightly stronger 75% solution is sometimes available, but is prone to precipitation in cool weather. A more common form of choline chloride is the 60% dry concentrate. The liquid solution is dehydrated and applied onto a ground corn cob meal base at separate conversion plants.

Choline chloride is the least expensive, easily handled form of choline. Choline alone has a pH of 14 and is highly flammable. The chloride salt has a neutral pH and is easy to handle. Since hydrochloric acid is such a low molecular weight acid, the salt form of choline chloride is advantageous because it yields a high proportion (87%) of choline in the total weight. As a comparison, the weight of choline chloride required to apply a certain amount of nutrient is about half that of choline bitartrate.

Choline bitartrate is prepared from tartaric acid, which is derived naturally from unrefined wine sediment or synthetically from maleic anhydride and hydrogen peroxide. Choline bitartrate is just as effective as choline chloride in releasing choline and providing the same metabolic functions. The presence of the tartrate is safe for ingestion, but may mean that a slight reformulation of the pre-mix or final feed is required. Generally, the amounts are too small to have any significant effect.

The major issue with any choline salt alternative is finding the supply of the raw materials to produce the equivalent volumes of choline. Since the tartrate radical is a large molecule, it makes up about 60% of the weight of choline bitartrate. The amount of tartaric acid required to produce choline bitartrate in Canada would be about 25 kT. This is currently not available and means that additional maleic acid and hydrogen peroxide

volume would be required. Table 8-1 lists these and other technical characteristics of CC and CBT.

Table 8-1: Technical Comparison of Choline Chloride and Choline Bitartrate

	Choline Chloride	Choline Bitartrate
Choline Content	<ul style="list-style-type: none"> • 87% 	<ul style="list-style-type: none"> • 46%
Amount of 60% dry form required for 1000 ppm dose	<ul style="list-style-type: none"> • 1923 mg/kg feed 	<ul style="list-style-type: none"> • 3600 mg/kg feed
Odour	<ul style="list-style-type: none"> • fishy 	<ul style="list-style-type: none"> • faint trimethylamine
Taste	<ul style="list-style-type: none"> • salty, bitter 	<ul style="list-style-type: none"> • acid
Absorbency	<ul style="list-style-type: none"> • extremely hygroscopic 	<ul style="list-style-type: none"> • highly hygroscopic
Adaptability		<ul style="list-style-type: none"> • effective; reformulation required
Raw Material Handling	<ul style="list-style-type: none"> • chlorine liquid: easy 	<ul style="list-style-type: none"> • solid tartaric acid: requires dissolution
Raw Material Supply	<ul style="list-style-type: none"> • readily available 	<ul style="list-style-type: none"> • low tartaric acid supply

8.4 Direct Replacement Cost

The direct replacement cost for hydrochloric acid by tartaric acid in choline chloride production is about \$199 million per year, as shown in Table 8-2. The model of substitution for choline chloride assumes complete replacement by choline bitartrate at the sole plant in Canada manufacturing choline chloride, the Chinook plant in Sombra, Ontario.

There is no commercially available feed grade choline bitartrate. In this scenario, it is assumed that feed grade choline bitartrate can be produced with the current Canadian production facilities. A small amount of investment in handling and solution tanks for the single Canadian plant would be required to handle the solid tartaric acid raw material. It is assumed the supply of tartaric acid can be made available at current price levels.

In the reaction required to produce CBT, tartaric acid reacts with trimethylamine and ethylene oxide instead of hydrochloric acid. The 33 kT of choline chloride production in 1993 required about 9 kT of hydrochloric acid as a raw material. To achieve the equivalent volume of choline, but in the bitartrate form, about 38 kT of tartaric acid is required, since

the tartaric acid molecule ($C_4H_6O_6$) has a high molecular weight (150) compared to chlorine (35). The price of tartaric acid has ranged from \$4,800 to 6,000 per tonne over the last few years. A value of \$5300 per tonne was chosen for purposes of comparison. This is substantially higher than the \$263/tonne average price of hydrochloric acid raw material.

Table 8-2: Direct Replacement Cost

	Hydrochloric Acid	Tartaric Acid	Difference
Volume (kT)	9	38	
Price (\$/T)	263	5300	
Value (\$M)	2	201	199

Source: CHEMinfo Services

8.5 Direct Replacement Cost Compared to End-Use Revenues

The direct replacement costs (\$199 million) represent 252% of estimated domestic revenues associated with choline chloride sales (\$79 million).

8.6 Socio-Economic Profile

The socio-economic profile of hydrochloric acid production was provided in Chapter Two. Domestic revenues from hydrochloric acid production are estimated at \$29 million, with employment estimated at 255 people.

8.6.1 Choline Chloride

Plants and Producers: There is only one Canadian producer of choline chloride. The privately-owned Chinook Group has a liquid choline chloride plant in Sombra, Ont., just south of Sarnia. Harcos Chemicals toll processes choline chloride for Chinook in its Kansas City ethylene oxide plant. Apart from direct shipments to pre-mix and feed companies, liquid choline chloride is shipped from Sombra to Chinook plants in Morrisburg, ON (15 kT/yr capacity) and North Branch, MN (25 kT/yr capacity) for conversion to the 60% dry form.

Production and Capacity: In 1993, production at Chinook was estimated at 33 kT, out of 35 kT capacity. Production at Chinook is equivalent to 60% of the North American demand for choline chloride.

Imports and Exports: Imports are negligible. Exports totalled 30 kT in 1993, mostly to the US with minor volumes to the Far East and Europe.

Revenues: Based on a price of \$2.40 per kilogram, domestic revenues are estimated at \$79 million. The value of domestic sales is estimated at \$7 million, with a trade surplus of \$72 million.

Manufacturing Employment: Manufacturing employment is estimated at 70 people.

8.6.2 Choline Bitartrate

Imports and Exports: No commercial manufacturing activity was identified in Canada. All domestic requirements for choline bitartrate are met by imports and usually handled by chemical distributors, which sell a broad range of products. There are no exports of choline bitartrate.

8.7 Summary

Choline chloride production uses approximately 9 of 84 kilotonnes of hydrochloric acid used in Canada in 1993. Choline chloride is used primarily as a choline source in poultry and swine feed. While other choline sources are available (ex. choline bitartrate) none compete with choline chloride in the animal feed market.

The direct replacement cost of choline bitartrate production for choline chloride production at the sole plant in Canada manufacturing choline chloride is estimated at \$199 million. This represents approximately 252% of the domestic revenues associated with choline chloride production (\$79 million). Table 8-3 summarizes the socio-economic information.

Table 8-3: Summary of Socio-economic Profile

Variables	Choline Chloride
Value of Domestic Sales (\$ million)	7
Trade Balance (\$ million)	72
Domestic Revenues (\$ million)	79
Manufacturing Employment	70
Manufacturing Employment/ Domestic Revenues	0.8

8.8 Contacts and References

8.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Chinook Chemicals

PART TWO

POLYVINYL CHLORIDE

9. PVC Industry

9.1 Introduction

Polyvinyl chloride (PVC) is a polymer that is used in the manufacture of many products, primarily construction materials, but also many consumer goods. PVC products are the final link in a production chain which extends from ethylene dichloride (EDC), and vinyl chloride monomer (VCM) production, through the production of PVC resin and compound, to the end-use PVC products such as pipe, windows, bottles, etc. In contrast to the base commodities discussed in the previous chapter, which are predominantly primary chemicals, PVC products are intermediate and end-use goods. End-use refers to products bought by consumers or exported¹.

The intermediate and end-use nature of PVC products implies that, in general, a selection of alternatives to PVC products will not generate changes in the production process for end use products, but material substitution in the type of products bought by producers and consumers. For example, municipalities always require use of water pipe, but have a choice between buying PVC water pipe and other types of water pipe (i.e. HDPE, ductile iron).

This chapter will describe the links in the PVC production chain, and summarize the socio-economic information on PVC products, and alternatives, contained in the following chapter, Chapter 10. Chapter 10 consists of the detailed technical and socio-economic assessment of the individual PVC products, including: market analysis, technical characteristics, direct replacement cost, direct replacement cost compared to end-use revenues, and socio-economic profiles of PVC products, and alternatives to those products.

9.2 PVC Production Chain

As described in Chapter 2, the PVC production chain begins with the production of ethylene dichloride (EDC) and vinyl chloride monomer (VCM). Dow Chemical Canada operates the only plant in Canada manufacturing these two primary goods in Fort Saskatchewan, Alberta. In 1993, total production of EDC was 994 kilotonnes, while VCM production was 428 kilotonnes. Production levels are expected to be relatively stable from

¹ PVC products are both end-use products, and intermediate goods, notably in construction. For example PVC siding is both an intermediate good when incorporated in the value of a new house, and an end-use or final good when bought by a home owner as a replacement for old siding.

1993 to 2000. The difference in production levels reflects the substantial export of EDC (256 kilotonnes), while VCM is produced primarily for the domestic market.

For the purposes of this report, the domestic revenues associated with these primary goods will be defined as the sum of the trade balance (exports-imports) for EDC (\$70 million) and VCM (\$ - 4 million). The trade balance for these two products is \$66 million. Domestic sales of VCM (\$209 million) are not included in domestic revenues since the value of these sales is incorporated in the value of PVC end-use products.

It is estimated that about 200 employees are employed in the production of EDC and VCM at the Dow plant in Fort Saskatchewan, Alberta. This represents approximately 15% of the 1350 people employed at the Fort Saskatchewan plant.

9.2.1 PVC Resin

The second step in the manufacture of PVC products is the manufacture of PVC resin from VCM. PVC resin is manufactured through the polymerization of VCM at 3 plants in Canada (See Table 9-1) by two different processes: suspension polymerization at the two Ontario plants, and bulk polymerization at the resin plant in Alberta.

Table 9-1: PVC Resin Plants, Location and Capacity, 1993

Company	Location	Capacity (kilotonnes)
The Geon Co.	Niagara Falls, Ontario	200
The Geon Co.	Fort Saskatchewan, Alberta	100
Imperial Oil Ltd.	Sarnia, Ontario	150
Total		450

Source: CHEMinfo Services

Production, Import and Exports: Table 9-2 lists the production, trade and demand for PVC resin. In 1993, PVC production was 419 kilotonnes, or 93% of capacity. Imports (147 kilotonnes) slightly exceed exports (115 kilotonnes) generating a trade deficit of 32 kilotonnes.

Table 9-2: PVC Resin Supply and Demand Balance, 1993

	Kilotonnes	% of Total Supply
Capacity	450	
Production	419	
Imports ²	147	26%
Total Supply	566	100%
Domestic Consumption	451	80%
Exports	115	20%
Total Demand	566	100%

Source: CHEMinfo Services

Revenues: The 1988-1993 average price for PVC resin is estimated at approximately \$894 a tonne. Thus the annual value of domestic sales, based on 1993 production levels, is approximately \$403 million dollars. Domestic revenues for PVC resin are defined in this study as equivalent to the trade balance, since the value of domestic sales is incorporated in the value of PVC final products, covered in Chapter 10. The trade deficit (exports minus imports) for PVC resin was approximately \$26 million in 1993.

Employment: Based on estimates provided from industry suppliers, approximately 315 employees are attributed to the production and sales of PVC resin in Canada.

9.2.2 PVC Compound

The next stage in the PVC production chain is the manufacture of PVC compounds from PVC resin. This process may be carried out by specialized custom compounders, or internally within PVC final products firms. Fabricators of pipe, siding, windows, or other high volume PVC products will typically compound resins in house. Firms requiring low volumes of PVC, or needing many grades and varying additive levels will tend to purchase compound from custom compounders. An example of PVC product manufacturers who rely on custom PVC compounders are wire and cable firms.

Compounding refers to mixing additives and fillers with PVC resin, in order to aid processing, improve functional performance, add aesthetic appeal, or decrease production costs. Table 9-3 contains examples of additives used in formulations for rigid and flexible PVC products.

² Imports and exports include PVC resin contained in imported and exported PVC compound.

Table 9-3: Common Additives Used for PVC and Other Polymers

Additive Group	Main Function	Examples
Antimicrobials	Protect against microbial degradation	10, 16-oxybisphenol arsine (OBPA), 2-n-octyl 1-4-isothiazolin - 3 one, N-(trichloromethylene) phthalimide
Antioxidants	Reduce oxidative degradation	Phenolics - butylated hydroxy toluene, Organophosphites
Antistatic agents	Reduce excess build-up of electric charge	Ethoxylated fatty amines, Long chain alkyl quaternary ammonium, Polymeric antistats
Blowing agents	Promote foamed polymeric structures	Bicarbonate, Citric acid, Azodicarbonamide, 5-phenyltetrazole
Coupling agents	Improve bonding in polymer, filler, reinforcement matrix	Silanes, titanates
Colourants	Provide colour	Inorganic pigments - i.e. titanium dioxide, iron oxide, Organic dyes - Azo, perinone, quinoline, anthraquinone
Flame retardants	Reduce rate of combustion and ignition potential	Brominated hydrocarbons, Phosphate esters, Chlorinated hydrocarbons, Aluminum trihydrate, Antimony trioxide
Heat stabilizers	Reduce thermal degradation at elevated temperatures	Lead, Barium/cadmium metal salts (soaps), Organotin mercaptides, maleates
Impact modifiers	Improve impact resistance, increase toughness	Acrylonitrile-butadiene-styrene (ABS), Methacrylate-butadiene-styrene (MBS), Ethylene vinyl acetate (EVA)
Lubricants	Reduce internal and external friction in molten polymer (during processing)	Metallic (i.e. calcium, zinc) stearates, Fatty acids, Fatty alcohols
Mold release agents	Reduce sticking of polymer to mold cavities	Silicones, Fluoropolymers, Metallic soaps, Waxes, Amides, HCFCs,
Cross linking agents	Promote polymerization, crosslinking, curing	Organic peroxides (i.e. Alkyl, dialkyl, hydrogen, ketone, and peroxyester peroxides)
Plasticizers	Provide flexibility to final products, enhance processability	Phthalate esters (i.e. dioctyl phthalate-DOP), Adipates, Benzoates
UV stabilizers	Reduce light degradation	Benzophenones (i.e. 2-hydroxy-4-n- octoxy benzophenone) Benzotriazole (i.e. 2-(2-hydroxy-5-t-octylphenyl) benzotriazole Hindered amines (HALS), Organo-nickel compounds
Fillers & extenders	Enhance thermal or mechanical properties, reduce cost	Non-metallic minerals (i.e. talc, calcium carbonate, kaolin, silica)

Source: Modern Plastics Encyclopedia, McGraw Hill, Highstown, NJ, Editions 1995, 1994, 1993, 1986, CHEMinfo Services)

The amount and type of additive used is dependent on resin grade, processing technology, performance quality and final product application. Plasticizers are added to the resin to create flexible products such as flooring, vinyl sheeting and stretch films. Rigid products, such as piping, siding and window profiles, do not contain plasticizers.

Plants: Table 9-4 lists the major PVC compounding plants in Canada. Synergistics Inc. is the largest PVC custom compounder.

Table 9-4: Major PVC Compounding Firms

Company	Location
Synergistics Inc.	Orangeville, ON
Synergistics Inc.	St. Remi, PQ
A. Schulman Canada	Mississauga, ON
A.W. Compounders	Stoney Creek, ON
CCC Plastics (Canada Colors)	Don Mills, ON

Source: CHEMinfo Services.

Production, Imports and Exports: An estimate of the amount of PVC resin that is used in the domestic manufacture of merchant PVC compound is 40-50 kilotonnes, or approximately 9% of total PVC resin supply. Table 9-5 describes the merchant market for PVC compound in 1993. Imports (70 kT) exceed exports (10 kT) generating a net trade deficit of 60 kilotonnes.

**Table 9-5: PVC Merchant Compound, Supply and Demand
Balance, 1993**

	Kilotonnes	% of Total Supply
Capacity	n.a	n.a
Production	90	56%
Imports	70	44%
Total Supply	160	100%
Domestic Consumption	150	94%
Exports	10	6%
Total Demand	160	100%

Source: CHEMinfo Services

Revenues: Prices for PVC compound are difficult to estimate as they will vary considerably depending on the specific application for which the PVC compound is formulated. An estimated average price for PVC compound would be approximately 60% more expensive than the price for PVC resin, or \$1,334 per tonne. Using this price the value of domestic sales for merchant PVC compound is approximately \$200 million.

Domestic revenues for PVC compound are defined in this study as equivalent to the trade deficit³ for merchant PVC compound, since the value of domestic sales is incorporated in the value of PVC final products. The trade deficit (exports - imports) is approximately \$80 million dollars.

Employment: Based on estimates obtained from company representatives, approximately 415 employees are involved in the PVC compounding business in Canada.

9.3 PVC Precursors Summary

Table 9-6 summarizes the principal indicators of the importance of PVC precursors to the Canadian economy: domestic revenues and employment. Domestic revenues from PVC precursors are defined in this study as only equivalent to their trade balances, since the value of domestic sales is incorporated in the value of PVC products. PVC products will be discussed in the following section. PVC precursors are estimated to have an annual trade deficit of \$40 million in 1993.

Table 9-6: Domestic Revenues from PVC and Precursors

PVC Precursors	(Trade Balance)	Employment
EDC,VCM	66	250
Resin	(26)	315
Compound	(80)	415
Total	(40)	980

³ An exception was made in the case of PVC compound used in wire and cable manufacture. In this case the PVC compound will be considered as the PVC product. This occurs as wire and cable producers commonly mix PVC, other polymers (ex. PE), as well as metals in any given type of wire and cable.

9.4 PVC Products Summary

This section will summarize the detailed evaluation of individual PVC product markets contained in Chapter 10. Table 9-7 below lists the PVC products and alternatives analyzed in Chapter 10 and the proportion of total PVC resin accounted for in these products. Since the range of products manufactured using PVC is so large, it is not practical to evaluate all PVC products. The method used is to choose the major PVC products in each application area, as listed below. These products account for approximately 90% of all PVC resin use in Canada.

Table 9-7: PVC Products and Alternatives

PVC Product	PVC Resin Use (kT) ⁴	(%)	Alternatives to PVC
Municipal Water and Sewer Pipe	91	20	Ductile iron, Concrete, HDPE
Other Pipe (e.g. Drainage)	48	11	HDPE, ABS, Copper/Iron
Siding	100	22	Aluminum, Brick
Window Profiles	69	15	Aluminum, Wood
Wire and Cable	29	6	PE, TPE, XLPE
Flooring	12	3	Polyolefin, Carpet, Ceramic tile
Food Wrap	14	3	PE
Plastic Bottles	4	1	PET, PE
Rigid Plastic Sheet - Packaging	12	3	PET, OPS
Flexible Plastic Sheet - Vehicle Trim	14	3	Fabric, TPOs, TPUs
Flexible Plastic Sheet - Pool Liners	6	1	TPE, Concrete, Fibreglass
Other	52	11	
Total	451	100	

Plastics Acronyms:

PE - polyethylene

PET - polyethylene terephthalate)

TPE - thermoplastic elastomer

HDPE - high density polyethylene

ABS - acrylonitrile-butadiene-styrene

TPO - thermoplastic olefin

XLPE - cross-linked polyethylene

OPS - oriented polystyrene

TPU - thermoplastic urethane

9.4.1 Market Share of PVC Products and Alternatives

In general, both the largest uses of PVC resin, and those applications with increasing PVC market share, are related to construction, particularly pipe, siding and windows. Much of the market acceptance of PVC products stems from its competitive cost characteristics where they are generally, but not exclusively, less expensive than alternatives. In some applications, technical factors partially account for increasing use of PVC products. Some

⁴ PVC resin use refers to kilotonnes of resin use in domestic manufacturing.

examples are non-corrosivity (pipe), ability to produce flexible compounds (wire & cable, film, sheet), and fire retardancy (commercial DWV pipe, wire and cable). A slight declining trend is observed in PVC flooring, flexible sheet used in car upholstery, and bottles, which is due mostly to competition from alternatives having higher aesthetic appeal.

Table 9-8 describes market share and trends in the use of PVC products and alternatives. A **high** market share refers to a market share over 70%, a **medium** market share to a market share between 30 and 70%, and a **low** market share refers to a market share under 30%. Trend refers to the trend in the use of the PVC product, with the description referring to the direction of the trend. For example strong, down refers to a strong, downward trend.

Table 9-8: Market Shares and Trends of PVC Products

PVC Products and Applications	Share (PVC)	Alternative Product (1)	Share (alt 1)	Alternative Product (2)	Share (alt 2)	Trend in PVC use
Water Pipe	Medium	HDPE	Low	Ductile iron	Low	Slight up
Sewer Pipe	Medium	HDPE	Low	Concrete	Medium	Slight up
Drainage Pipe	Low	HDPE	Medium	Concrete	Medium	Stable
DWV (Drain, Waste, Vent) pipe	Low	ABS	Medium	Copper/ Cast Iron	Medium	Slight up
Other Pipe (Industrial)	Medium	HDPE	Medium	HDPE	Medium	Stable
Siding	High	Aluminum	Low	Clay brick	Low	Slight up
Window Profiles	Medium	Wood	Medium	Aluminum	Low	Strong up
Flooring	Low	Polyolefin	Low	Ceramic tile, Carpet	Low	Slight down
PVC Compound, Wire and Cable	Medium	PE, XLPE, TPE	Low			Slight down
Food Wrap	High	PE	Low			Stable
Plastic Bottles	Low	PET	High	HDPE	Low	Slight down
Rigid Sheet, Thermoformed Packaging	High	PET	Low	OPS	Low	Stable
Flexible Sheet, Vehicle Trim	Low	Fabric	High	TPOs, TPUs	Low	Slight down
Flexible Sheet, Swimming Pools	High	Concrete	Low	Fibreglass	Low	Slight up

9.4.2 Direct Replacement Cost

For PVC products, direct replacement costs are primarily annual differences in material and labour costs, rather than changes in production technology. For example, municipalities continue to use water pipe, but have choices between buying PVC water pipe and other types of water pipe. The capital costs involved in plant investment in alternatives in order to meet the additional demand of substituting for PVC products are assumed to be incorporated in the price of the alternate materials, thus, in most cases, the capital costs are relatively small. Table 9-9 describes the direct replacement costs by PVC application.

Table 9-9: Direct Replacement Costs for PVC Products
(\$ million, 1993)

PVC Products	Alternatives	Low Cost Alternative				High Cost Alternative			
		Capital	Ann. Cap.	Ann. Oper.	Total Annual	Capital	Ann. Cap.	Ann. Oper.	Total Annual
Water Pipe	HDPE (low), Ductile Iron (high)	0	0	20	20	0	0	20	20
Wastewater Pipe	HDPE (low), Concrete (high)	0	0	29	29	0	0	51	51
Drainage Pipe	HDPE (low), Concrete (high)	0	0	0	0	0	0	9	9
DWV pipe	ABS (low) Copper/Iron (high)	0	0	0	0	0	0	21	21
Other Pipe	HDPE	0	0	(5)	(5)	0	0	(5)	(5)
Siding	Aluminum (low), Clay brick (high)	0	0	80	80	0	0	1253	1253
Window Profiles	Wood (low), Aluminum (high)	0	0	(118)	(118)	0	0	55	55
Flooring	Polyolefin (low); Cer. tile/ Carpet (high)	0	0	338	338	0	0	426	426
PVC Cmpd; Wire & Cable	PE, XLPE, and TPE	70	8	173	181	70	8	173	181
Food Wrap	PE	0	0	(9)	(9)	0	0	(9)	(9)
Plastic Bottles	HDPE (lo), PET (hi)	10	1	(3)	(2)	14	1	2	3
Rigid Sheet	OPS/PET	0	0	6	6	0	0	6	6
Flexible Sheet, Vehicle Trim	Fabric /TPO (low), Fabric /TPU (high)	0	0	25	25	0	0	60	60
Flexible Sheet, Swimming Pools	TPE (low), Concrete (high)	0	0	8	8	0	0	100	100
Total		80	9	544	553	84	9	2162	2171

The annual low direct replacement cost estimate for PVC products is \$553 million/year. The largest costs are the direct replacement costs for PVC flooring (\$338 million/yr) and wire and cable (\$181 million/yr). PVC flooring, especially low-cost vinyl composition tile, dominates the low-cost flooring market and the recently-developed polyolefin alternative has a higher price. The alternative materials to PVC for wire and cable are expensive, involving fire resistant compounds and flexible thermoplastic elastomers.

The high cost estimate for PVC products is \$2171 million/yr. The magnitude of the high cost estimate for PVC products is largely due to the selection of relatively expensive clay-brick as the high cost alternative (\$1253 million/year) in PVC siding.

9.4.3 Direct Replacement Costs Compared to Domestic Sales

A comparison of the direct replacement cost to domestic sales revenues at end use is used to place the costs in context. An end-use is the product either bought by a consumer or exported. The closest analogy to the ratio of the direct replacement cost to end-use revenues is that of a price increase in the end-use market.

PVC products are both intermediate and end-use goods. For example, PVC siding is an intermediate good when used in the construction of a new residential home, and an end-use good when bought by a home owner. In order to account for this problem, two measures will be used. The first is a comparison of the direct replacement cost to total revenues generated in the markets for PVC products. For example, the direct replacement cost for PVC siding will be compared to the value of the total siding market for 1993.

The second is a comparison of the direct replacement cost for selected PVC intermediate goods to the value of the end-use products in which they are incorporated. For example, the direct replacement costs for siding in new construction will be compared to the total value of new domestic construction in 1993. For simplicity, this measure will include the following end uses; water supply and sewage (water and sewer pipe), construction (siding, windows, wire and cable, flooring), and automobiles (vehicle trim). In general, the other end-use markets for PVC products are too fragmented to analyze. For example, all of the consumer products which incorporate PVC packaging (e.g. thermoformed rigid packaging, plastic bottles, food wrap) are too fragmented to provide any comparison.

9.4.3.1 Direct Replacement Cost Compared to Total Market Value

Table 9-10 compares the direct replacement costs with the market value of PVC products and alternatives. In total, the direct replacement costs represent 6% of the value of product markets based on the low cost estimate, and 23% based on the high cost estimate. None of the low cost estimates is greater than 11% of the total market value. The three highest

ratios are for substitutions with polyolefin for PVC flooring (11%), a variety of polymers for PVC in wire and cable (11%) and aluminum for PVC siding (10%). Markets exhibiting cost savings at the low cost estimate are: Other Pipe (drainage, DWV, conduit) (1%), window profiles (10%), food wrap (11%) and plastic bottles (1%). The clay-brick alternative for siding and the concrete swimming pool alternative for pool liners have high cost ratios of 152% and 65%, respectively.

Table 9-10: Direct Replacement Cost Compared to Total Sales Value
(\$ millions, 1993)

PVC Products	Alternatives	Direct Replacement Cost (Low)	Direct Replacement Cost (High)	Total Market Value	Ratio (Cost to Market Value)
Municipal Water and Sewer Pipe	HDPE (low), Ductile Iron and concrete (high)	49	71	1280	4% (low), 6% (high)
Drainage, DWV, Other Ind. Pipe	HDPE, ABS (low), Conc, Copper, HDPE (high)	(5)	25	668	(1%) (low), 4% (high)
Siding	Aluminum (low), Clay brick (high)	80	1253	823	10% (low), 152% (high)
Window Profiles	Wood (low), Aluminum (high)	(118)	55	1200	(10%) (low), 5% (high)
Flooring	Polyolefin (low) Cer. tile/Carpet (high)	338	426	3000	11% (low), 14% (high)
Wire and Cable, PVC Compound	PE, XLPE, TPE	181	181	1600	11%
Food Wrap	PE	(9)	(9)	84	(11%)
Plastic Bottles	HDPE (low) PET (high)	(2)	3	225	(1%) (low), 1% (high)
Rigid Sheet, Packaging	OPS/PET	6	6	104	19%
Flexible Sheet, Vehicle Trim	Fabric/TPO (low), Fabric/TPU (high)	25	60	497	5% (low), 12% (high)
Flexible Sheet, Swimming Pools	TPE (low) Concrete (high)	8	100	154	5% (low), 65% (high)

9.4.3.2 Direct Replacement Costs Compared to End Use Revenues

Table 9-11 compares the direct replacement costs for selected PVC intermediate goods to the value of certain end-use sectors, which could be identified and quantified. In the construction sector, it is assumed that 60% of sales are associated with new residential construction, thus the direct replacement costs for siding, windows, flooring that appear in the table below have been reduced by 40% to compare on the same basis. In the wire and cable comparison, only the residential portion of PVC wire market (10%) was examined.

Table 9-11: Direct Replacement Cost Compared to End-Use Revenues (\$ million, 1993)

PVC Products	Direct Replacement Cost, Low	Direct Replacement Cost, High	End Use	Value of End Use Sales	Ratio (Cost over End-Use)
Municipal Pipe	49	71	Water and Sewage	3283	1.5% (low) 2.2% (high)
Vehicle Trim	25	60	Automobiles and Auto Parts	41734	0.04% (low) 0.1% (high)
Siding	48	752	New Residential Construction	42884	0.1% low 1.8% high
Windows	(71)	33	New Residential Construction	42884	(0.2%) low 0.1% high
Flooring	203	256	New Residential Construction	42884	0.5% low 0.6% high
Wire and Cable *	10	10	New Residential Construction	42884	0.02%
Total Construction	190	1050	New Residential Construction	42884	0.4% low 2.4% high
Total	264	1181		110280**	0.2% low 1.1% high

* direct replacement cost of 10% of the 58 kT of PVC compound used in residential building wire

** The total figure does not equal the sum of all listed numbers, because double counting is eliminated.

For the PVC products selected, the low cost estimate is 0.2% of revenues, while the high cost estimate is 1.1%. Using the low cost estimate, the highest ratio is for pipe used in municipal water and wastewater at 1.5% of revenues. Cost savings are shown in windows used in residential construction (0.2%), where the substitute material is wood. Using the high cost estimate, the highest ratio is the aggregate direct replacement costs for PVC used in construction, at 2.4% of the value of new residential construction. The largest

individual ratios for those selected PVC products used in construction are siding (1.8%) and flooring (0.6%), where the substitute materials are clay-brick and a combination of ceramic tile and commercial carpeting respectively.

9.4.4 Revenues From the PVC Industry

The revenues derived from the sale of products is another measure of the importance of the PVC industry, and alternatives, to the Canadian economy. Two different measures of revenues will be used:

- a) the value of domestic sales; and
- b) the value of domestic revenues, where domestic revenues are defined as: value of domestic sales + value of exports - value of imports. The value of exports - imports will be referred to as the trade balance. Domestic revenues are equivalent to the value of shipments (or production) referenced in Statistic Canada publications.

Both of these measures are useful indicators: a) describes the value of sales in domestic markets for PVC products; and b) describes the value of domestic industrial activity associated with production, by incorporating trade information.

Two methods for assessing the relative importance of the PVC industry will be used:

- a) a comparison of revenues of PVC and alternatives in markets where PVC and alternative products compete directly.
- b) a ranking of the PVC industry with industries which supply competing products to PVC products, as well as other products.

In order to rank the relative importance of the PVC industry, an appropriate comparison is with other large, integrated industrial sectors. These other sectors may supply one or more alternatives to PVC products, as well as many other products. For example, the aluminum industry provides alternatives to some PVC applications (e.g. windows, siding), along with many other applications of aluminum products. Using this measure allows a comparison of the economic importance of the PVC industry to industries which supply similar products to those of the PVC industry.

9.4.4.1 Comparison of PVC and Alternative Product Revenues, by Market

Table 9-12 compares the revenues of the PVC products studied to directly competing alternatives. The value of domestic revenues for PVC products is \$1.9 billion compared to \$2.2 billion for alternatives to PVC products. The PVC products industry exhibits a trade surplus of \$45 million, compared to a trade deficit of \$719 million for alternative products.

Table 9-12: Domestic Sales, Trade and Revenue for PVC Products and Alternatives
(\$ million, 1993)

PVC Products	PVC			Alternative Products	Alternatives		
	Domestic Sales	Trade Balance	Domestic Revenues		Domestic Sales	Trade Balance	Domestic Revenues
Pipe	329	29	358	HDPE, Ductile Iron, Concrete, ABS	339	5	344
Siding	161	42	203	Aluminum, Clay brick	118	6	124
Window Profiles	463	93	556	Wood, Aluminum	786	(4)	782
Flooring	468	(108)	360	Polyolefin, Tile & Carpet	1034	(295)	739
Wire and Cable, PVC compound ⁵	100	0	100	XLPE and TPE	59	(46)	13
Food Wrap	68	0	68	PE	16	(5)	11
Bottles	15	0	15	HDPE, PET	210	10	220
Rigid Sheet	31	2	33	OPS, PET	73	(73)	0
Flexible Sheet	185	(13)	172	Fabric /TPOs, TPUs	317	(317)	0
Total	1820	45	1865	Total	2952	(719)	2233

⁵ The trade balance for merchant PVC compound is found in Section 9.2.3.

9.4.4.2 Ranking of PVC and Alternative Industry Sectors by Domestic Revenues

In order to rank the PVC industry in terms of comparable industrial sectors which provide one or more alternatives to PVC products, estimates of domestic revenues were derived from Statistics Canada data on the value of shipments, imports and exports in 1993. The methodology used to create comparable industrial sectors is described in Section 9.6. In comparing the PVC industry to other sectors, the PVC industry ranks fifth out of six industry sectors which provide options to PVC products. Table 9-13 lists the ranking of industrial sectors by domestic revenues.

Table 9-13: Ranking of Industries Supplying Alternatives to PVC Products

Rank	Industry Sectors	PVC Product Alternatives	Domestic Sales (\$ million/yr)	Trade Balance (\$ million/yr)	Domestic Revenues (\$ million/yr)
1	Wood Products	Windows, Siding, Flooring	8776	10307	19083
2	Plastic Products other than PVC	Pipe, Wire and Cable, Food Wrap, Bottles, etc	5434	(779)	4655
3	Aluminum Metal Products	Siding, Windows	4097	(390)	3707
4	Textile Products	Flooring, Vehicle Trim	3435	(679)	2876
5	PVC Plastic Products ⁶		2022	50	2072
6	Concrete Products	Sewer Pipe	817	0	817
	Total Alternatives		22679	8459	31138

9.4.5 Employment

The comparison of employment in PVC products and alternatives will use the same approach as for revenues. Initially, employment related to PVC products will be compared with employment in alternatives to PVC products, in specific markets. A proxy for labour intensity will be estimated as the ratio of employees to domestic revenues. A second measure will rank employment in the PVC industry with employment in the other large integrated industrial sectors supplying options to PVC products.

⁶ Since the domestic sales, trade and revenues in Table 9-12 represent only about 90% of the PVC industry, the total PVC industry numbers are estimated by multiplying these numbers by 1/0.9 (1.11).

9.4.5.1 Comparison of PVC and Alternative Product Employment, by Market

Employment related to the PVC products studied is estimated at approximately 5,740 people, compared to employment of 12,983 people in alternative industries. Table 9-14 shows that the ratio of employment to domestic revenues for PVC products is 3.1 employees per million dollars of domestic revenues compared to a ratio of 5.8 employees for alternatives. The ratio indicates that, in general, manufacturing of alternatives is more labour intensive than PVC product manufacturing.

Table 9-14: Ratio of Employment to Domestic Revenues
(employment per \$ million in domestic revenues)

PVC Products	PVC		Alternative Products	Alternatives	
	Employment	Ratio of Employment to Domestic Revenues		Employment	Ratio of Employment to Domestic Revenues
Pipe	2000	4.5	HDPE, Diron, Concrete, ABS	2200	6.4
Siding	800	3.9	Aluminum, Clay brick	739	6.0
Window Profiles	800	1.4	Wood, Aluminum	5852	7.5
Flooring	700	1.9	Polyolefin, Cer. tile, Carpet	3212	4.3
PVC Compound Wire & Cable ⁷	200	4.2	PE, XLPE, TPE	200	14.3
Food Wrap	120	1.8	PE	30	2.7
Bottles	20	1.3	HDPE, PET	800	3.6
Rigid Sheet	100	3.0	OPS, PET	0	0
Flexible Sheet	1000	5.8	Fabric/TPOs, TPUs	n.a	n.a
Total	5740	3.1	Total	12983	5.8

⁷ Employment related to merchant PVC compound production is described in Section 9.2.2.

9.4.5.2 Ranking of PVC and Alternate Industrial Sectors

Table 9-15 estimates that 6,908 people are employed in the total PVC industry, which includes products, merchant PVC compounding and resin production. Since the PVC products studied account for 90% of total PVC resin consumption in Canada in 1993, it is estimated that 6,378 people are employed for all PVC products, through extrapolation. Another 215 people are assumed to be employed in other merchant PVC compound manufacturing (not associated with wire and cable, which is included in the products estimate). The employment in PVC resin production is estimated to be 315 people.

Table 9-15: Employment for Total PVC Sector

	Employment
Total PVC Products Studied	5740
Extrapolated Total (All PVC Products) ⁸	6378
Add: Other Merchant PVC Compound ⁹	215
PVC Resin Production	315
Total Sector	6908
Employment/Revenues (No/\$M)	3.3

Table 9-16 ranks the employment in various industries supplying alternatives to PVC products. It indicates that the PVC industry is the fifth ranked of the six industrial sectors studied. This lower ranking reflects the relative size and lower labour intensity of PVC products compared to other industrial groupings.

⁸ Estimate based on employment of 5740, representing 90% of PVC resin use, multiplied by 1/0.9 (1.11).

⁹ Estimate represents a remainder, based on total merchant compound employment of 415 people and the portion for wire and cable compound of 200 people. See Table 9.6.

Table 9-16: Ranking of Employment in PVC and Comparable Industrial Sectors

(Employees per \$ million in Domestic Revenues)

Rank	Industry Sectors	PVC Product Alternatives	Employment	Ratio of Employment to Domestic Revenues
1.	Wood Products	Windows, Siding, Flooring	92000	4.8
2.	Plastic Products other than PVC	Pipe, Wire and Cable, Food Wrap, Bottles, Packaging, Vehicle Trim	35086	7.5
3.	Textile Products	Flooring, Vehicle Trim	22446	7.8
4.	Aluminum Metal Products	Siding, Windows	18612	5.0
5.	PVC Sector		6908	3.3
6.	Concrete Products	Sewer pipe	5787	7.1

PVC Sector	6908	3.3
Total Alternative Sectors	173931	5.6

9.5 Summary

This chapter has described the production chain for PVC products, as well as summarized the more detailed analysis of PVC products and markets contained in the following chapter. The PVC production chain runs from the production of EDC and VCM in Fort Saskatchewan Alberta, to the production of PVC resin, and merchant PVC compound. In 1993, these precursors had a trade deficit of \$40 million.

PVC products were examined that covered 90% of all PVC resin used in domestic manufacturing. The markets accounting for the majority of PVC resin use are the construction markets, particularly pipe, siding and windows. These are also the principal markets where PVC has a sizeable and growing market share. The increasing market shares are generally the result of the lower cost of PVC products, which are designed to meet performance specifications. In general, other PVC products exhibit stable or slightly decreasing market shares. In all applications, PVC has both technical advantages and disadvantages compared to its alternatives.

In all of the PVC markets studied, currently available alternatives compete with PVC products. The annual low direct replacement cost estimate for PVC products studied is \$553 million, and the annual high cost estimate is \$2.2 billion. The low direct replacement cost is dominated by the cost of substituting for PVC flooring (\$338 million). The high cost estimate incorporates products which fit different and up-scale market niches compared to PVC products (e.g. clay-brick siding, thermoplastic urethanes).

PVC products can be both end-use and intermediate goods. For example, PVC siding is an end-use when bought as a replacement by a home-owner, and an intermediate good when incorporated in the price of a new home. In comparing the low range of substitution to the total value of PVC product markets (e.g. total value of siding market) all direct replacement costs are 11% or less of total market value. High direct replacement cost estimates are more variable and range up to 152% of the value of the siding market. In comparing the direct replacement costs to the value of selected end-uses which incorporate PVC products as an intermediate good (e.g. value of residential construction), the costs are at or below 3% of total domestic sales.

Annual domestic revenues for the PVC industry in the applications studied are estimated at \$1865 million, with a trade surplus of \$45 million. This compares to domestic revenues of \$2233 million for alternatives competing in the same markets, having a trade deficit of \$719 million. In comparing the PVC sector with similar large industry sectors that produce alternatives to PVC products, among other products (e.g. wood products, other plastic products), the PVC industry ranks fifth out of six industries by size of domestic revenues.

Manufacturing employment in the PVC sector in assessed applications is estimated at 5740 people, compared to employment of 12983 in alternatives to PVC products. In ranking the PVC sector with sectors that produce alternatives to PVC products, among other products, the PVC industry ranks fifth out of six industries by number of employees. This low ranking by employment reflects the relative size and generally lower labour intensity of PVC production (higher capital intensity) compared to alternatives.

9.6 Methodology

The construction of comparable industrial groupings for comparison with the PVC industry requires some adjustments and harmonization of the two industry classification systems used by Statistics Canada, the SIC (Standard Industrial Code) for production, and the HS (Harmonized System) code for imports and exports. Neither code corresponds to classification of industries by product material. For example, while most PVC products fall into the two digit SIC code 16 (plastic products), PVC flooring and PVC coated textiles are classified under 3993; Floor tile, linoleum, coated fabric. These are part of the two digit SIC code 39; Other Manufacturing Industries.

The value of PVC roughly accounts for 25% of the value of the total plastics industry. In this analysis, value estimations for all plastics other than PVC have been derived by multiplying data for SIC code 16 (all plastic products) by 0.75. Employment was based on manufacturing employment in the SIC code 16 minus employment in PVC production. The other SIC and HS codes used are listed below in Table 9-17.

Table 9-17: Codes Used to Create Comparable Industry Groupings

Industries	SIC Code (Production)	HS Codes (Imports and Exports)
Wood Products	25	4401-4421
Aluminum Products	296, 3031, 3099	7603-7616
Textile Products	19	5601-5902
Concrete Products	354	n.a
Plastic Products other than PVC	16 (x 0.75)	3916-3926

Source: Stats Can. 1993, cat. 31-203, 65-004, 65-007.

10. PVC Products and Markets

10.1 Introduction

This chapter provides a detailed socio-economic and technical analysis of the various PVC products and alternatives summarized in Chapter 9. These products and alternatives are identified below in Table 10-1. Since the range of products manufactured using PVC is so large, it is not practical to analyze all PVC products. The method used is to choose the major PVC products in each application area. These products accounted for approximately 90% of all PVC resin used in domestic manufacturing of PVC products in 1993.

Table 10-1: PVC Products and Alternatives

PVC Product	PVC Resin Use ¹	(%)	Alternatives to PVC
Municipal Water and Sewer Pipe	91	20	Ductile iron, Concrete, HDPE
Other Pipe (e.g. Drainage)	48	11	HDPE, ABS
Siding	100	22	Aluminum, Brick
Window Profiles	69	15	Aluminum, Wood
Wire and Cable	29	6	PE, TPE, XLPE
Flooring	12	3	PE/PP Sheet Flooring; Carpet; Ceramic tile; Hardwood; Rubber
Food Wrap	14	3	PE
Plastic Bottles	4	1	PET, PE
Rigid Plastic Sheetting used in Thermoformed Packaging	12	3	PET, OPS
Flexible Plastic Sheet - Vehicle trim	14	3	Fabric, Leather
Flexible Plastic Sheet - Pool Liners	6	1	TPE, Concrete, Fibreglass
Other	52	11	
Total	451	100	

Source: CHEMinfo Services

For each of the product applications identified, this chapter will provide market description, a technical assessment of characteristics of PVC products, and alternatives, and an estimate of the direct replacement cost. To place the direct replacement costs in context, they will be compared to the total value of products sold into the specific market segments identified. Finally, the socio-economic profile will describe the industries producing PVC products, and those industries producing alternatives. The variables used in the socio-economic profile are production, exports and imports, revenues, and manufacturing employment.

¹ PVC resin use refers to resin use in domestic manufacturing.

10.2 Pipe

In 1993, the total volume of PVC resin used in Canada for pipe, conduit, ducting and fittings is estimated at 139 kT. This is the largest end use application for PVC resin, accounting for 31% of total Canadian domestic consumption. As Table 10-2 indicates, there are many different types of PVC pipe applications, with the largest uses being the municipal market for watermain and sewer pipe. This chapter will assess the different markets for PVC pipe, focusing principally on the market for municipal watermain and sewer pipe.

Table 10-2: PVC Resin Use in Pipe

	PVC Resin (1993 - kT)	Alternatives
Watermain	40	Ductile iron, HDPE
Sewer	51	Concrete, HDPE
Drainage	11	HDPE, Concrete
Drain, Waste and Vent (DWV)	6	Copper/Cast Iron, ABS
Electrical ducting and conduit, industrial, other.	31	HDPE
Total	139	

Source: CHEMinfo Services

10.2.1 Market Description for Pipe

10.2.1.1 Municipal Water Distribution and Sewer Pipes

As with all construction materials, municipal pipe demand depends strongly on new urban development, and correlates well with housing starts. In Canada, demand for pipe was strong in the late 1980s when new residential construction was strong. Since 1990, there has been a weaker market. The replacement market is expected to grow substantially in the upcoming years as old urban watermains and sewers require repair and replacement.

The municipal market for pipe can be segmented into water distribution, sanitary sewer, storm and drainage pipe markets, with each market being further sub-divided into various pipe diameter sizes. The water distribution piping market is typically divided into small diameter pipe (4" - 12") and large diameter pipe (14" - 36"). Sewage pipe has been categorized into three size segments: small (4" - 15"), medium (18" - 36") and large sizes (over 36"). Small diameter pipe accounts for about 65% (by length) of total demand for pipe.

Currently, PVC has a large share of the market for small diameter pipe in the watermain, sanitary sewer and storm sewer markets, while traditional materials (ductile iron, concrete) continue to have substantial market shares in the larger diameter pipe. High density polyethylene (HDPE) pipe has a relatively low market share in water and sewer markets. Table 10-3 lists estimated market share for different materials and diameters.

Table 10-3: Water and Sewer Pipe Market Share, 1993
(% of length)

Type of Pipe	Water main		Sanitary and Sewer Pipe		
	4"-12"	14"-36"	4"-15"	18"-36"	36"+
PVC	88%	25%	85%	34%	0%
HDPE	0%	10%	5%	2%	0%
Ductile iron	12%	35%	0%	0%	15%
Concrete	0%	30%	10%	64%	85%
Total	100%	100%	100%	100%	100%

Source: CHEMinfo Services

In the early 1960s, when PVC pipe first entered the Canadian market, cast iron, asbestos cement, concrete pressure pipe and reinforced concrete pipe were used for most piping requirements. Ductile iron pipe was developed in the 1960s and today, it represents the major alternative to PVC used for new installations and repairs of water distribution pipes. Concrete pressure pipe is also used for higher diameter transmission service. Reinforced concrete pipe is the major alternative for sewer pipe installation and repair, although HDPE pipe also competes in storm sewer and drainage uses.

For pressurized water distribution systems, PVC is estimated to account for about 10-20%, ductile iron 20-25%, and concrete pressure pipe (<5%) of total in-place pipe, since there remains a large inventory of cast iron (40-50%) and older asbestos cement (10-20%) in the ground². PVC likely holds a similar share of in-place sewage pipe, but the majority of in-place sewer pipe inventory is concrete.

Over the last 30 years, PVC pipe has penetrated the smaller diameter segment of the pipe market in new installations and replacements, due to several reasons. Some of the contributing factors to the growth of PVC in this segment identified by industry include:

² CHEMinfo estimates based on AWWA 1990 US inventory figures.

- lower cost PVC for small diameter pipe;
- focused marketing effort in this segment;
- ability to meet technical specifications and achieve desired performance;
- asbestos cement pipe no longer specified for water mains.

Over the last 10 years, the pipe market has become more competitive in Canada. The PVC pipe market is dominated by IPEX Inc., but there are at least 4 other domestic suppliers. Ductile iron pipe is produced by one domestic producer, Canada Pipe Co., which supplies about 80% of the domestic market, and several US companies who export the remaining 15% into Canada. There are many concrete pipe producers in Canada, distributed throughout all regions.

PVC pipe has been claiming some market share in municipalities where only ductile iron was specified until recently. For example, in the late 1980's in southwestern Ontario, there were about 30 municipalities which specified only ductile iron pipe for water service. Today, in this region, there are only about 2 municipalities which still specify only ductile iron. Table 10-4 shows the penetration of PVC pipe into the watermain segment of the pipe market between 1976 and 1993.

The same penetration is also seen in the sewer pipe segment. Much of the growth has come about through private developers choosing PVC pipe that meets specifications for new residential and commercial developments. PVC pipe has also been developing a presence in the higher diameter sizes, which have been dominated by ductile iron and concrete pressure pipe because of better cost advantages. Conversely, ductile iron pipe has recently increased sales into smaller diameter sizes, reclaiming some share from PVC. The introduction of ductile iron pressure class 350 pipe in small diameters in the early 1990's has helped ductile iron to compete with PVC pipe.

Reinforced concrete pipe still has the major share of new sanitary and storm sewer segments with diameters greater than 14" primarily because of cost and strength. Over the last 10-20 years, concrete pipe producers have made significant improvements in pipe design and quality to be able to meet demanding specifications. New extrusion processes have allowed PVC pipe to meet the strength requirement of pipe performance standards (ASTM D3034) in sizes up to 48 inches in diameter and penetration of this segment has increased.

The current market is described by industry sources as "approaching equilibrium", which is more reflective of the highly competitive US market, where all three major pipe materials claim a portion of most markets.

Table 10-4: Trends in Watermain Pipe Market Share

	1976	1987	1993
Ductile Iron	57%	24%	15%
Asbestos concrete	24%	0%	0%
PVC	13%	67%	75%
Concrete	6%	7%	8%
HDPE	2%	2%	2%
Total	100%	100%	100%

Source: CHEMinfo Services

In the case of HDPE, one reason for the low market share is the different marketing strategies initially employed for PVC and HDPE. Though HDPE has always been a competing plastic, with a longer history of use in pipe than PVC, the initial target markets for HDPE pipe suppliers were industrial settings, such as the chemical process industries, and the mining sector. In contrast, PVC pipe suppliers, who also sold ductile iron pipe, targeted municipal infrastructure pipe markets. As a result, municipal design engineers and contractors are more familiar working with PVC pipe, and seldom specify or design HDPE systems.

Another alternative material that has been gaining market share in the sewer and drainage market is low cost, spiral ribbed galvanized steel pipe, also called corrugated metal pipe. The product has been promoted as a rigid, lightweight material with flow characteristics similar to pipe with smooth interior walls. Pipe suppliers claim Ministry of Transportation authorities have allowed the material for drainage applications.

10.2.1.2 Drainage, Plumbing, Ducting and Conduit, Other Industrial Pipes

In the drainage pipe market, PVC competes primarily with HDPE. PVC is more commonly seen in building drainage applications, while corrugated HDPE drainage pipe is more commonly used in farm and road drainage service. Concrete and galvanized steel (corrugated metal pipe) are also used extensively in this area.

Plumbing applications in Canada are known as the drain, waste and vent (DWV) market. In the residential DWV market, PVC pipe has a minor position compared with acrylonitrile-butadiene-styrene (ABS) pipe, though the market share of PVC is

increasing. PVC is used mostly in commercial service, where fire codes specify flame retardance. Copper and iron are still used as plumbing pipe in apartments and commercial buildings due to these specifications.

In the case of electrical and telecommunications wire protection, PVC is the dominant plastic for both conduit (above ground), and duct (below ground) applications. In industrial settings, and natural gas distribution systems, HDPE has the major share of the market.

Table 10-5 shows that between 1988 and 1993, the demand for plastic pipe in other pipe markets decreased with the general economic decline. This decline was principally due to the recession and is not reflective of a long-term trend.

Table 10-5: Major Plastics³ for Other Pipe Markets

	1988 (kT)	1993 (kT)
PVC	52	39
Polyethylene	39	30
ABS	26	14
Polypropylene	1	1
Total	118	84

Source: *Canadian C2+Petrochemical Report* published by CHEMinfo Services

³ Plastics include virgin resin only. This will underestimate polyethylene (PE) pipe demand by approximately 15-25% as additional PE pipe is manufactured from 10-15 kilotonnes of recycled PE resin. PE pipe demand (excluding municipal markets) is estimated by multiplying total PE pipe demand by 0.9.

10.2.2 Technical Characteristics of PVC Pipe and Alternatives

10.2.2.1 *Municipal Water Distribution Pipes*

PVC vs Ductile Iron

This section compares the major technical properties of PVC, ductile iron (DI), and HDPE water distribution pipe. Water distribution systems are a tree-like pipe network consisting of transmission lines (water mains - typically 36" diameter or less), distribution lines (lower diameter sizes: 6" - 12"), and service connections (from street to building). Water mains typically operate at pressures from 100 to 150 lbs per sq. in.(psi), while distribution lines operate between 40 and 100 psi. Service connection lines are usually a diameter of 1" or less and can be made of various materials: polyethylene, PVC, iron or copper pipe.

Pipe systems are complex engineering designs which are different for many types of service and soil conditions. The current market has demonstrated that alternative materials can be used in most situations, since there is a great deal of design flexibility in the products available. Pipes are available with variations in thicknesses, coatings, internal linings, reinforcements, supports and other protective measures. This flexibility in design allows municipal engineers to develop complete systems to meet local, site-specific conditions.

An important technical consideration which influences the choice of water distribution pipe material is its durability, particularly in regard to leaks. It is quite common for utilities to report water loss rates at between 5 to 20% of source volume, but there are systems, particularly with older pipes and higher pressures, which have loss rates as high as 50%. The loss of water represents a major revenue loss for utilities. In addition, pipe breakage, due to failure under stress (soil or frost), represents a large maintenance cost for excavation and replacement, not to mention the obvious public health concerns due to the potential for water contamination. The long term durability of piping systems depends on many factors, including the soil environment, proper installation, material properties such as corrosion resistance, chemical resistance and strength and the performance of joints.

One of the reasons that PVC has increased its share of the water main market is because it is a durable, corrosion resistant material. The structure of PVC pipe is not affected by naturally corrosive soils, which may induce electrochemical reactions in metal surfaces resulting in galvanic corrosion. PVC itself is a rigid, durable resin and, when properly compounded with additives, produces a slightly flexible pipe that will not oxidize significantly (except in prolonged exposure to UV radiation in sunlight), nor readily biodegrade in normal conditions.

Flexibility

Despite the fact that both PVC and ductile iron materials are hard, the pipes are both described as being flexible, being able to deflect under stress. Pipe sections of both materials can be curved slightly to accommodate variations in the trench, PVC moreso than ductile iron, but this can introduce unwanted stresses to the pipe walls. Both materials are designed to meet specifications for withstanding stresses from both the water service pressure and the external soil load.

Strength

An important feature of ductile iron pipe is that it has a very high material strength. This is reflected in several parameters, including: tensile strength, pipe stiffness, resistance to hydrostatic pressure, and impact strength. DI pipe has about eight times the tensile strength, up to eight times the resistance to crushing load, up to four times the resistance to hydrostatic pressure and more than 13 times the impact strength of PVC pipe.⁴ Furthermore, these properties remain relatively unchanged throughout the possible range of installation temperatures, unlike PVC, for which tensile strength decreases with increasing temperatures and impact resistance decreases with decreasing temperatures. High material strength gives DI pipe a higher resistance to potential damage due to soil stresses, external loads, and impacts during shipping, handling and installation. Both materials can be tapped directly, although the strength of ductile iron walls makes tap failures less likely than for PVC pipe⁵.

Corrosion

Although the majority of soils are not significantly corrosive to DI pipe, certain wet, alkaline or contaminated soil environments are considered potentially corrosive environments. The corrosivity of soils is usually determined by a simple on-site resistivity test; soil with resistivity less than about 2000 ohms/cm requires special attention. Some soils require laboratory analysis. Some examples of corrosive soils include: tidal areas with salt water tables (particularly fluctuating levels), marshy bogs and other wet areas, or mixed fills (in old industrial areas). Generally, uniform granular soils with good drainage are not significantly corrosive.

In particularly corrosive soils, the iron surface, not naturally corrosion-resistant, must be protected. It should be noted that the modified carbon structure in DI pipe makes it more corrosion resistant than the older, grey cast iron pipes used for many decades. In virtually all DI pipe sold in Canada, the inner surface is lined with a thin layer of cement mortar to minimize tuberculation. DI pipe can be encased or wrapped in polyethylene film for exterior protection. Other protective measures having a higher cost are: broad 2-ply tape

⁴ Ductile Iron Pipe Research Association (DIPRA), Ductile Iron Pipe vs. PVC Brochure, 1992, Birmingham, AL

⁵ Ductile Iron Pipe News, Direct Tapping Comparison: Ductile Iron Pipe vs PVC Pipe, Fall/Winter 1987, p. 8-11

wrapping; yellow jacket resin coating; and cathodic protection, which involves placing a sacrificial (zinc) anode on "hot spots" and sending a mild electrical current through the ductile iron pipe to prevent galvanic corrosion of the iron⁶.

Many municipalities claim that corrosion is not a significant issue when a DI pipe system is properly engineered and installed. However, when it does occur, over a long time frame, corrosion can be a weakness to the inherent durability of DI pipe. Corrosion can attack the pipe wall resulting mostly in pitting and small holes. Structural failure is much less common in ductile iron pipe and usually occurs only with significant external forces, such as uneven settling or frost action.

Leakage

A survey collecting water main pipe break data for the years 1992 and 1993 in 23 Canadian urban municipalities was performed by the Institute for Research in Construction (IRC) at the National Research Council (NRC) and funded by IPEX Inc.⁷ The survey sample covered 21,000 km of in-place water main pipe length, which accounts for roughly 15% of the estimated total Canadian pipe inventory of 150,000 km⁸. A total of about 14,000 breaks (defined as any leaks) were recorded in 1992 and 1993 and were evenly split between each year. The number of breaks for each type of pipe, when divided by the distance of each type of pipe, showed that PVC had fewer leaks per 100 km of pipe (1%) than concrete (14%), DI (16%), and cast iron (68%). Concrete pressure pipe, although only a minor proportion (4%) of the water main total, had roughly the same reported break frequency (1%) as PVC pipe.

The majority of pipe leaks in Canada appear to come from grey cast iron pipes, which represent the oldest and most prevalent type of material in place. The most common cast iron failure modes were circular splits (64%) followed by corrosion holes/pits (19-21%). Typically, these cast iron pipes are weakened by corrosion, become more brittle if cold, and crack under stress. The majority of ductile iron pipe breaks (76%) were reported as corrosion holes/pits, with only some (15-19%) circular splits. The predominant failure mode for PVC pipe incidents was through longitudinal breaks and joint leaks.

The NRC study did not normalize the data for the age of the pipe in the ground, and there was no information about the installations or the relative corrosivity of the soils. Many of the ductile iron breaks were concentrated in only a few cities. The overall results of this study give only a preliminary indication of historical pipe performance. The results may not necessarily translate into an accurate comparison between the performance of new

⁶ Ductile Iron Pipe Research Association (DIPRA), Installation Guide for Ductile Iron Pipe, 1994, Birmingham, AL.

⁷ National Research Council Canada, Gathering of Data on Different Material Types of Pipes Used in Water Distribution Systems, Client Report A-7019.1, June 1995, for IPEX Inc.

⁸ CHEMinfo Canadian estimate based on AWWA 1990 US inventory estimate of 1.3 million km

installations of PVC pipe and concrete mortar-lined ductile iron pipe, since there have been improvements in recent years in pipe protection, jointing and installation techniques. A research project by IRC/NRC for the Canadian Mortgage and Housing Corporation to extend the scope of this study to smaller municipalities and storm and sanitary sewer systems has apparently been completed as of April 1997 in draft form⁹.

Joints

Pipe sections of both material types are now commonly connected by a friction fit bell and spigot joint using a synthetic rubber gasket to provide a tight compression seal. The push-on joint design for both types of pipe is well engineered to fine tolerances such that, under normal conditions, joints remain sealed permanently and provide long-term reliability. A styrene-butadiene rubber gasket is most commonly used in the bell to provide the seal. Deflection in joints (off a straight line) can be accommodated to a limited degree, more so with ductile iron than with PVC pipe. Mechanical joints (which use bolted flanged ends sealed by gaskets) are still used to connect sections to fittings and dissimilar materials. PVC pipe can be joined using butt-fusion techniques, particularly for rehabilitation projects. All pipe systems are pressure tested and inspected, so pipe leaks from joints of either material are rare for new, properly installed systems.

Density

PVC pipe sections are relatively lighter than ductile iron sections of the same length and diameter. For smaller diameters, this makes PVC easier to handle during distribution and installation, since a crew of two can usually handle a typical 20' length. Ductile iron lengths in most diameters require equipment. This factor is largely irrelevant in larger diameter distribution or water main pipes, since most pipe installation is performed with heavy machinery.

Bedding

In Canada, water pipe must be buried deep enough to avoid the frost layer. Even in mild Canadian climates like southern Ontario and the lower BC mainland, this level is often at least 5-6 feet deep. Ductile iron pipe in diameters about 20" and smaller is considered to have sufficient tensile strength to be able to transmit more of the backfill soil weight load through the pipe walls and bedding to the foundation beneath the pipe and, therefore, not require as much supportive sidefill. PVC pipe and ductile iron pipe 24" and larger have higher flexibility, therefore, require proper pipe bedding and full sidefill support to resist deflection.¹⁰ Ontario Provincial Standards call for flexible pipes to have embedment (homogeneous granular support material) at least 1 foot above the top of a pipe and be compacted.¹¹ Essentially, the bedding, the embedment sidefill and the walls of these

⁹ Dr. Balvant Rajani, IRC/NRC, personal communication, April 1997

¹⁰ Howard, A.K., Pipe Bedding and Backfill, US Bureau of Reclamation, Materials Engineering Branch, Jan 1992.

¹¹ taken from Ontario Provincial Standard Drawing Nos. OSPD 802.010 & 802.013

"flexible" pipes together must form an integral structure to resist the pipe deflection caused by the external load of the overlying backfill soil. The bedding and sidefill should be composed of material fine enough to evenly absorb the vertical load and must be well tamped down in the backfill stage. Both materials are able to handle most variations in bedding: PVC pipe responds to uneven stresses through its flexibility and ductile iron offers high resistance largely through its tensile strength. A tracer wire is usually required to be strung along a PVC pipe to help locate the pipe in future if necessary.¹²

Longevity

There is much debate over the durability and expected lifespan of PVC and ductile iron pipe. The life of a pipe system depends not only on the material, but the installation and the surrounding environment. Both types of pipe have been on the market for over 30 years, and while there are examples of pipe failures for both materials, this study did not find conclusive evidence to suggest that one material has a significantly different lifespan from the other. When properly designed and installed, pipe systems of both materials can be sufficiently durable to withstand many decades of services.

Water Contamination

In some abnormal conditions, it has been found that the water in some jointed pipe systems has been contaminated by organic chemicals from outside the pipe. The most common mechanism of contamination is through leakage, where contaminants penetrate directly through a leak in the gasket at the joint or through a mechanical defect (crack or hole) in the pipe wall. All types of jointed pipe are susceptible to contamination through joint leakage.

A much less common mechanism for contamination is through permeation, where organic compounds from a contaminated soil environment diffuse through the joint gasketing material or pipe wall. Tests have shown that the fastest permeation breakthrough occurs through the rubber gasketing material in jointed pipe¹³. Both ductile iron and PVC pipe systems are susceptible to permeation through styrene-butadiene rubber gaskets, commonly used in their joints. Where gross organic chemical contamination exists, it is not advisable to install a gasketed water pipeline without first conducting a remedial site clean-up.¹⁴ Gasket materials with higher solvent resistance and for higher temperature service are available at extra cost.

¹² DIPRA, Ductile Iron Pipe vs. PVC Brochure, 1992, Birmingham, AL

¹³ The Vinyl Institute (division of SPI), Evaluation of the Permeation of Organic Solvents Through Gasketed Jointed and Unjointed PVC, Asbestos Cement and Ductile Iron Pipes, (by Batelle Columbus Laboratories, Oct. 1983.

¹⁴ Region of Hamilton-Wentworth Regional Environment Dept., Proposed Use of PVC Pipe for Municipal Watermain Construction, Feb. 5, 1997

The walls of normal ductile iron pipe are impermeable to organic contaminants. PVC is susceptible to permeation of organic contaminants through the pipe wall, but only where soils are grossly contaminated with organic solvents. Research shows that organic solvents can soften and permeate PVC pipe when the solvent contamination in soil exceeds a 0.25 "activity" level.¹⁵ This threshold level is defined as 25% of maximum soil saturation contamination, corresponding to roughly 125 ppm in the ground water and is considered high by environmental standards. PVC is a good barrier up to this level of soil saturation, due to extremely low (Fickian) diffusion kinetics.¹⁶

A 1987 US survey of water utility plastic pipe users estimated the extent of organic chemical permeation problems in water distribution piping and service connections.¹⁷ The data collected included the number of permeation incidents found, the type of pipe, the number of service-connection-years (for small diameter service connections), and the number of water main mile-years (for water mains). Based on the total water main mile-years reported, the survey appeared to be a sample of about 5% of the total US system.

For PVC service connections, only one permeation incident was reported from a sample of 461,620 PVC service connection-years (roughly 5% of all plastic service connections in the survey). Polyethylene and polybutylene pipes, accounting for 77% and 18% of the plastic service connection-years in the sample, had much higher permeation rates (25 and 28 incidents respectively).

For PVC water mains, three permeation incidents were reported from a sample of 64,821 main mile-years, a result reported as a rate of 4.6 incidents per 100,000 water main mile-years. With the amount of PVC pipe in Canada estimated at 100,000 - 200,000 water main kilometre-years, the rate from this US study suggests that there should have been about 3 to 6 PVC permeation incidents in Canada over the last 30 years. There have been no PVC watermain pipe permeation incidents reported in Canada to date. Although the extrapolation of this data may not be very accurate, the analysis provides an order of magnitude estimate for the risk frequency of the PVC permeation issue.

Hydraulics

PVC pipe generally has smoother internal pipe surfaces than the concrete mortar lining of DI pipe. The Hazen-Williams "C" factor (inversely proportional to friction levels) for PVC is about 150, compared with a range of about 90-140 for DI pipe. However, for comparable nominal pipe sizes, the actual inner diameter of ductile iron is larger than that of PVC pipe, resulting in a lower velocity, and therefore a lower pressure drop for any

¹⁵ US EPA Region VIII, Clement, B., Volatile Organic Chemical Permeation of Plastic Pipe.

¹⁶ Berens, A.R., Prediction of Organic Chemical Permeation Through PVC Pipe, AWWA Journal, Nov. 1985.

¹⁷ Thompson, C. & Jenkins, D., Review of Water Industry Plastic Pipe Practices, Report to AWWA Research Foundation, Contract 104-85. Dept. of Civil Engineering, U. of California, Berkeley, 1987.

given volume flowrate. The overall effect is that, for any given volume flowrate, ductile iron pipe has a lower effective head (pressure) loss, despite its slightly rougher inner surfaces, than the same nominal diameter PVC pipe, due to its larger diameter. In other words, ductile iron's larger inner diameter more than compensates for its slightly higher wall roughness.

Table 10-6 summarizes some of the important technical factors between PVC and ductile iron pipe.

Table 10-6: Technical Comparison of PVC and Ductile Iron Pipe

Technical Characteristics	PVC	Ductile Iron
Material Properties		
Corrosion Resistance	Resistant to acids	Can corrode; requires protection in some acidic soils and septic waters
Chemical Resistance	Can soften/degrade with organic solvents at high concentrations	Resistant to organic solvents; requires protection from acids
Impact Resistance	Moderate	High
Hydrostatic strength	Moderate	High
Tensile Strength	Moderate	High
Pipe Stiffness	Flexible; bends moderately	Flexible; bends slightly
Installation Factors		
Handling, weight	Light (~15 kg/m - 8" DR 18)	Heavy (32-36 kg/m - 8" Class 350)
Joining	Push on joints most common; mechanical and butt-fusion joints possible	Push-on joints most common; accommodates some deflection; mechanical joints possible
Bedding	generally requires more sidefill support to control deflection	more rigid at lower diameters; still requires careful bedding
Service		
Durability	High	High (with corrosion control as required)
Joint Integrity	Long term reliability	Long term reliability
Water Flow	Smooth walls; low friction factor	Slightly higher friction factor; larger internal diameter; higher flow
Temperature Range	Lower impact resistance with decreasing temperatures; lower tensile strength with increasing temperatures	Handles very high and low temperatures

Source: CHEMinfo Services

PVC vs HDPE

In general, a comparison of PVC and HDPE pipe indicates that HDPE pipe is a roughly equivalent material for many PVC watermain applications, notably in terms of corrosion resistance and durability.

HDPE has a slight advantage in terms of preventing leaks due to a joining process specific to HDPE pressure pipe, butt-fusion joining. Butt-fusion joining provides stronger, tighter, more leak proof joints compared to the bell and spigot joints used in PVC pipe. Butt-fused joints may also be more cost effective for continuous joining of HDPE pipe lengths, with few angles. As a result of the technical characteristics of HDPE that allow for this joining technique, current HDPE pressure pipe applications tend to be long continuous transmission lines, water crossings (i.e., rivers), relining damaged pipe, other horizontal direction drilling jobs, or situations where pipe needs to be pulled during installation.

HDPE is also more ductile than PVC. This is an advantage in some applications, notably in northern areas where ice can form in the pipe, expanding and breaking the pipe. HDPE pipe (insulated with polyurethane foam) is commonly used in colder, northern Canadian communities. PVC pipe may also possess enough ductility to withstand the expansion forces of freezing water.

Although both types of materials are defined as flexible, HDPE pipe is usually more flexible than PVC pipe. The advantage of flexible pipe is in applications where continuous lengths are required. HDPE can be coiled in smaller diameters, generally less than 8 inches. Continuous HDPE pipe also can be plowed in, which may represent a cost effective installation alternative for long continuous lengths. Flexibility may, however, also be a disadvantage for some applications where a more rigid piping system is desired. Although HDPE may deform slightly to better fit in the soil environment due to its flexibility, it may also have a reduced capability to withstand potential distortion due to major soil stresses.

A disadvantage with HDPE pipe is tensile strength, where PVC has a greater tensile strength compared to HDPE. As a result at larger diameters (greater than 24") HDPE becomes too thick, and cannot compete with PVC on cost.

Table 10-7 summarizes some of the important technical factors between PVC and HDPE pressure pipe.

Table 10-7: Technical Comparison of PVC and HDPE Pipe

Characteristic	PVC	HDPE
Durability	Decades	Decades
Joining	bell and spigot push-on	butt-fusion above ground mostly, bolted flange for equipment connections
Joint integrity	tight seals; low leakage	butt-fusion results in tight seals
Weight	more dense than HDPE	less dense than PVC
Ductility	more stiff than HDPE	less stiff than PVC
Flexibility	rigid	flexible
Pressure rating	more susceptible to surge, hammer shocks	less susceptible to surge, hammer shocks
Tensile strength	PVC has better strength to volume ratio	HDPE has less strength to volume ratio
Internal wall smoothness	close to HDPE	close to PVC
Abrasion resistance	moderate	high
Chemical resistance	moderate	very good
Impact resistance	brittle at very low temperature, glass transition temperature higher than HDPE	better low temperature resistance, glass transition temperature lower than PVC
Fire resistance	will not sustain combustion	will sustain combustion
Tapping	mechanical taps	fusion or mechanical tapping

Source: CHEMinfo Services

10.2.2.2 Sewer Pipe

PVC vs Concrete

This section compares the technical characteristics of PVC, concrete and HDPE sewer pipe. Sewer systems are often grouped into 3 categories: sanitary sewers, which handle wastewater; storm sewers, which handle rain runoff, and often run in parallel to sanitary systems; and culverts, which channel water under bridges and structures. In sanitary and storm sewer systems, PVC, reinforced concrete and HDPE pipe are the types of pipe which can be specified for service. PVC has a large share (80-90%) of the small diameter sewer pipe segment. These smaller lines are commonly used in the collection network of subdivisions. In this segment, the competing concrete pipe is non-reinforced concrete pipe in 8" and 10" sections. The smallest diameter reinforced concrete pipe is usually 12" pipe.

Rigidity

Concrete pipe is a rigid structure, composed of aggregate, cement binder and additives. For smaller diameters, no reinforcing is necessary. Higher diameter pipes require reinforcement with metal rods for strength. Under the Ontario Provincial Standards, a rigid pipe is defined as one which cannot deflect more than 2% without cracking. Under this definition, concrete pipe is classified as rigid. Only a minor degree of flexibility is provided by the metal reinforcing. As previously discussed, PVC pipe is defined as flexible, capable of deflecting under stress.

Corrosion/Chemical Resistance

As previously mentioned, PVC is resistant to corrosion, but is susceptible to softening by solvents in high concentrations. Although there are examples of corrosion damage to metal reinforcements, corrosion is not usually a significant issue with concrete pipe, when designed and installed properly. Concrete can be susceptible to sulphate attack, a condition caused by excessive levels of hydrogen sulphide (H_2S) gas in the wastewater. In high holding areas, where water sits in the lines for a long time, H_2S gas can be generated from "septic water." The gas forms a weak sulphuric acid solution, which can react with the lime binder in the concrete matrix, weakening the structure. This salt attack can cause spalling, a light flaking of the concrete surface. This problem is prevented in several ways, including: lining the walls with plastic, designing thicker, "sacrificial" walls, or creating better sloping in the drainage grade.

Abrasion Resistance

Abrasion resistance is an important property affecting service life in storm sewers and culverts, where sand and other abrasive material flow with the water against the surface of the pipe. Under aggressive conditions of high velocities (high slope) and heavy aggregates, the invert (inner bottom) of concrete pipe can erode, especially in increasing

acidic conditions.¹⁸ However, for most installations, where pH rarely falls below 4.0, and slopes rarely exceed 2-3%, the condition of concrete pipe remains in very good condition with long expected service life.¹⁹ Both PVC and concrete storm systems can be designed to withstand abrasion through protective measures and design modifications.

Strength

The rigidity of concrete pipe provides a very strong and durable structure in the ground, particularly when reinforcement is used. Concrete pipe is designed in several different load classes, based on ability to resist vertical deflective load:

- Non-reinforced pipe (6" - 18") in two classes, Class 2 and Class 3
- Reinforced pipe (12" - 144") in four classes, 50-D, 65-D, 100-D and 140-D.

Bedding

The concrete pipe wall itself provides about 80% of the total structural support needed to absorb the vertical load of the backfill. Sidefill support for concrete pipe above the springline (midline) is unnecessary for pipe support. Like water distribution pipe, PVC requires good bedding and sidefill preparation to be able to absorb the vertical load, since its walls only provide about 10-20% of the total structural support required. It is also available in different wall thicknesses. Generally, backfill standards for flexible pipe call for compacted embedment material to a level at least 12" above the pipe. This additional soil envelope can add to the installation cost of PVC pipe.

Density

Concrete pipe is heavier than PVC pipe due to its thicker, more dense walls. To compensate for its weight, most concrete pipe is produced in shorter length sections of 3' for smaller diameters and 7' for larger diameters, while PVC sewer pipe is most commonly sold in 13' lengths. Concrete pipe has a higher density (S.G.=2.4) than PVC pipe (S.G.=1.38). While concrete pipe is heavier, it better resists buoyancy forces from any water surrounding the pipe which may affect the line and grade of the system. While concrete pipe sections are not as flexible as PVC for long curved lengths, the higher number of sections in a system provide some degree of flexibility based on the number of joints. Of course, the higher number of joints in the system also increases the potential leak points.

Infiltration

In contrast to water distribution pipe, sewer pipe is not in pressurized service, where hydrostatic strength is a more important performance factor. However, as with water

¹⁸ Gabriel, L.H., A Comparison of Sewer Pipe Products in Abrasive Conditions, California State University, Mar. 1992 (funded by Unibell PVC pipe producers)

¹⁹ American Concrete Pipe Association, Culvert Durability Study, No. 02-902, June 1982.

distribution pipe, one of the most important issues involved in sewer pipe is durability, particularly in regards to sewer pipe infiltration and leaking. Infiltration occurs when groundwater enters the sewer system through leaks in the joints or walls. Of course, in a leaking pipe situation, depending on the external pressure, contaminated wastewater can also leak out of the pipe, creating potential health hazards. Infiltration increases the amount of wastewater to be treated, and thus the cost of waste water treatment systems. Common sources of water infiltration are leaking joints where gaskets have not been used, and the cracking of older, non-reinforced concrete pipe as a result of soil stresses or tree root intrusion.

A US standard for sewage water infiltration allowance is 200 gallons per inch diameter per mile per day. PVC pipe producers have claimed that their pipe systems are able to reduce infiltration to 25% of this standard. Concrete pipe producers claim that the development in gaskets and installation techniques has also improved their leak performance. Both PVC and concrete pipe sections are joined with a bell and spigot design using rubber gaskets of various designs. Both pipe products are manufactured to fine tolerances and, when installed properly, joints are highly reliable in the long term.

Hydraulics

There is very little difference in the hydraulic performance of PVC and concrete pipe, since the walls of each type of pipe are comparably smooth. The Manning's friction factor is 0.009 for PVC and 0.010 for concrete in lab tests; and about 0.013 for both in practice. Once in service, the buildup of biological matter on pipes with slower velocities becomes common to both types of pipe.

Temperature Range

Both PVC and concrete are designed to meet performance specifications throughout the operating temperature range. PVC loses some impact resistance at very cold temperatures and becomes more flexible at higher temperatures. While care must be taken in cold weather installation, these factors do not affect normal performance. The properties of concrete pipe do not change appreciably over the full temperature range. Concrete pipe withstands extremely high temperatures. This can be a benefit in the occasional application of hot combustion gases to melt ice buildups in exposed sewer boxes and culverts.

Table 10-8 summarizes some of the important technical factors between PVC and concrete sewer pipe.

**Table 10-8: Technical Comparison of PVC and Concrete
Sewer Pipe**

Technical Characteristics	PVC	Concrete
Material Properties		
Corrosion Resistance	resistant	resistant
Chemical Resistance	susceptible to some hydrocarbon solvents	susceptible to acids (i.e. sulphuric acid); solvents may cause dissolution
Impact Resistance	moderate; reduced at very low temperatures	moderate
Abrasion Resistance	high	high; moderate under acidic conditions
Tensile Strength	moderate; flexible	high; rigid sections; flexibility in system due to shorter lengths
Soil Stress Resistance	flexible; withstands stress with sidefill support	withstands high soil loads
Installation Factors		
Handling, weight	light (13 kg/m); long (6.1m) sections (8" basis)	heavy (72 kg/m); short (1.2 m) sections (8" basis)
Joining	push on joint	push-on joint; more joints
Bedding	180° bed tamping required	lower half support may be necessary
Service		
Durability	high; long life span expected, not proven beyond 30 years	high; long lifespan
Joint Integrity	long-term reliability with proper installation	long-term reliability with proper installation
Water Flow	smooth walls; low friction	smooth walls; low friction
Temperature Range	lower impact resistance with decreasing temperatures; flexibility increases with increasing temperatures	wide range application

Source: CHEMinfo Services

PVC vs HDPE in Sewer Pipe

As with PVC and HDPE in watermain pipe, HDPE is a roughly comparable alternative to PVC pipe in sewer systems. HDPE sewer pipes are also available in diameters ranging from 4 inches to 36 inches, although for storm sewer, much of the demand is for 10 to 15 inch, while for sanitary 8 to 12 inch are popular diameters. The main market where HDPE is an alternative to PVC is in the small diameter sewer pipe. At larger diameters, the major market share is held by concrete, primarily due to cost.

Both PVC and HDPE sewer pipe offer similar infiltration rates, depending on the type of joints used. Both HDPE and PVC sewer systems can use bell and spigot joints. These will be comparable in terms of their integrity and infiltration rates. However, HDPE pipe systems which use clam-shell type connections (around corrugations) are more susceptible to infiltration. If butt-fusion joints are used for HDPE sewer pipe the infiltration rate will be superior to PVC sewer pipe.

HDPE may have a greater tolerance over a broader pH range and a broader range of hydrocarbon solvents than PVC. According to one pipe supplier, HDPE is able to tolerate a pH range between 1.5 and 14, slightly higher than PVC. Table 10-9 summarizes some of the technical factors between PVC and HDPE in sewer pipe.

Table 10-9: Technical Comparison of PVC and HDPE Sewer Pipe

Characteristic	PVC	HDPE
Durability	decades	decades
Joining	bell and spigot push-on	bell and spigot push-on, butt-fusion, clam shell connections
Joint integrity	tight seals; low infiltration	tight seals; low infiltration (higher for clam shell enclosures)
Weight	more dense than HDPE	less dense than PVC
Ductility	less ductile than HDPE	more ductile than PVC
Flexibility	flexible	flexible
Tensile strength	better strength/volume ratio	lower strength to volume ratio
Internal wall smoothness	close to HDPE	close to PVC
Abrasion resistance	moderate	high
Chemical resistance	softens with solvents at high concentrations	very good
Impact resistance	decreases at very low temps., glass transition temp. higher than HDPE	better low temp. resistance, glass transition temp. lower than PVC
Fire resistance	resistant to combustion	will sustain combustion

Source: CHEMinfo Services

10.2.2.3 Drainage, Plumbing, Ducting and Conduit, Other Industrial Pipes

Beyond water and sewer uses, there are many niche applications of pipe where PVC is used in smaller quantities. In drainage pipe, electrical and telecommunications ducting, the main alternative to PVC is HDPE. In some low temperature industrial uses, HDPE can be used, but stainless steel is the next best alternative for more aggressive service environments where corrosion may be a problem. In the plumbing or DWV market, PVC is used mostly in commercial and industrial buildings where the National Fire Code dictates a flame-resistant product. Although ABS pipe is used extensively in the residential market, it is not fire resistant and copper or cast iron piping are more likely alternatives.

Table 10-10 summarizes some of the technical factors between PVC and other materials.

Table 10-10: Technical Comparison of PVC and Other Materials

Drainage, and other Industrial Pipe	PVC	HDPE
Joining	bell and spigot push-on	bell and spigot push-on, or split coupler, butt-fusion
Joint Integrity	tight seals; low leakage	less reliable split coupler seals leak, butt-fusion results in tight seals
Weight	more dense than HDPE	less dense than PVC
Abrasion Resistance	moderate	high
Chemical Resistance	moderate	very good
Impact Resistance	brittle at very low temperature	better low temperature resistance
Fire Resistance	will not sustain combustion	will sustain combustion
Plumbing (DWV)	PVC	Copper/Cast Iron
Joining	adhesives (3-5 minute cure time)	soldering, mechanical joints
Joint Integrity	tight seals	tight seals
Weight	lighter than metal	heavier than PVC
Availability of Fittings	broad range	broad range
Chemical resistance	good	not acid resistant

10.2.2.4 Surveyed Commentary of Pipe

A survey of municipal engineers from 10 Canadian municipalities (see Table 10-11) was conducted to gather comments on the materials used for watermain and sewer pipe. The survey does not have a large enough sample for statistical validity. Municipalities using different proportions of pipe in service were contacted in an attempt to provide a cross section of views. Most sewer systems combined the use of PVC and concrete pipe, while many municipalities were polarized in their choices of water main pipe between PVC and ductile iron. These comments are provided solely as examples of the issues identified and should not be interpreted as endorsements or generalizations. A selection of the notable comments appears below.

Table 10-11: Municipalities Contacted for Pipe Comments

Municipality	Predominant Pipe for New Water Service
Burnaby, BC	Ductile Iron
Calgary, AB	PVC
Edmonton, AB	PVC
Halifax, NS	Ductile Iron
London, ON	PVC
North Bay, ON	Ductile Iron
Oakville, ON	PVC
Stratford, ON	Ductile Iron
Vancouver, BC	Ductile Iron
Welland, ON	PVC

PVC Pipe Comments

- “the flexibility of PVC pipe allows it to handle variations in bedding; some sections of city have hard ground conditions”
- “PVC pipe is strong and durable”
- “smaller diameters are much more economical to install; low weight makes it possible for a crew of two to handle the pipes”
- “PVC pipe must be completely embedded and compacted - cost is not too significant”
- “care must be taken during maintenance excavation to not damage the pipe wall”
- “in high depths (>20’) some PVC sewer pipe has come out of shape and there is concern over its integrity”
- “had 25 years experience with PVC; not sure of its actual life”
- “our first PVC installation was 17 years ago; its life expectancy is quite long”
- “we’ve had occasional tap splits”
- “although most of our pipe is ductile iron, PVC pipe is chosen for use in wet areas”

Ductile Iron Pipe Comments

- "takes rough handling better, especially in winter"
- "has better strength in terms of impact and pressure"
- "better pipe in terms of structural integrity"
- "high impact resistance is one of the biggest factors favouring ductile iron pipe in a busy city utility corridor (where there is frequent excavation)"
- "major issue is corrosion: in most soils, the costs are comparable; in corrosive soils, the extra job costs for protection of ductile iron can be prohibitive"
- "in very corrosive soils, we have stopped using ductile iron with cathodic protection"
- "both pipe materials should have full embedment compaction; this is not always possible and ductile iron is far more tolerant of faulty bedding (uneven loads)"
- "very easy to direct tap"
- "our crews are more comfortable wet-tapping DI than PVC"
- "leak and break rate are very low for ductile iron; most leaks come from small corrosion pitting; when physical breaks occurred, it was due to settlement over a rigid mass"
- "easier to detect leaks through sonic detection"
- "easier to thaw service connections on ductile iron mains using electric thawing machine"

Concrete Pipe Comments

- "expect at least 50-100 years of service from concrete"
- "more economical than PVC for diameters over about 24" (several comments)
- "high strength handles deep (>20') installations"
- "great improvement in pipe quality and joint integrity in last decade" (several)
- "some sections of pipe have been corroded from inside due to septic attack"
- "susceptible to corrosion from soils with high sulphide levels"
- "sections found where bottom has gone; believed due to acidic chemical disposal"
- "shorter lengths and more joints create more flow resistance"
- "concrete more durable when reexcavating"
- "takes longer to cut (tap or replace) concrete pipe sections than PVC pipe sections"

HDPE Pipe Comments

- "less dense, not as strong"
- "not a lot of experience with HDPE in water main service"
- "more leakage with older HDPE joints vs PVC; new bell and spigot joints good"
- "not as tight more difficult to tap"
- "butt fusion welding gives good seal"
- "easier to lay in smaller diameters; contractors like working with it"

10.2.3 Direct Replacement Costs for PVC Pipe

10.2.3.1 Assumptions

All direct replacement costs are estimated using prices based on an assumed median PVC pipe size in each application, with the total quantity of pipe adjusted to reflect the amount of PVC resin used in each application. The pipe diameters reflect the most commonly sold PVC pipe diameters in each market. The median PVC pipe diameter sizes for watermain, sewer and other industrial uses are 8"; for drainage, 15"; and DWV, 3". The direct replacement costs were then calculated based on a comparison of costs per metre with alternative products in the same nominal pipe diameter.

Cost data were taken from the most current "**Means Construction Cost Data Handbook**" (Means, 1995). Costs were selected from this standard industry reference, which is based on comprehensive annual surveys of manufacturers, dealers, distributors and contractors across the U.S. and Canada. We have adjusted U.S. national cost average data from Means to represent the Canadian market over a five-year period between 1989 and 1993 using historical cost indices and city cost indices. City cost indices are provided in Means which permit conversion of U.S. averages to local cities and currency. In this analysis, we adjusted to local conditions for Toronto, Ont. Historical cost indices permit time and inflation adjustments to be made. In this analysis, 1995 U.S. cost data were adjusted to give the 1989 - 1993 five-year average. Data used included: labour, equipment, excavation and backfill. Material costs for watermain and sewer pipes were based on surveys of Canadian manufacturers. Straight averages for these prices were used in the analysis.

It should be noted that there is great variation in pipe prices and installation costs, such that generalizations about the average cost of one pipe material versus the other may not be representative of all applications and markets. The following sections describe the assumptions made in the costing model for each market sector.

Water Distribution and Sewer Pipes

In 1993, the most common alternative to PVC used in water distribution markets was class 52 ductile iron pipe. Five-year average (1989-93) material costs for 8" PVC pipe (PVC, class 150, SDR 18) were \$25/m, and those for an equivalent size of DI pipe (DI, class 52, cement-mortar lined) were \$30/m. Labour, equipment and site preparation costs increased this differential to a total installed cost of \$46/m for PVC pipe and \$53/m for ductile iron pipe. Extra embedment compaction costing \$2/m was assumed for PVC pipe. No polyethylene wrapping or cathodic protection was assumed for ductile iron pipe. The equivalent material costs for HDPE pipe (HDPE, DR 13.5) were \$28/m. The

additional labour, equipment, and site preparation costs result in installed HDPE costs of \$51/m. All HDPE pipe is assumed to be butt fused.

For sewer applications, the average (1989-1993) material cost of 8" PVC pipe (SDR 35) was \$8/m and the cost for an equivalent pipe size of non-reinforced concrete was \$12/m. Total installed costs, including labour, equipment, and site preparation were \$26/m for PVC and \$33/m for concrete. Extra costs of \$2/m for embedment and compaction were assumed for PVC pipe. Labour costs per linear foot from Means are higher for concrete. The equivalent material costs for HDPE sewer pipe (320 KPA stiffness by ASTM D2412) were also \$8/m. Total installed costs for HDPE sewer are \$28/m, including butt fusing.

Building Drainage, Plumbing (DWV) and Other Industrial Pipe Applications

In the drainage market, a 15-inch standard drainage pipe was assumed as the median pipe size. The pipes assumed to be used for this service were: ribbed PVC pipe, corrugated HDPE pipe, and non-reinforced concrete pipe. The price of PVC and HDPE pipe to a high-volume contractor was roughly equal at about \$21/m, while the average price of non-reinforced concrete was about \$30/m. Installation costs for PVC and HDPE were assumed equal due to similar properties. Overall installation costs for PVC and concrete are assumed to be roughly comparable, with the higher costs of embedment and compaction for PVC pipe offset by its higher labour productivity.

In the commercial/industrial DWV market, a 3" diameter pipe is assumed, with the prices of PVC being roughly \$5/m and the equivalent copper/cast iron price being roughly \$12/m.

The estimate for other pipe uses (electrical, telecommunications, industrial etc.) assumes a standard 8-inch PVC duct pipe valued at \$24/m. A similar HDPE pipe is slightly less expensive at \$22/m.

10.2.3.2 Direct Replacement Cost Summary

Two comparisons of alternatives were used, one based principally on modern traditional materials (DI, concrete), and one based principally on substitution with HDPE.

Table 10-12 shows that the direct replacement costs using modern traditional materials is estimated at \$96 million annually, based on substitutes DI (watermain), concrete (sewer, drainage), copper/cast iron (DWV) and HDPE (other industrial). The major cost impacts are on the municipal infrastructure markets (\$71 million); with smaller impacts (\$25 million) on the other pipe markets.

Table 10-12: Direct Replacement Cost (High) for PVC Pipe
[Using Ductile Iron (watermain) and Concrete (sewer pipe, drainage)]

	PVC Resin (A)	PVC Resin Per Metre (B)	Equivalent Pipe Length (A/B)=(C)	Alternate Material	Installed Cost Diff (D)	Total Difference (C x D)
	(kT/yr)	(kg/metre)	(million metre)		(\$/metre)	(\$million/year)
Watermain (8 inch)	40	14	2.9	Ductile Iron	7	20
Sewer (8 inch)	51	7	7.3	Concrete	7	51
Drainage (15 inch)	11	11	1.0	Concrete	9	9
DWV (3 inch)	6	2	3.0	Copper/ Cast Iron	7	21
Industrial, ducting etc. (8 inch)	31	12	2.6	HDPE	(2)	(5)
Total	139					96

Source: CHEMinfo Services

Table 10-13 shows the annual direct replacement cost for PVC, using HDPE as substitute material for watermain, sewer, drainage and other industrial applications, and ABS for the DWV market, is \$44 million per year. ABS may not be able to completely substitute for PVC in commercial installations. The major impact is on the municipal infrastructure market (\$49 million), with net cost savings in the other pipe uses markets (- \$5 million).

Table 10-13: Direct Replacement Cost (Low) for PVC Pipe
[Using HDPE/ABS for watermain, sewer, drainage, other]

	PVC Resin (A) (kT/yr)	PVC Resin Per Metre (B) (kg/metre)	Equivalent Pipe Length (A/B)=(C) (million metre)	Alternate Material	Price Difference (D) (\$/metre)	Total Difference (C x D) (\$million/year)
Watermain	40	14	2.9	HDPE	7	20
Sewer	51	7	7.3	HDPE	4	29
Drainage (15 inch)	11	11	1.0	HDPE	0	0
DWV (3 inch)	6	2	3.0	ABS	0	0
Industrial, ducting, etc. (8 inch assumed)	31	12	2.6	HDPE	(2)	(5)
Total	139					44

Source: CHEMinfo Services

10.2.4 Direct Replacement Cost Compared to End Use Revenues

In order to put the direct replacement costs in context, they will be compared to the estimated value of domestic sales of pipe into two market classifications, the municipal market, and the other pipe market. In order to derive an estimate of the total value of pipe sold in the municipal market, the following estimates of municipal sales as a percentage of domestic sales were used: 80% of PVC pipe, 100% of DI pipe, 80% of concrete pipe, and 10% of other plastics (HDPE, ABS). All other percentages of pipe sales are attributed to the other pipe markets, covering drainage, DWV, and other industrial applications. The value of domestic sales for PVC products and alternatives can be found in the following socio-economic profiles.

Table 10-14 shows that substituting for PVC products would increase the annual cost of municipal pipe purchases by a range of 4 to 6%, while increases to other pipe users would be approximately -1 to 5% of all pipe purchases. As discussed in chapter 5 "Chlorine in Water and Wastewater Treatment", 1993 annual revenues derived from water rates to municipal water utilities are \$3282 million. The costs of substituting for PVC pipe in the municipal pipe market represents 3% (high) and 1% (low) of total revenues from water and sewer rates.

Table 10-14: Direct Replacement Cost Compared to Value of Domestic Pipe Sales
(\$ million)

Market	Direct Replacement Costs		Estimated Annual Value of Domestic Pipe Sales, Installed ²⁰	Direct Replacement Cost to Value of Domestic Product Sales (%)
	Low	High		
Municipal (watermain, sewer)	49	71	1280	4% (low), 6% (high)
Other Pipe (drainage, DWV, other industrial)	(5)	25	668	-1% (low), 4% (high)
Total	44	96	1948	2% (low), 5% (high)

²⁰ The value of installed pipe is generated by multiplying the revenues from domestic pipe sales contained in the socio-economic profile with the ratio of total installed pipe costs to material costs contained in the direct replacement cost section.

10.2.5 Socio-economic Profile

In this section the different pipe products will be profiled, using the variables of plants, capacity, production, revenues, and employment. As with many of the PVC construction materials, it is not possible to perfectly separate the variables for PVC products from other products and, in the case of pipes, particularly other plastic products. For example, many PVC pipe producers also extrude PE, and ABS plastics. Nevertheless this profile will attempt to separate producers of the different competing materials. As the distribution chain for pipe will commonly distribute both PVC and alternative products, the distribution chain for pipe products will not be described.

10.2.5.1 PVC

Number and Location of Producers: There are 4 PVC pipe and fittings manufacturers operating some 15 plants in Canada. The market is dominated by IPEX Inc. with ten plants located throughout Canada. Pipe is the dominant product of IPEX, and IPEX holds about 60-70% of the PVC pipe market. Royal Plastics Ltd. operates three pipe plants and has about 20% of the PVC pipe market. A high proportion of Royal's sales come from other construction products such as PVC siding, vertical blinds, window and custom profiles, housing systems, as well as ABS pipe. Two small regional processors also compete in the industry. Les Tuyaux Duchesne, based in St-Joseph-de-Beauce, PQ, is a major construction materials supplier, including other plastic products. Rehau Plastics of Canada, which also produces windows, extrudes pipe in their Prescott, ON plant.

Production and Capacity Levels: Based on 139 kilotonnes of PVC resin used in domestic pipe, multiplied by 1.1 to account for additives, total domestic demand for PVC pipe was 153 kilotonnes. Adding exports of 23 kilotonnes allows an estimate of domestic production of 175 kilotonnes.

Imports and Exports: A total of 23 kilotonnes of PVC pipe was exported in 1993, with this level relatively stable for the past five years. Imports into Canada totalled 9 kilotonnes of PVC pipe, leading to a net export surplus of 14 kilotonnes. (Stats. Can, 1993, 65-004, 65-007).

Revenues: In 1993 domestic revenues for PVC pipe are valued at \$358 million, based on 70% of total plastic pipe revenues for manufacturing shipments of plastic pipe (Stats Can., 1993, 31-203). Domestic sales are estimated at \$329 based on exports of \$47 million and imports of \$18 million. The trade surplus for PVC pipe is \$29 million.

Number of Employees: The total employment associated with PVC pipe and fittings production is estimated to be about 2,000 people. IPEX employs 1,300 people, the

majority of whom are affiliated with pipe. Royal employs 1,855 people in total, approximately 130 of whom are affiliated with pipe.

10.2.5.2 Ductile Iron

Number and Location of Producers and Distributors: Canada Pipe Co. Ltd of Hamilton, Ont is currently the only manufacturer of ductile iron pipe in Canada. The company is a wholly-owned subsidiary of McWane Incorporated, a U.S.-based company.

Production and Capacity Levels: Canada Pipe Co. produces between 50 to 80 kT of pipe per year, with current levels being closer to the higher end of this range. Estimated production in 1993 was 65 kilotonnes. Close to 90% of Canada Pipe's product is produced for the watermain market, with the remaining 10% going to the wastewater market. The company produces pipe within the 4" to 30" diameter range, and has supplied larger diameter pipe in the past by importing product from its U.S. affiliate.

Imports and Exports: Imports of ductile iron pipe have been historically low, and virtually non-existent in 1993. Canada Pipe Co. reports that it exports about one-third of its production. Given an estimated 1993 production level of 65 kT, this would suggest annual exports of approximately 22 kT.

Revenues²¹: Total value of domestic sales of DI pipe is estimated at approximately \$26 million. Exports are estimated at \$9 million dollars, generating domestic revenues of \$35 million.

Number of Employees: It is estimated that Canada Pipe employed approximately 200 people in 1993.

10.2.5.3 Concrete Pipe

Concrete pipe is part of a larger industrial sector known as concrete products (SIC code 354). In 1993 domestic revenues and employment in this area were \$773 million, and 6,400 respectively (Stats. Can., 1993, 31-203).

²¹ Revenues are estimated using relative market shares of PVC and DI pipe, by length, in the watermain market, and the ratio of prices of PVC to DI pipe (per meter) taken from the costs of substitution section. Additional variables used include the weight of PVC (by kilotonnes) in the watermain market, and revenues accruing from the sale of PVC pipe products. All revenues are rough approximations.

Number and Location of Producers: There are 30 concrete pipe producers in Canada, with some companies being vertically integrated Canadian subsidiaries of international cement companies. Table 10-15 lists the major concrete pipe plants in Canada.

Table 10-15: Major Concrete Pipe Plants in Canada

Company	Location
Beton Provincial Ltee	Matane, PQ
Canadian Concrete Products (Calgary) Inc.	Calgary, AB
Con Cast Pipe	Guelph, ON
Fauteux Concrete Products	Windsor, ON
Fortier Montreal	
Groupe Tremca Inc.	Iberville, PQ
Inland Pipe	Calgary, Edmonton, AB; Saskatoon, SK
Hyprescon	Saint-Eustache, PQ
Industries Fortier	Trois-Rivieres, Saint Henri de Levis, Blainville, PQ
Lafarge Canada	London, Markham, Ottawa, Guelph, Mississauga, Thunder Bay, ON; Winnipeg, MB; Calgary, Edmonton AB
Les Industries de Ciment La Guadeloupe	La Guadeloupe, PQ
Langley Concrete & Tile	Langley, BC
Les Produits de Ciment Sherbrooke	Sherbrooke, PQ
Les Tuyaux de Beton Brunet	Valleyfield, PQ
Loc Pipe	Whitby, ON
Lombard Precast	Victoria, BC
M-con Products Inc.	Ottawa, ON.
Miceli & Freres	Mascouche, PQ
Munro Concrete Products	Barrie, ON
Ocean Construction Supplies	Vancouver, BC
Precon Products	Abbotsford, BC
Les Produits de Beton Casaubon	Ste. Elizabeth, PQ
Rainbow Concrete Industries	Sudbury, ON
V.J Rice Concrete Ltd.	Bridgetown, NS
Shaw Pipe	Lantz, NS; Moncton, NB
Strescon Ltd.	Saint John, NB
Turcotte, J.M., Ltee	Riviere du Loup, PQ
Tuvico	Laterriere, PQ
Tuyaux Vibres	L'Ancienne-Lorette, PQ
Ciments Vibracan	Laval, PQ
Waterloo Concrete Ltd.	Waterloo, ON
Weldon's Concrete Products	Saskatoon, SK
Wilson Concrete Products	Red Bank, NB

Production and Capacity Levels: The concrete pipe industry is suffering through a prolonged downturn due to low construction activity and significant PVC pipe substitution. Shipment volumes are reported at 589 kilotonnes for 1992, with reinforced pipe making up 85% of sales. This is well down from the 1985 level of 979 kilotonnes. There is considerable unused capacity in the industry.

Imports and Exports: Imports and exports of concrete pipe products are small due to the weight of the material and the cost of transportation. There are limited exports known to US border cities of Seattle, Detroit and Buffalo.

Revenues: In 1993 total shipments of concrete pipe, or the value of domestic sales, are estimated at \$155 million (Stats. Can., 1993, 31-203).

Number of Employees: The Canadian Concrete Pipe Association estimates total employment in Canada at about 2000-2300 people. The Ontario Concrete Pipe Association estimates that about 800 of these are employed in Ontario. Tubécon, the association of Quebec concrete pipe producers, estimates that around 700 people are employed in Quebec. Statistics Canada reports employment in 1993 at 987 (Statscan 1993, 31-203). For the purpose of this study, employment is estimated at 2000.

10.2.5.4 Other Plastic Pipe (PE, ABS)

As with PVC, other plastic pipe products (e.g. PE, ABS pipe) are part of a larger aggregation or industrial sector, plastic products (SIC 16). For the purpose of this study, PVC products are estimated to be 25%, by value of shipments, of this larger industrial sector, while employment is estimated by subtracting manufacturing employment related to PVC production from plastics products manufacturing employment²². In 1993, the total value of shipments (domestic production, including exports) for plastic products was 6.2 billion dollars, with employment of 41,323 (Stats. Can., 1993, 31-203). Based on 25% of production being PVC, domestic revenues for plastics products other than PVC is 4.65 billion, with employment of 30,992 people.

Number and Location of Producers

Table 10-16 show that there are about 25 companies operating about 35 plants producing some form of PE pipe or tubing. Big O Inc., of Exeter, ON, is one of the largest Canadian consumers of PE resin for pipe extrusion. Big O has 11 plants from Quebec to British Columbia, chiefly extruding PE corrugated farm and building drainage tubing, and at

²² The SIC code 16 (Plastic Products) does not contain all PVC production, notably PVC flooring and PVC coated textiles which are classified under SIC code 3993; Floor Tile, linoleum, coated fabric.

some plants, culvert and storm sewer pipe. IPEX also has a substantial presence in PE pipe in Canada. KWH Pipe (Canada) Ltd. of Huntsville, ON, the second largest Canadian consumer of PE resin, makes HDPE water pressure and sewer pipe up to 63 inches and MDPE and HDPE gas distribution pipe at plants in Huntsville, ON and Saskatoon, SK. The latter is primarily devoted to gas pipe production.

Table 10-16: Major PE Pipe Producers

Company	Location
Big O Inc.	Lauzon, Coteau du Lac, PQ; Forest, Hensall, Chesterville, Tilbury, Comber, ON; Taber, AB; Abbotsford, BC
Bovac Plastics Ltd.	St. Joseph Beauce, PQ
Bow Plastics Ltd.	Granby, PQ
Bruce Tile Inc.	Walkerton, ON
Caledonia Plastics Inc.	Concord, ON
Royal Industries Inc.	Abbotsford, BC
Foothills Plastics Industries	Calgary, AB
Ginn Bros Ltd.	Verdun, PQ
Thompson Plastics Inc.	Winnipeg, MB
Gravenhurst Plastics Ltd.	Gravenhurst, ON
Group Plasti-Drain Ltd	St Clet, Warwick, Alma, PQ
Ideal Drain Tile	Erva, ON
Imperial Pipe Corp.	Peterborough, ON
IPEX Inc.	St. John, NB
KWH Pipe (Canada) Ltd.	Huntsville, ON.; Saskatoon, SK
Modern Drainage Systems	Les Cedres, PQ
Oxford Plastics	Embro, ON
Plasco Manufacturing Inc	Langley, BC
Polytubes (West) Ltd	Edmonton, AB
PPE Extrusions Inc	Waterloo, ON
Progressive Pipe Inc	St Eustache, PQ
Royal Plastics Inc.	Weston, ON
SDM Inc	St. Lazare, PQ
Soleno-SPD Inc	Iberville, PQ
Temiskaming Plastics Ind	Earlton, ON

Production and Capacity Levels: Table 10-17 shows that total domestic demand for PE resin, including the processors' use of recycled material approached 46 kilotonnes in 1993.

Table 10-17: PE* Resin Demand for Pipe Applications
(kilotonnes)

	1990	1993
Corrugated HDPE	20	19
Non-pressure-HDPE	9	8
Pressure pipe-HDPE	8	7
Gas pipe-HDPE, MDPE	5	4
General purpose LDPE	9	6
Duct HDPE	2	2
Total resin	53	46

Source: CHEMinfo Services. * Includes 10 to 15 kilotonnes of recycled polyethylene

Assuming that the total weight of PE domestic demand for pipe is equal to 1.1 times the amount of resin (due to additives) generates an estimate of domestic demand for PE pipe of 51 kilotonnes. Including domestic demand of 14 kilotonnes of ABS, and exports of plastic pipe other PVC (15 kilotonnes) generates estimated production of 80 kilotonnes of plastic pipe other than PVC.

Imports and Exports: Exports of other plastic pipe are estimated at 15 kilotonnes, with imports of 17 kilotonnes (Stats. Can., 1993, 65-004, 65-007).

Revenues: Domestic revenues for other plastic pipe are estimated at \$154 million, based on 30% of total value of shipments of plastic pipe. The value of domestic sales of other plastic pipe is estimated at \$158 million, with exports valued at \$29 million, and imports valued at \$33 million.

Employment: It is estimated that this subsector employs approximately 800 people. Big O Inc. employs approximately 350 people across Canada, and KWH Pipe employs 150 people in their two locations. Many of the smaller plants employ a total of 20 to 30 people, not all of whom are involved in production-related activities.

10.3 Siding

PVC siding currently represents approximately 25% of total PVC resin demand in Canada, corresponding to a requirement of approximately 100 kT of PVC resin per year. The principal alternatives to PVC siding are aluminum siding and clay-brick, with other alternatives including wood and stucco.

A similar product market to siding is the soffit, fascia and rainware market (eaves, downtroughing, etc.), another market where PVC and aluminum compete. This market uses approximately 10% of the sheet area that siding does. PVC has only about 10% of this market, since installation is more labour intensive and troughs are not as leakproof as aluminum. The soffit, fascia and rainware volumes are included in the siding totals for this section.

10.3.1 Market Description for Siding

PVC siding was first introduced in the 1960s and now holds the major share of the siding market, as seen in Table 10-18. PVC siding first gained acceptance in the home renovation market. In the mid-1980s, when vinyl siding began to outsell aluminum siding, it held roughly 80% of the home renovation market, and 25% of the new home construction market. Currently the siding market is split 60% in new home construction and 40% in home renovation, with PVC siding having equally dominant positions (80-85%) in each segment. Sales in the siding market correlate well with new home construction, and home renovation. In the recent recession, growth slowed for new housing starts, although the renovation market fared better.

Table 10-18: PVC Growth in Siding
(millions of square meters)

	1984	1988	1993
PVC resin demand (kT)	34	54	102
Domestic Demand			
PVC siding (Mm ²)	10	15	23
Aluminum siding (Mm ²)	15	11	4
Total siding market	25	26	27

Source: CHEMinfo Services

Less than 2% of exterior siding installations are wood or stucco. Clay brick is also used, predominantly in new home construction, but fits an up-scale market niche compared to PVC and aluminum siding, being three to five times more expensive. Clay brick is estimated to account for 6 million square metres of siding in 1993. A major factor influencing market trends is that PVC siding is less expensive than aluminum siding or clay-brick, while possessing comparable technical characteristics to aluminum.

10.3.2 Technical Characteristics of PVC Siding and Alternatives

PVC resin alone is vulnerable to weathering by the elements. Thus, PVC siding manufacturers generally compound PVC resins to ensure the appropriate technical characteristics. Protective additives, such as UV stabilizers, prevent colour fading while impact modifiers prevent embrittlement, giving it increased weatherability, impact resistance and longer life. The inert nature of the PVC resin makes it resistant to salt corrosion and denting. Pigment is mixed throughout the resin, so scratches are often not visible. PVC can be embossed with a wood grain finish to provide surface texture.

Aluminum siding is produced through a metal extrusion process in which molten material is forced through profile dies under heat and pressure to form a continuous shape of uniform cross-section. Aluminum is very durable under normal conditions. The colouring on aluminum siding is a protective coating to prevent oxidation. Protective coatings, available in a broad range of colours, are applied to a cleaned surface. Since aluminum does not burn, it is specified in building codes for densely packed housing in certain urban areas. This zero lot zoning regulation is intended to prevent the spread of fire from one dwelling to the next. While PVC and aluminum siding are made using distinct technologies, their technical properties are fairly similar. Table 10-19 provides a brief comparison of technical factors.

Table 10-19: Technical Comparison of PVC and Aluminum Siding

Characteristic	PVC	Aluminum
Ease of Installation	High (similar to aluminum)	High (similar to PVC)
Weatherability	Good	Good
Chemical resistance	High; salt resistant	Medium; salt corrosion
Substrate impact resistance	High; resilient, bounces back	Low; dents
Heat distortion temperature	Low (80°C)	High
Cold impact resistance	Medium; can crack	Good; won't crack
Scratch resistance	High; uniform colour	Low; surface colour only
Colour flexibility	Medium; mostly pastels	High; all colours
Surface texture	can be embossed with finish	difficult to finish with texture
Fire resistance	Medium;	High

Source: CHEMinfo Services

10.3.3 Direct Replacement Cost for PVC Siding

The direct replacement model for PVC siding assumes that the 1993 domestic demand for PVC siding (23 Mm²) is replaced by an equivalent area of aluminum siding. As a comparison, complete substitution with clay-brick is also calculated. The model assumptions are as follow:

- aluminum siding cost is a 1988-93 average, and is 50% greater than PVC
- identical installation prices (1988-93) for aluminum and PVC siding;

As seen in Table 10-20, the direct cost of replacing PVC with aluminum is estimated at \$80 million/yr, while the direct replacement cost with clay-brick is estimated at \$1253 million/yr. All cost estimates incorporate the cost of installation.

Table 10-20: Direct Replacement Cost for PVC Siding

	PVC	Aluminum	Clay Brick
PVC siding annual sales (Mm ² /yr)	23	23	23
Material costs (\$/m ²)	7.00	10.50	16.00
Installation (\$/m ²)	8.50	8.50	54.00
Total installed cost (\$/m ²)	15.50	19.00	70.00
Total cost (\$million)	357	437	1610
Cost difference vs PVC (\$million)		80	1253

Source: CHEMinfo Services.

10.3.4 Direct Replacement Cost Compared to End Use Revenues

In 1993, the total value of domestic sales of siding (material and installation) in Canada is estimated at \$823 million, based on a domestic sales of \$162 million for PVC siding, \$37 million for aluminum siding, and \$91 million for clay brick, plus the costs of installation²³. The direct replacement costs (\$80 million) with aluminum represent 10% of the total installed value of domestic siding sales, while the costs of substituting with clay brick (\$1253 million) represent 152% of the value of total installed siding sales.

²³ The total costs (material plus installation) are generated by multiplying the value of domestic material sales by the ratio of total costs (material plus installation) to material costs contained in the direct replacement cost section.

The direct replacement cost using aluminum siding in new residential construction (\$48 million) represents 0.1% of the value of new residential construction (\$42,884 million). Using clay-brick, the ratio is 1.7%. In both cases, the total direct replacement costs are multiplied by 0.6 to account for siding used in new construction, rather than renovation.

10.3.5 Socio-economic Profile

As with other construction materials, the manufacturers of PVC siding and aluminum are not totally distinct, with some companies manufacturing both PVC and aluminum siding. Nevertheless, the producers are sufficiently specialized that the two manufactured products can be described, and compared, in terms of plants, capacity, production, import and exports, revenues, and employment. However, the distribution chain for the two products cannot be distinguished, with the same distributors selling both PVC and alternative products. The distribution chain will not be discussed further in this profile.

10.3.5.1 PVC Siding

Number and Location of Producers: Table 10-21 lists the 7 major PVC siding, soffit, fascia and rainware manufacturers in Canada. Most are located in Ontario, with one plant each in Quebec and British Columbia.

Table 10-21: Major PVC Siding Manufacturers

Company	Plant Location
Royal Building products	Woodbridge, ON
EMCO (formerly Building Products of Canada)	Acton, ON
Jannock (Daymond Building Products)	Mississauga, ON
Mitten Vinyl Inc.	Paris, ON
GenTek Building Products (Vytec Corp.)	Lambeth, ON
Duchesne et fils.	Yamachiche, PQ
Saunders Industries Ltd.	Richmond, BC

Production and Capacity Levels: Production capacity is estimated to be about 60 million m² per year. In 1993, the PVC siding production level in Canada was estimated to be 29 million m².

Imports and Exports: Approximately 20-25% of domestic production was exported in 1993, or about 6 million m² of PVC siding. Imports are assumed to be minimal (0).

Revenues: The value of shipments from domestic production of PVC siding (including exports) is \$203 million, based on a average 1988-1993 material price of \$7.00 per m². Domestic sales (excluding exports) are valued at \$161 million.

Number of Employees: Based on stakeholder interviews and other available information, employment in this subsector is estimated at 800 people. BPCO employs about 160 people in the siding plant. Daymond employs 225 people at the Mississauga plant, although not all are involved in PVC siding production. Royal produces siding from its Woodbridge plant, which employs about 100 people.

10.3.5.2 Aluminum Siding

Aluminum siding and other sheet and rain ware represents a small portion of all extruded aluminum products manufactured in Canada. An industry sector for aluminum products was constructed based on SIC codes 296 (aluminum rolling, casting and extruding), 3031 (metal door and windows) and 3099 (other metal fabricating industries). Domestic revenues associated with this larger aggregation are estimated at \$3.7 billion in 1993. Employment associated with aluminum products is estimated at 18,612.

Aluminum siding is part of SIC code 3099; other metal fabricating industries. This sector has domestic revenues of \$1.2 billion and employment of 7,928 (Statscan, 1993, 31-203).

Number and Location of Producers: Aluminum siding is produced by a small number of firms, including GenTek Building Products, Reynolds Building Products and Kaycan Ltee. The siding manufacturing plants for these three companies are located in Quebec, close to the raw material source. These three producers control about 80% of the market, with the remainder of the market share being held by a number of small manufacturers.

Production and Capacity Levels: Annual aluminum siding production levels in Canada are estimated to be 3.1 million m². This is roughly half of the production levels of 1988. Production levels of aluminum siding are decreasing at a rate of 12 to 15% per year, with PVC siding picking up the majority of this lost market share.

Imports and Exports: Total exports for 1993 were estimated at 0.5 million m². Imports are assumed to be minimal (0).

Revenues: Based on an estimated 1988-1993 price of \$10.50 per m² the current value of production (including exports) can be estimated as \$33 million. The annual value of domestic sales (excluding exports) is estimated at \$27 million.

Number of Employees: Based on the ratio of domestic revenues from aluminum siding (\$33 million) to domestic revenues in SIC code 3099 (\$1.2 billion) multiplied by employment in SIC code 3099 (7928), employment in aluminum siding manufacture is estimated at 218 people in 1993.

10.3.5.3 Clay-Brick

Number and Location of Producers: There are about 10-15 brick producers in Canada, over 75% of whom are located in Ontario, where brick use in houses is more common.

Production and Capacity: Based on SIC code 3511; clay products from domestic clay, domestic revenues from clay-brick manufacture are estimated at \$91 million (Stats. Can. 1993, 31-203). Using a material price of \$16 per square metre, production of clay-brick is estimated at 6 million square metres in 1993.

Imports and Exports: Imports and exports are assumed to be negligible (0).

Revenues: Domestic revenues are estimated at \$91 million in 1993. (Statscan, 1993, 31-203).

Number of Employees: Manufacturing employment in clay brick production is estimated at 521 (Stats. Can., 1993, 31-203).

10.4 Window Profiles

Window profiles are the linear extruded components used in the fabrication of window frames. The window profile market includes both commercial and residential segments. However, since little PVC is used in the commercial window profiles market (which is dominated by aluminum) only the residential window profiles market will be described.

In 1993, the total amount of PVC resin used for rigid window profiles was 69 kT. This represents approximately 18% of total PVC resin use in Canada. The major alternative materials in the residential window market are aluminum and wood. In addition to all-aluminum and all-wood profiles, materials are often combined to reduce cost, improve energy efficiency, and improve strength.

10.4.1 Market Description for Windows

As with other construction materials, the window market follows trends in construction, and demand correlates well with new housing starts. With changing demographics, the large-home market has declined in the last couple of years (early 1990s), and a higher number of smaller homes are being built. This leads to an overall decrease in the average home size, with a lower average number of windows per house. However, new home owners are often preferring larger, energy efficient windows in living areas.

The 1993 residential window market was about 4.3 million openings. In 1993, wood was still the leading Canadian window material in total with about 42% of the residential market. PVC was second and growing, with about 33% of the market. Aluminum has the lowest market share, at about 24% of the residential market.

As shown in Table 10-22, the residential windows market is divided into new construction and renovation, of which new construction is about 57% and renovation the remaining 43% of window openings. In the new construction market, PVC holds about 26% of the market, while wood holds about 42% of the market, and aluminum holds about 24% of the market. In the renovation market, PVC holds about 45% of the market, while wood (31%) and aluminum (24%) share the remaining market.

PVC window profiles first appeared in the Canadian market in the late 1970's. In 1982, solid PVC windows were estimated to have only about 4% of the total window market, held mostly in the renovation segment. Through the late 1980s, PVC windows grew to gain about 15-20% of the residential window market share. While growth was stagnant during the 1989-91 recession, there has been high annual growth since 1991. Current trends indicate that PVC will likely surpass wood as the leading Canadian window material by 1996, at the expense of both wood and aluminum.

Table 10-22: Canadian Residential Windows Market, 1993
(million openings)

	New Construction		Renovation		Total Residential	
Wood	1.2	50%	0.7	31%	1.9	42%
PVC	0.7	26%	0.8	45%	1.5	33%
Aluminum	0.6	24%	0.4	24%	1.0	24%
Total	2.5		1.9		4.4	100%

Source: CHEMinfo Services

The principal reasons for increasing market share for PVC windows compared to wood is durability and low maintenance. Aluminum offers a durable, low maintenance alternative, but it has had difficulty competing on cost with PVC windows.

10.4.2 Technical Characteristics of PVC Windows and Alternatives

Both PVC and aluminum windows offer durable materials which have a long product life. The weather resistance of wood windows tends to be lower than PVC or aluminum. A paint layer, which needs regular maintenance every 3-5 years, adds to cost, but prevents the underlying wood from drying out, warping and cracking. The main technical advantage of PVC over aluminum is lower heat conduction, but all windows can be designed with thermal insulation breaks to achieve high insulating value.

The main determinant of the durability of PVC compared to aluminum windows is the composition of the PVC compound used in production. Cracking, warping and heat deflection can occur under extreme temperature and sunlight conditions if the PVC profile is too thin, contains too much filler or is not properly compounded. In addition to filler, impact modifiers and UV stabilizers are added to extend the life of the material. These additives will typically comprise from 5-10% of the weight of the PVC compound.

PVC and wood do not have the comparable strength of aluminum, which partially explains the relatively stable market share of aluminum material in larger residential windows. Table 10-23 summarizes some technical factors between PVC windows and alternatives.

Table 10-23: Technical Comparison of Window Frame Alternatives

Characteristic	PVC	Aluminum	Wood
Durability/Longevity	High	High	Low
Strength	Medium	High	Medium
Warping	Medium	Low	Medium
Impact Resistance	Medium	High	Medium
Electrical conduction	No	Yes	No
Thermal efficiency	High	Low	High
Maintenance	Low	Low	High
Ease of Assembly	Medium	Low	Medium
Colour range	Low; pastels	High	High; with paint
Design Flexibility	High	Medium	Medium

Source: CHEMinfo Services

10.4.3 Direct Replacement Cost for PVC Windows

Economic comparisons between window materials are very difficult to make because of the wide variety of design features such as style and size. The assumptions used to estimate the costs of substituting for PVC windows are listed below:

- the total number of annual PVC window openings (1456 thousand) is replaced by wood, or aluminum.
- cost/window was based on consumer pickup price (excluding taxes) for a standard 3' by 5' double casement window, since this is the most common type of window sold in the residential market;
- cost/window was based on a sample of five window companies; and
- installed prices were not included, since manufacturers indicated that installation costs depended on size, not materials.

As shown in Table 10-24, the replacement of PVC window profiles with wooden windows is estimated to result in an annual savings of approximately \$118 million. Replacement with aluminum windows would result in an annual cost of \$55 million.

Table 10-24: Direct Replacement Cost for PVC Windows

	PVC	Wood	Aluminum
Number of Openings (millions)	1.5	1.5	1.5
Average Cost ¹ (\$/window)	309	230	345
Total Cost (\$ millions)	463	345	518
Cost Difference (\$ millions)		(118)	55

¹ Consumer pickup price average: 3'x5' double casement standard.

10.4.4 Direct Replacement Cost Compared to End Use Revenues

For 1993, the total domestic value of window sales is estimated at approximately \$1.2 billion, based on domestic sales of \$463 million for PVC, \$419 million for wood, and \$367 million for aluminum windows. The direct replacement cost with wood, (-\$118 million) represents a savings of approximately 10%, while the direct replacement cost with aluminum (\$55 million) represents an added cost of approximately 5% of the total value of window sales.

In the residential market, the direct replacement savings with wood (60% of \$118 million) represents a cost savings of 0.28% of the value of new residential construction (\$42,884 million). The direct replacement cost with aluminum (60% of \$55 million) represents 0.08% of the value of new residential construction. In both cases, the total direct replacement costs are multiplied by 60% to account for new construction only, and not renovation.

10.4.5 Socio-economic Profile

Two distinct manufacturing businesses are involved in the production of windows, producers of profiles and lineals, and window fabricators. The extrusion of PVC and aluminum window profiles and lineals is carried out by a small number of companies serving regional, national and export markets, while wood lineals are supplied by lumber yards. These products are then assembled into windows by a large number (about 250) of window and door fabricators. Large regional and national window and door fabricators typically handle custom designs and smaller regional fabricators tend to handle standard designs. Fabricators will typically handle more than one alternative product, producing finished windows from lineals and profiles supplied by PVC or aluminum extruders, or in the case of wood, lumber yards.

As with other construction materials, there is a similar trend in the production of window profiles and lineals, particularly with aluminum and PVC. Many aluminum and PVC producers (extruders) operate plants producing both aluminum and PVC window profiles. Nevertheless the socio-economic profile will attempt to distinguish between production of aluminum, PVC and wood window profiles and lineals.

10.4.5.1 PVC Windows

Number and Location of Producers: Three firms are the major producers of PVC window lineals and profiles in Canada. The largest is Royal Plastics Ltd. of Weston, Ont., the largest producer in North America. Window profiles are Royal's original and largest product line. Royal is estimated to hold 80% of the Canadian PVC windows market. Rehau Building Products of Burlington is a Canadian subsidiary of Rehau of Germany. They produce window lineals, among other PVC products, at three plants: Montreal, PQ; Prescott, ON; and Winnipeg, MB. Rehau has strong connections with the European market, where PVC building products are firmly entrenched. GenTek Building Products Ltd. is the former building products division of Alcan, a major presence in the market, which operates a PVC extrusion plant in Lambeth, ON

Production and Capacity Levels: Total domestic production of PVC windows is estimated at 1.8 million openings.

Imports and Exports: Annual exports for 1993 are estimated at 300,000 openings, or approximately 17% of production. Imports are assumed to be minimal (0).

Revenues: Based on 1.5 million domestic openings, and an 1988-1993 average price of \$309 per opening the value of domestic sales of PVC windows is \$463 million. Adding exports of 300,000 openings allows an estimate of domestic revenues (domestic sales plus exports) of \$556 million.

Number of Employees: Total manufacturing employment in this subsector is estimated at 800 people.

10.4.5.2 Aluminum Windows

As with aluminum siding, aluminum windows are a small component of all aluminum products. Aluminum windows form part of the four digit SIC code 3031; Metal Door and Window Industry. Domestic revenues for this four digit code are \$922 million, with employment of 6491. (Stats. Can., 1993, 31-203)

Number and Location of Producers: As with siding, the aluminum window profiles sub-sector is controlled by a small number of firms, including GenTek Building Products and Reynolds Building Products.

Production and Capacity Levels: In comparison to total revenues for this sector from domestics sales, revenues attributed to imports and exports are negligible. Therefore, domestic production of aluminum window profiles should approximate domestic sales of 1.1 million openings.

Exports and Imports: Imports and exports of doors, windows and frames of aluminum are \$16 million and \$11 respectively (Stats. Can., 1993, 65-004, 65-007). Assuming that 40% of these sales are for windows generate estimates of \$6 million in imports, and \$4 million in exports of windows, for a trade deficit of \$2 million.

Revenues: The total value of domestic sales for aluminum window profiles is estimated at \$367 million based on domestic demand of 1063 thousand openings, and a average price of \$345 per window. Domestic revenues are estimated at \$365 million.

Number of Employees: Based on the ratio of domestic revenues in aluminum windows (\$365 million) to domestic revenues in metal doors and windows (\$922 million), multiplied by employment in metal doors and windows (6421), employment in aluminum windows manufacture is estimated at 2543 in 1993.

10.4.5.3 Wood Windows

Wood lineal and profile production is simpler than the high volume extrusion techniques employed in PVC and aluminum window profiles and lineals. The industry in Canada is therefore more fragmented. Regional lumber companies supply local fabricators with lineal stock, generally made of pine or cedar.

Wooden window lineals and profiles are a small component of a larger industry product sector, Wood Industries (SIC 25). In 1993 total domestic revenues associated with this sector were \$19 billion dollars, while associated employment was 92,000. The majority of wood products from this sector are structural components for housing. The four digit SIC code corresponding to wooden windows is 2543: Wooden Door and Window Industry. Domestic revenues associated with this sector are \$1 billion, with employment of 7,936.

Number and Location of Producers: There are several manufacturers of wood window profiles in Canada. Some of the larger firms are: Dashwood Windows (Centralia, ON),

Lock-wood Ltd. (Scoudouc, NB), C.P. Loewen Enterprises of (Steinbach, MB) and Mason Windows of Pickering, ON.

Production and Capacity Levels: Domestic production of wood window profiles should approximate sales at 1.8 million units.

Imports and Exports: Exports of wooden windows are valued at \$30 million, while imports are valued at \$32 million (Stats Can, 1993; 65-004, 65-007) for a trade deficit of \$2 million.

Revenues: The total value of domestic sales of wood profiles is estimated at \$419 million, based on 1823 thousand window openings, at an average price of \$230 per opening.

Number of Employees: Based on the total number of manufacturing employees employed in SIC code 2543 (7936), multiplied by the ratio of domestic revenues in SIC code 2543 (\$1 billion) to domestic revenue from wooden window manufacturing (\$419 million), employment is estimated at 3309.

10.5 Wire and Cable

PVC and polyethylene are the principal materials used in the Canadian wire and cable industry to provide insulation and jacketing for more than 30,000 different types of wire and cable products. The different types of polyethylene used in this industry are linear low-density (LLDPE), medium-density (MDPE), high-density, (HDPE), and cross-linkable polyethylene, (XLPE). Lesser amounts of nylon, polypropylene, styrenics, acrylic, thermoplastic elastomers (such as EPDM), fluoropolymers, and other resins are also used.

As shown in Table 10-25, there was an estimated 29 kT of PVC resin used for wire and cable insulation and jacketing in Canada in 1993. Due to the requirement for material flexibility in wire insulation and jacketing, the wire and cable industry uses PVC compounded with plasticizers and additives rather than raw PVC resin, which is rigid. PVC lends itself to wire and cable usage because of its flame retardant properties and its ability to be compounded to attain a variety of performance properties for a relatively complex and diverse set of applications.

Table 10-25: Polymer Use in the Wire and Cable Industry
(kilotonnes)

	1983	1988	1993
Polyethylene	19	38	33
PVC	22	32	29
Other	3	5	5
Total	44	75	67

Source: CHEMinfo Services

A typical average PVC wire and cable compound consists about 50% resin, 20% plasticizer and 30% fillers and stabilizers. This yields an estimate of 58 kT of flexible PVC compound consumed in this industry in 1993. Roughly two-thirds of this material is compounded from PVC resin and additives on-site (captively) by a few major wire and cable producers. The remaining compounded material on the market is purchased by smaller wire and cable producers, who represent a major market segment for merchant PVC compounders.

In contrast to PVC, polyethylene is more commonly purchased in pure resin form which may require only minor compounding, sometimes with the addition of small amounts of colour concentrates. Cross-linkable polyethylene generally requires the addition of catalysts and optional colouring agents.

There are four general categories of wire and cable in which polymer insulation and jacketing are used extensively.

1. **Building wire** is all electrical wiring for the interior of buildings. It is typically rated for 600 volts or less and includes lower voltage residential and commercial wire and higher voltage industrial cable. Building wire represents approximately 38% of the value of domestic shipments of wire and cable.
2. **Power cable** is all of the insulated cable used in an electrical distribution system, from the generating station through primary and secondary distribution networks to the building or plant entry point. Approximately 30% of the value of shipments of domestic production is power cable.
3. **Telecommunications cable** (telecable), includes copper and fibre optics telephone voice and data transmission lines, TV and radio cable, and electronic signal and control cable. It represents about 24% of the value of domestic shipments.
4. **Miscellaneous wire and cable** includes flexible electrical cords for small appliances, heaters and fixtures; control wire and cable; automotive wiring, and light-duty portable electrical wire. This category makes up the remaining 8% of the value of domestic shipments.

The following market analysis will discuss the markets for wire and cable using the four different types of wires and cables listed above.

10.5.1 Market Description of Wire and Cable

As with other construction materials, wire and cable demand is linked closely to economic activity, particularly to industrial and residential construction. Based on 58 kT of PVC compound, 33 kT of PE resin, and 5 kT of other resin, the market shares of polymers used in the wire and cable industry are 60% (PVC), 34% (PE), and 6% (other). Some of the other compounds used in this market include: ethylene-vinyl acetate (EVA) copolymer, thermoplastic elastomers (TPEs) and some block copolymers.

PVC compound is used in several major application areas, including: low voltage building wire insulation and jacketing, low and medium voltage equipment cable

jacketing, control cable jacketing, indoor telecommunications cable, automotive wire and flexible cords.

PVC demand has increased in wire and cable due to general economic growth and an increased global use of commodity cables using a PVC construction. One significant trend away from PVC is the increasing adoption of low- or zero-halogen PE resins in jacketing for new and replacement electrical and telecable installations in transit systems, shipboard systems, major commercial and institutional buildings (office towers, schools, hospitals etc.) and telephone switching stations. A second development is the switch from PVC-nylon insulation to moisture-cured XLPE in the NMD-90 residential building wire niche. This has been undertaken by one major Canadian wire and cable producer.

One of the major determinants of market demand in this sector are standards. All wire and cable standards in Canada, including building wire, power cable and telecommunications cable are developed by the Canadian Standards Association (CSA), in the U.S. by Underwriters Laboratories (UL) and in Mexico by National Association of Standardization and Certification of the Electrical Sector (ANCE). The governing standards are in accordance with the rules of the Canadian Electrical Code (CEC), the U.S. National Electrical Code (NEC) and the Mexican Electrical Code. Harmonization of Canadian, U.S. and Mexican building wire and power cable standards is in progress. Standards for flexible cords, shipboard cable, telecommunications cable and many types of power cable have been harmonized as per the NAFTA initiative. The effect of this harmonization allows wire and cable producers to compete more freely in the continental North American market.

The Electro Federation of Canada (which represents wire and cable producers) and several industry technical managers claim that the substitution for PVC by alternatives in some products may result in significant cable design changes to match performance levels and may require changing some standards. The process to bring about changes to standards typically involves a detailed review and consensus from a CSA Subcommittee of the Technical Committee on Wiring, who review technical and economic feasibility. This operates under the jurisdiction of the CSA Steering Committee on the Canadian Electrical Code. Final review is required by the Standards Council of Canada for approval as a National Standard of Canada.

In Europe, PVC has been replaced in a few wire and cable applications. The market has accepted the use of non-halogen flame retardant PE and moisture-cured XLPE for insulation and jacketing in some flexible cords, appliance wires, building wire and many other end uses. The use of inexpensive aluminum trihydrate ($\text{Al}(\text{OH})_3$) flame retardant additive is quite common. Calcium carbonate can also be used as a filler to provide a PE compound that is price-competitive with PVC compound. Some companies, like IKEA of Sweden, have started with their own specifications and converted appliance cords to non-

halogenated PE alternatives. The specifications are undergoing review. For regulation of broader applications, like changes to the building codes, the process can take several years.

The following sections will briefly describe the markets for different types of wires, including the relevant standards mandating different types of polymers for specific types of wires.

10.5.1.1 Building Wire

Building wire is any low-voltage (typically less than 600 volts) electrical power wire installed inside buildings. More than 15,000 types of building wire are manufactured. They differ on many variables including: number of wires (including ground wire if necessary), conductor gauge, voltage rating, insulation (type, thickness and temperature rating), jacketing, shielding (armour), and moisture resistance. There are also different constructions for export markets. Despite the wide variety, the building wire market has standardized, with many of the high-volume wires produced as commodities. Table 10-26 summarizes the main types of wires used.

Table 10-26: Building Wire Types and Polymer Used²⁴

Class	Market Share	Insulation	Jacketing
Multiple conductors			
NMD-90	38%	PE, PVC-nylon	PVC
AC-90	24%	XLPE	PVC/Metal
Single Conductors			
RW-90	14%	XLPE	none
T-90	11%	PVC-nylon	none
TW-75	13%	PVC	none

Source: Electro-Federation of Canada

NMD-90 is the most widely used building wire, accounting for 38% of use. Until recently, NMD-90 had almost always been insulated with a PVC-nylon construction, plus a PVC jacket over the three or four-wire assembly. The tough, thin nylon membrane contributes high-temperature tolerance and the mechanical properties required by the relevant CSA standard. In 1990, Alcatel/Canada Wire switched from PVC-nylon to

²⁴ Market share data, based on dollar value of domestic shipments only, is for 1990.

moisture-cured XLPE for NMD-90 insulation, while the jacketing remained as PVC compound. Other producers continue to use the PVC-nylon construction for insulation.

This change was complementary to a standards change in the U.S. permitting XLPE in NMD-90, in addition to the traditional standard PVC. There is currently no indication that producers or users will seek standards changes that would allow XLPE use for the other PVC-insulated building wire types (i.e. TW-75 and T-90) which account for about 20% of PVC volume and 10% of polymer volume in all building wire.

AC-90 and RW-90 are insulated with XLPE, and neither product has polymer jacketing, since it is usually run through ducts. Consequently, no PVC is used in the manufacture of these products. RW-90 is a heavyweight alternative to the PVC-insulated T-90 single wire type also used in similar building applications. Both T-90 and TW-75 are insulated with PVC.

10.5.1.2 Power Cables

Power cable is defined here as any electric power wiring carrying over 550 volts for the distribution of electric power. This includes the following types of cable:

- high voltage primary distribution cable
- secondary distribution cable (underground and overhead lines)
- commercial and industrial low and medium voltage power cable
- control cable

High and medium voltage overhead wire used in conjunction with ceramic insulators is usually an uninsulated aluminum construction. Most insulated overhead wiring is in secondary distribution lines carrying 300-600 volts. PVC is almost never used for insulation of power cables above 600 volts, due to its lower insulating property. In the Canadian marketplace, PE types are widely accepted. PE types employed for power cable are low-density crosslinkable (XLPE), thermoplastic medium-density polyethylene (MDPE) and high-density polyethylene (HDPE) grades. In the past, MDPE has been the insulating polymer of choice for overhead cables, but XLPE has taken much of this market away. Peroxide-cure or moisture-cure XLPE are used almost interchangeably for power cable insulation. The peroxide-cure XLPE cable insulation is slightly more durable and offers better flame retardant compounding ability as compared to moisture-cure XLPEs.

PVC and XLPE are both used for power cable jacketing in Canada. Underground wiring (buried with or without ducting) is insulated with XLPE, MDPE or HDPE and can have a PVC jacket, a XLPE jacket, or none at all. One supplier estimates that only about 50% of

Canadian power cable is jacketed, since several provinces specify unjacketed cable for underground distribution ducts. The removal of jacketing allows larger diameter conductors, carrying a higher capacity, to be used in ducts. Hydro-Québec, for example, specifies only unjacketed cable and it represents about 25% of the market for underground cable. Saskatchewan is undergoing a rewiring of the province using mostly unjacketed cable.

Low and medium voltage power cable is used to distribute power in large buildings, industrial sites, and transit systems. Medium voltage control cable is used to regulate voltage on large electrical equipment. There is a large amount of PVC jacketing used for these two applications, due to fire code restrictions on flame propagation. To date, there has been very little flame-resistant PE or XLPE jacketing used in these higher risk applications. However, in certain niches (such as in certain commercial and transit cable installations), there has been increasing use of low-smoke, halogen-free jackets because of the other fire risks of smoke emission, corrosivity and toxicity. Some commercial buildings (like the World Trade Center in New York), US Navy vessels and Newfoundland offshore drilling applications have chosen to replace PVC jacketed power cable. Many transit systems have specified low-smoke, halogen-free cables for underground areas.

In the United States, a PVC/nylon construction is used for insulating wire with voltages less than 1 kV and EPDM is often used to insulate medium voltage wire (1-5 kV). The use of XLPE for insulation is not as prevalent in the US as it is in Canada, since the moisture-cure technology has not taken hold there. In Europe, PVC is employed in insulation for cables up to 5000 volts, but heat losses become unacceptable beyond that. PVC is more susceptible to moisture permeation, but is preferred for power cable jacketing because of its superior flame-resistance, flexibility, good weatherability and low cost.

10.5.1.3 Telecommunications Cable

Telecommunications cable, or telecable, includes standard copper cables, fibre optics cable, TV and radio coaxial cable, and the various electronic data transmission and low-voltage pulse wiring used for computers and as signal and control system wiring. There are over 3,000 different telecable wiring types, with differing gauges, insulating materials, shielding methods, ohm ratings and other specifications as dictated by end-use requirements and installation environment. Fibre optics cable constructions are generally unique to each manufacturer. In Canada, about 75% of telecable demand originates with telephone utilities and the rest with suppliers of business teledata systems.

The PE/PVC usage ratio in Canadian telecable production is about 3:1. PE is generally used for insulating and jacketing of telecable installed outside buildings, while PVC is used for cable inside buildings, due to its superior flexibility and flame retardant properties. Canadian building codes require use of PVC telecable. PE-based resins with equivalent flame-resistant properties to PVC are available at higher costs. However, at the present time, approval of the PE resins by standards-writing bodies and market acceptance is uncertain.

Electronic wiring, or pulse code modulation (PCM) cable, is low-voltage (up to 24 volt) wiring designed to carry digital electronic signals. Electronic wiring is variously insulated with PVC, XLPE, LDPE and MDPE and most often jacketed with PVC. A typical construction consists of multiple pairs of conductors, each conductor being insulated with 10 mil of PVC and covered with an aluminum-mylar composite shielding tape which serves to prevent noise transmission between adjacent conductor pairs. The assembly is sheathed with a PVC jacket.

Control cable and instrument cable are insulated either with PVC or XLPE, the former being more widely used. XLPE-insulated wire is more expensive than PVC and is generally used for wiring for higher temperature (125°C) and severe service environments.

10.5.1.4 Miscellaneous Wire and Cable

The miscellaneous wire and cable segment includes low voltage flexible cords and automotive wire. Flexible cords, appliance and equipment wire represent over half of the wire and cable sold. PVC compounds account for over 80% of compounds utilized in this category.

Automotive wiring represents less than half the use in this category. Primary wire and ignition wire are produced. Primary wire, about 90% of the total, is used for electrical circuits for headlights, etc., and consists of a copper conductor insulated with either PVC or XLPE made to Society of Automotive engineers (SAE) specifications. The choice of PVC- or XLPE-insulated wiring is related to temperature, XLPE being used for high temperature (i.e., 125°C by SAE specifications) under-the-hood applications. Some vehicle models have PVC-insulated wiring throughout. In Canada, PVC still accounts for a large portion of use. XLPE can be formulated to nearly match PVC performance. Use of XLPE in primary automotive wiring in Canada is small, although XLPE is being increasingly specified in place of PVC by original equipment manufacturers. One compound supplier reports that the US has converted most automotive wire uses to XLPE, while Europe has not joined the trend. One issue is that cross-linked material does not recycle easily, so is less favourable in the development of fully recyclable vehicles.

10.5.2 Technical Characteristics of PVC in Wire and Cable and Alternatives

Wire and cable systems are designed to meet a wide variety of individual performance requirements by using different constructions of materials each with a different set of properties. It is often very difficult to isolate the effect of one material component on the performance of a entire cable construction. Due to the highly diversified nature of wire and cable products and the complexity of specifications for various applications, this technical comparison of PVC wire and cable products will highlight only a few key technical characteristics which influence the choice of material.

Flame Retardance

The principal technical characteristic that differentiates between PVC and PE types of wire and cable is the flame retardant qualities of PVC resin. The intent of fire code specifications is to ensure that insulation and jacketing materials are sufficiently flame resistant to delay the spread of fire long enough for people to safely evacuate a building. The presence of chlorine in the molecular structure of PVC resin gives the material a much higher flame resistance than other thermoplastics such as PE.

PVC, unlike most other common thermoplastic resins is too rigid to be processed in pure resin form. It has to be stabilized, and in most cases, plasticized. In the case of PVC compounds for wire & cable applications, the use of plasticizers to soften and provide good low temperature properties is a common practice. While plasticizer additives such as phthalates are flammable, the PVC resin itself is resistant to combustion and the propagation of flames. For this reason, PVC compound is chosen as an inexpensive jacketing material in many interior wire and cable applications.

Thermoplastic or cross-linked PE resin with no flame retardant will burn easily in a fire. It is possible to load PE or XLPE with flame retardant additives to various degrees which will give the compound certain flame retardant properties, some comparable to that of PVC. A common halogenated flame retardant system includes the use of decabromodiphenyloxide ("decabrome") combined with antimony oxide. Common inorganic flame retardants include aluminum trihydrate and magnesium hydroxide. Flame retardant PE or XLPE can be compounded to meet or exceed PVC in limiting oxygen index²⁵ (LOI) tests, but may have different performance or hazards than PVC in actual fire conditions. High levels of flame retardant additives may adversely affect some of the physical properties of the compound, such as melt index, tensile strength, elongation and flexural modulus. Where inadequate resistance to flame propagation is experienced, these

²⁵ Defined as the minimum concentration of oxygen in air required to sustain combustion. A higher number indicates a better flame retardant system.

compounds can only be used on larger diameter conductors having a higher heat sink. (In flame tests, larger conductors draw more heat away from the flame site, increasing the time required for flames to propagate.) The Electro Federation of Canada²⁶ has stated that, "PE-based resins with equivalent flame resistant properties to PVC are available at higher costs and lower all around performance." A US-based compound supplier echoes this sentiment, saying that a compromise in some specifications may be required if PVC is to be replaced in some high performance applications.

An adverse consequence of the flame retardant nature of PVC is the risk of generating potential health and environmental effects associated with the combustion by-products generated when PVC is burned. The combustion by-products produced when PVC is burned include smoke, acid gases (predominantly hydrogen chloride) and organochlorine compounds. Low acid gas PVC compounds are available with the addition of brominated and antimony flame retardants. These reduce the potential HCl concentration from levels of 20-36% down below 14%. PE compounds with low- or zero-halogen flame retardants have been developed to address these concerns.

According to resin suppliers, there are differences between the various flame retardant polyethylene compounds. First, there is a difference between the ability of the two main types of XLPE to be loaded with flame retardants. Peroxide-cure XLPE can handle significantly higher loadings of flame retardant additives and can be compounded to meet flame tests. A US compounder claims that by using halogenated flame retardants, a peroxide-cured XLPE can pass the most severe flame tests, while the use of inorganic flame retardants is less preferable. Moisture-cure XLPE is sensitive to a pre-curing tendency from the hydration action of some inorganic additives and the curing process can be retarded by the presence of halogens in some flame retardants. One wire and cable producer claims that flame retardant, moisture-cure XLPE isn't likely to pass severe flame tests. Second, thermoplastic PE can be compounded with flame retardants for jacketing materials, but has a limitation on high temperature (>75°C) service and does not perform as well in flame tests due a tendency to lose its physical structure under heat.

Building Code Flame Tests

There are different levels of building code fire standards that must be met by wire and cables in different interior applications. These tests measure the performance of a complete cable construction, not just the jacketing material. An example of a low severity standard is the CSA FT-1 flame test for low voltage building wire, used commonly in residential housing. The test applies a flame having about 500 watts of energy (the rough equivalent of a bunsen burner flame) to a wire for five 15-second applications. The CSA FT-4 flame test is much more demanding for cables in vertical trays, with flame energy levels (about 70,000 BTU/hr) about 40 times higher than the FT-1 test. Typically, a cable

²⁶ Electro Federation of Canada, letter from Mike Hopkins to Tom Muir, Oct. 16, 1996.

requires aluminum armouring or a highly flame retardant PVC compound combined with the jacketing in order to pass this test. The most severe flame test is the CSA FT-6 horizontal flame and smoke test, which is mandated for plenum²⁷ installations in some provinces such as Ontario, Quebec and BC. Flame and smoke retardance is critical in plenum areas of buildings, since air from this area is usually returned through ventilation systems to heating or air conditioning units and redistributed by fans throughout a building or plant. No non-halogen materials will meet this standard. With increasing severity of fire code flame tests, the ability of a flame retardant XLPE to meet specifications can be increasingly compromised by other physical performance factors, due to the extra loading of flame retardants.

Electrical Insulation

PE and XLPE have better insulating properties (lower dielectric constants) than PVC and are used in more applications. This property allows less of the energy transmitted down the conductor to be lost through heat dissipation. In Canada, PVC is not used for insulation in wire having voltages above about 600-1000 volts.

Temperature Range

PVC can be compounded to retain its performance properties over a broad temperature range. Most PVC is rated for safe use at 90°C and 75°C in wet conditions, but some can be used safely up to 105°C. Most XLPE is rated for 90°C in both wet and dry conditions. Development work continues to increase the maximum temperature rating of both compounds to 105°C, in order to increase the capacity to carry current. Thermoplastic PE will not operate satisfactorily at temperatures of 90°C, since it softens and melts near this temperature. Above about 107°C, XLPE softens somewhat, but is still more resistant to deformation than PVC, and continues to provide good insulation at temperatures up to about 150°C.

Flexibility

The flexibility of compounded PVC is an important property in wire and cable applications. PVC, when properly compounded, can meet cold temperature performance standards as measured by cold bend and impact tests. In cold weather service, such as a outdoor wire and cable, it is very important to retain flexibility and prevent cracks from forming in insulation or jacketing in installation or under flexural stress during service. Outdoor cable is usually required to pass tests at -40°C. This requirement has recently been harmonized with the US from -35°C to -40°C for flexible cords. Flexibility is required when installing cables through conduits and around bends in buildings. The integrity of a cable can be compromised if a crack occurs due to over-bending. The use of PVC adds more flexibility to a cable than PE or XLPE does. One supplier reports that in

²⁷ The plenum is the general air space above ceiling panels and beneath structural ceilings where wires are run and where smoke can accumulate.

BC, electrical unions demanded and received a concession that PVC jacketing be specified over PE for power cables due to ease of handling concerns. However, this is at the expense of lower resistance to moisture vapour permeability and abrasion resistance.

Durability

The cross-linking of polyethylene by catalytic action creates a much more durable thermoset material than the thermoplastic resins. XLPE generally has higher tensile strength with higher resistance to abrasion and weathering. XLPE used mainly in insulation applications in power cables, but sometimes in jackets when resistance to abrasion or to hydrocarbon oils and fluids is required. Even in fire situations, flame retardant XLPE retains its physical structure far longer than flame retardant thermoplastic PE, making it the preferable alternative for higher risk areas.

The downside of the cross-linked structure is that since XLPE is no longer a thermoplastic, it cannot be recycled easily. This requires more care during production, to keep scrap levels down. Although there are some outlets for XLPE scrap, its disposal is mainly by incineration. XLPE is not usually as flexible a compound as plasticized PVC. Some cables with a XLPE construction can be somewhat stiffer and more difficult to handle than ones having plasticized PVC in the construction.

Thermoplastic elastomers (TPEs) are a broad range of products which combine the processability properties of a thermoplastic with the flexibility and durability properties of a thermoset elastomer. While they tend to be expensive compounds, they provide excellent cold weather flexibility and high resistance to aggressive (chemical, mechanical stress) conditions. There is only a minor volume of flame retardant TPEs on the market for niche applications.

Processing

As thermoplastics, the processing of PVC, thermoplastic PE and TPE wire and cable is a relatively straight-forward extrusion process. In contrast, the processing of XLPE is a reactive system which can require special handling of multiple raw material components, unique product curing technologies (using one of several processes) and increased process control requirements.

Peroxide-cure XLPE is the traditional process which requires a capital-intensive continuous vulcanization (CV) process which uses a very long, pressurized steam/water curing tube to provide heat. Auxiliary systems include a dedicated steam boiler, water treatment and water pumps and upgraded metering and control systems, which add significant costs. One drawback of this process is that aluminum interlocked armour is difficult to extrude through the pressurized steam tube, which prevents flame retardant peroxide-cure XLPE from being used widely in high risk industrial areas. The production rate for many peroxide-cure systems is about one-third that of PVC, due to the slow

curing process. Some peroxide cure processes in the US have very long steam tubes which allow production rates with comparable speeds to thermoplastic extruders.

Moisture-cure XLPE may require compound dryers, storage and blending systems, and high temperature/humidity curing tanks for finished extruded cable. The running rate is about 75-90% that of PVC and operating costs (mainly steam or hot water) are higher. Irradiation-cure XLPE has a minor share in the market, and is mostly for automotive use. It is a highly capital intensive process, and most production is in the U.S., where a high production volume is required to be economical. Other types of curing processes include: mold cure and salt cure, but these are not commonly used.

Table 10-27 summarizes some of the technical factors between PVC and PE materials used in wire and cable constructions.

Table 10-27: Technical Comparison of PVC and PE in Wire & Cable

Characteristic	PVC	Thermoplastic PE	Cross-linked PE (XLPE)	TPEs
Flame Retardance	High	Low (needs additives)	Low (needs additives)	Low (need additives)
Acid Gas Emission	High	Low	Low	Low
Abrasion Resistance	High	Medium	High	High
Chemical Resistance	High	High	High	High
Tensile Strength	Medium	Medium	High	Medium
Weatherability	High	Medium	High	High
Dielectric (Energy Containment)	Medium	High	High	High
Heat Deformation Resistance	Medium	Low	High	High
Cold Impact Resistance	High (when compounded)	Medium	Medium	High
Cold Flex at -40°C	High (when compounded)	Medium	Medium	High
Maximum Service Temp (C°)	105	75	125-150	100-150
Ease of Processing	High	High	Moisture: Med. Peroxide: Low	High
Moisture Resistance	High	High	High	High
Moisture Permeation	High	Low	Low	Medium

10.5.3 Direct Replacement Cost for PVC in Wire and Cable

10.5.3.1 Assumptions

The complexity of the wire and cable market makes it difficult to find one option to PVC for use in insulation and jacketing. In some applications, PVC compound is used exclusively and there are no commercially proven alternatives which have been tested to meet all specifications. A substitution for PVC would have to be carried out on a case by case basis, involving testing and compound modification. The substitution model is inherently far too simple to account for the complex nature of the industry, but is developed in order to highlight the major issues involved with the use of alternatives.

The substitution model concentrates only on the direct capital and operating replacement costs of alternative technologies and materials. Since proven commercial alternatives are not available for all applications, there are other indirect costs which may be incurred in a substitution, including:

- research and development of new higher performance flame-resistant compounds
- testing and compliance with standards
- possible changes to some standards if products fail to meet certain performance tests
- possible insurance premium increases if standards are changed

It is beyond the scope of this study to quantify these costs, but they represent significant issues for the wire and cable industry, the CSA and government regulatory agencies.

The substitution model was developed based on interviews with technical personnel from the Electro-Federation of Canada (EFC), major Canadian wire and cable producers and technical managers from firms supplying resins and compounds to the industry. The responses regarding alternatives were varied and non-definitive. The direct cost substitution model below is based on a series of assumptions that have varying degrees of validity. It combines comments from several sources into a layered model, which tries to illustrate the complexity of the market, while highlighting the key segments. Table 10-28 summarizes the alternatives assumed for PVC use in the wire and cable industry.

Table 10-28: Alternatives Assumed For PVC in Wire and Cable

Description of PVC Use Segment	Assumed PVC Volume %	Key Factors	Selected Alternative
Low voltage building/industrial wire insulation and jacketing	10	alternatives currently available	Moisture-cured XLPE; new capital required
Outdoor and underground power cable jacketing; appliance cords	15	alternatives available; flame retardants not critical	Thermoplastic PE; extruder adjustments only
Power and telecables requiring high flexibility and durability	20	high flexibility, physical & chemical resistance	Thermoplastic elastomers (TPEs)
Flame retardant cable jacketing: (indoor power/equipment/telecable)			
medium fire risk service; auto and equipment leads	15	need flame retardants; FT-4	Flame retardant, peroxide-cure XLPE compound
Industrial/ commercial/ control jacketing - high fire risk (FT-4 & 6)	40	needs high flame retardant levels; FT-4, FT-6	Flame retardant PE and thermoplastic elastomers (TPEs)
Total	100		

In the first two PVC use segments, there are commercial alternatives to PVC. Moisture-cured XLPE was selected for low voltage building wire, since it already is used by Alcatel for NMD-90 cable insulation. Low voltage building wire is estimated to account for about 10% of the PVC volume. Conversion to moisture-cure XLPE, in addition to being more expensive material, requires the installation of a complete moisture-cure extrusion system for each PVC extruder replaced. This includes blending/storage systems, compound dryers, conductor pre-heaters, electronic control/drive modifications and high temperature/humidity curing tanks. The estimated median capital cost per extruder is \$150,000, based on a recent EFC survey of its members. A low flame retardant jacketing is required that would meet the FT-1 flame test.

In utility service cable (underground and overhead) thermoplastic PE is used by some utilities and is assumed to replace PVC jacketing. There are also some flexible appliance cord uses where PE could be used. This segment is estimated to account for about 15% of the PVC volume. Black compound is required for better UV stability in outdoor use. Thermoplastic PE can be processed on existing extruders with minor modifications of the screw and feed systems. This is estimated to cost \$25,000 per extruder.

Some applications require high flexibility for conditions such as cold weather performance, difficult installations, or operating motion. Other applications require

materials having resistance to aggressive chemical (acids, chemicals, solvents or gasolines) and mechanical (abrasion and weathering) environments. These applications are estimated roughly at 20% of the PVC volume, including flexible power cable and some industrial jacketing. A range of thermoplastic elastomers are assumed to be the most effective substitute. While costing more, these materials, like thermoplastics, can be extruded on the same equipment with minor modifications of about \$25,000 per extruder.

The remaining 55% of PVC compound is used in a variety of industrial/commercial low and medium voltage power distribution cable, telecommunication cable and equipment applications which generally require high flame resistance or resistance to severe service conditions, such as temperature extremes. In this broad segment of the PVC cable market, the non-chlorinated alternatives currently have a very small market share, present only in niche applications. Significant development costs would likely be required to meet existing standards for all applications. A combination of two types of compounds are assumed to be able to meet the flame retardant applications in this segment. The first is the use of flame-retardant, peroxide-cure XLPE jacketing for 15% of PVC volume in medium fire-risk power cable constructions, automotive wire and equipment lead applications. The second is the use of a range of flame-retardant, thermoplastic elastomers for 40% of PVC volume in higher risk industrial and commercial applications meeting FT-4 and FT-6 flame tests. This includes power, telecommunications and control cable used in high risk areas of buildings governed by fire codes.

The flame-retardant peroxide-cure XLPE material requires a heavy capital investment, since a new extruder system with auxiliaries costs about \$1.3 million and, assuming that the extrusion rates of these compounds are only a third of that of a thermoplastic extruder, 3 extruders would be required for each PVC extruder replaced (to match the PVC extruder capacity). It is assumed that moisture-cure XLPE cannot compete with peroxide cure XLPE for this segment due to lower flame retardancy.

A range of flame-retardant TPE materials is assumed to be available as an alternative to about 40% of PVC volume. Minor extruder modifications estimated at \$25,000 per extruder are assumed. The material costs for flame-retardant TPEs are high, almost four times that of PVC compound. There may be some low applications where a flame-retardant thermoplastic PE or other thermoplastics could be used at lower cost, but this model assumes the use of the more expensive material under the assumption that it has the range of products and capabilities to meet all service conditions.

Changes in resins involves modifications to existing equipment and die design. For compounded thermoplastic resins, each extruder machine would require a different screw for the new resin, along with minor design changes for heating, cooling, and speed, estimated to be \$25,000 per extruder. For moisture-cure XLPE, the capital cost is

estimated to be \$150,000 per extruder. For peroxide-cure XLPE, the capital cost is estimated to be \$1.3 million per extruder system, with three times the number required.

It is estimated that there are 116 extruders in Canada operating at 90% capacity to process the 58 kT of PVC compound utilized by the wire and cable industry annually. This machine estimate is based on an average compound throughput rate of 70 kg per hour per machine, which is considered reasonable by the industry. It is assumed that all alternative resins, with the exception of peroxide-cure XLPE, will have the same capacity per machine per year as PVC, such that additional extruders are not necessary.

Contract prices of PVC compound and various alternative resins have been obtained from major resin suppliers. Prices for moisture-cure XLPE, thermoplastic PE and flame retardant, peroxide-cure XLPE jacketing compound were obtained from Union Carbide. For the thermoplastic elastomers, a commonly quoted TPE material (Monsanto's "Santoprene") was chosen. Pricing for PVC compound, XLPE and TPE are from 1989 to 1993. For other materials, current prices were adjusted to prices for this 5-year period, based on resin trends, and averaged. All prices were adjusted to Canadian currency.

10.5.3.2 Direct Replacement Cost Summary

The annual direct operating replacement costs for PVC in wire and cable applications is estimated to be \$173 million per year. An additional total capital cost of \$70 million is required. The capital investment of \$70 million, when annualized at an 9% interest rate and 20 year equipment life, amounts to about \$8 million per year. Therefore, the total additional annual costs of alternatives to PVC in wire and cable, including operating costs, are \$181 million per year. Table 10-29 summarizes the direct replacement costs.

Table 10-29: Direct Replacement Cost for PVC in Wire and Cable

Market Segment		Alternative Market Segments and Resins					Total Alternatives
Market Segment		Low Voltage Building Wire	Power Cable Jacketing; Appliances	Power requiring Flexibility, Durability	Flame retardance - Medium Risk	Flame retardance - High Risk	
Resin	PVC	Moisture-cure XLPE	Thermoplastic PE	Thermoplastic Elastomer	Peroxide-cure XLPE (FR)	Thermoplastic Elastomer (FR)	
Operating Costs							
Total PVC Resin (kT)	29						
Total PVC Compound (kT)	58						
Option Material Layers		10%	15%	20%	15%	40%	100%
PVC Replaced (kT)		5.8	8.7	11.6	8.7	23.2	58
Compound Prices (\$/T)	1,725	1,800	1700	4,200	4520	6900	
Total Cost (\$ million)	100	10	15	49	39	160	273
Cost Difference (\$ million)		0	0	29	24	120	173
Capital Investment							
No. of Extruders	116	12	17	23	17x3	46	149
Equipment Costs (\$K/mach)		150	25	25	1.3	25	
Total Capital Cost (\$ million)		1.8	0.4	0.6	66.3	1.2	70
Annualized Capital (\$M/yr)							8

10.5.4 Direct Replacement Cost Compared to End Use Revenues

Domestic sales revenue associated with wire and cable manufacturing in Canada are approximately \$1.6 billion (Stats. Can., 1993, 31-203), using SIC code 305; wire and wire product industries. The annual direct replacement costs of \$181 million dollars represent approximately 11% of domestic sales revenue associated with wire and cable manufacture.

10.5.5 Socio-economic Profile

The socio-economic profile of compound used in wire and cable manufacture will describe the major importers and manufacturers of PE resins used in wire and cable manufacture. Wire and cable firms in Canada rely heavily on merchant compounders of PVC resin. The socio-economic profile of the merchant PVC compound industry was provided in Chapter 9. The major Canadian merchant PVC compounding firm is Synergistics Industries Inc. Total supply in Canada is estimated at 160 kilotonnes, with imports accounting for approximately 44% of total supply. The total value of domestic sales is estimated at \$200 million, with a trade deficit of \$80 million. Based on 58 kilotonnes of PVC compound used in wire and cable manufacture, at a price of \$1725 per tonne, the value of domestic sales of PVC compound used in wire and cable manufacture is \$100 million. Since approximately half the domestic market value for compound is wire and cable uses, approximately half of the 415 people employed in merchant PVC compounding (about 200) are assumed to be employed for compounding PVC for wire and cable in Canada.

The major alternatives to PVC are other polymers, principally PE, XLPE and thermoplastic elastomers. PVC, PE, XLPE and TPE products are part of the broader aggregation of Plastic Products (SIC code 16). Domestic revenues and employment associated with plastic products is described in Section 10.2.5.

10.5.5.1 Polyethylene Resin

Union Carbide Corp. of Danbury, CT dominates the PE wire and cable resin market in Canada, with an estimated 80% market share. All their wire and cable grades are now supplied from the New Jersey distribution facility, which itself is supplied from various U.S. compounding locations. Other major suppliers of polyethylene and compounds for wire and cable include resin suppliers Nova, AT Plastics, Quantum (US) and compounders Synergistics and Nova Borealis (US).

Number and Location of Producers: AT Plastics Inc. of Brampton, Ont. supplies PE grades for building wire, power cable and telecable. Synergistics of Mississauga, with

plants in Ontario and Quebec, as well as in the United States, supplies both PVC and PE wire and cable compounds, and will custom compound other resins for cable producers.

Production and Capacity Levels: Domestic production is assumed to be in the area of 7 kT annually.

Imports and Exports: Imports are estimated at 26 kT, primarily from Union Carbide's U.S. operations. Exports are assumed to be 0.

Revenues: Based on a PE resin price of \$1800 per kilotonne the value of domestic sales to wire and cable firms is estimated at \$59 million. Domestic revenues are estimated at \$12.6 million dollars with a net trade deficit of \$47 million.

Number of Employees: Employment in this subsector is estimated to be 150 people.

10.5.5.2 Thermoplastic Elastomers

The family of thermoplastic elastomer wire and cable compounds are produced by several US companies. There is no production of TPEs in Canada. Bayer Canada of Sarnia, ON produces synthetic rubbers, but no thermoplastic elastomers. Canadian companies distribute products from their US production plants. Major US suppliers of TPEs include: Monsanto, Du Pont, Schulman and Teknor Apex.

Number and Location of Producers: Synergistics Industries may produce some compounds from this material. Burton Rubber of Tilsonburg is a major compounder of TPEs from Du Pont. There are perhaps less than 5 Canadian compounding facilities operating.

Production and Capacity Levels: Domestic production of TPEs is zero, but compounding of wire and cable materials is assumed to be less than 2 kT.

Imports and Exports: Imports are estimated at about 3 kT, primarily from Du Pont and Monsanto. Exports are assumed to be 0.

Revenues: Based on a TPE resin price of \$4200 per kilotonne, the value of domestic sales to wire and cable firms is estimated at \$13 million. Domestic revenues are estimated at less than \$2 million dollars with a net trade deficit of \$11 million.

Number of Employees: Employment in this subsector is estimated to be 50 people.

10.6 Flooring

PVC flooring is one of the smaller PVC end use applications in Canada, representing about 2.5% of the total PVC consumed in domestic manufacturing (12 kT of PVC resin). Vinyl flooring appears in three different product groupings: sheet vinyl (SV), vinyl composition tile (VCT) and homogeneous vinyl (HV). Sheet vinyl is the most common form of PVC flooring, making up about 65% of the total. It is a slightly spongy, composite-layered material most often used on residential surfaces such as kitchens and bathrooms. Vinyl composition tile accounts for about 30% of the PVC floor market. It is an "economy" grade, commercial flooring material, typically composed of only 12% PVC resin and a high calcium carbonate filler level. The majority of VCT is used in commercial flooring such as supermarkets and large department stores. Homogeneous vinyl makes up the remaining 5% of the PVC flooring market, and is most commonly used in institutions such as hospitals and schools. It is a PVC compound typically containing 30% binder (PVC resin and plasticizer) with the balance being filler.

The principal alternatives to PVC differ by the type of vinyl flooring. The main alternative to SV used in residential markets is ceramic tile. The principal alternative to the VCT and HV used in the commercial and institutional markets is commercial carpet. A new polyolefin homogeneous sheet flooring introduced in 1996 in Europe is used in commercial markets. Hardwood flooring will also be discussed as an alternative in both markets, although hardwood flooring serves up-scale market niches, compared to PVC flooring.

10.6.1 Market Description of Flooring

The flooring market can be divided between residential and commercial segments. Residential use is approximately 65% and commercial use 35% of the flooring market.

Table 10-30: Canadian Floor Covering Market, 1993
(millions of square meters)

Floor Covering Material	Volume	Market Share (%)
Carpet/area rugs	57	61%
PVC-based (sheet, VCT)	26	28%
Hardwood	5	6%
Ceramic Tile	1	1%
Other	4	4%
Total	93	100%

Source: Floor Covering Weekly (U.S.), 1994, Annual Review, CHEMinfo Services

Broadloom carpeting and area rugs have the largest market share of floor coverings at 61% of the market. The majority of carpet sales (74%) are in the residential market, where it is still the preferable material for the majority of living spaces in the home (living rooms, halls, bedrooms). Residential carpeting is not often used in areas commonly occupied by vinyl sheet or ceramic tile (e.g., kitchens, bathrooms, washing areas). Within the residential market, replacement sales outnumber new home installations by a ratio of about 2 to 1. It is in the commercial contract market (26%) where carpet competes with vinyl more directly. More durable forms of carpeting are used in high traffic areas of offices, hotels, shopping areas and institutions.

Carpeting is slowly losing market share in the home to hard surface flooring alternatives such as hardwood. One hardwood marketing manager claimed that residential carpeting had reached its peak in the mid 1980's and is now experiencing a stagnant market. Carpet representatives do not dispute this. Commercial carpet use is increasing, with the recent development of highly durable carpet tiles in 18" (46 cm) and 6" (15 cm) square sizes. These tiles are easy to install and replace.

While holding 26% of the flooring market, the sales trend of PVC flooring is declining with resin consumption falling 30% from its record level of 16.6 kT between 1988 and 1993. In residential markets this trend is driven primarily by aesthetic considerations as ceramic tile and hardwood have become more fashionable, while in commercial markets carpet has become a more practical alternative. These trends are occurring despite the significantly lower cost of PVC flooring compared to alternatives.

Several other alternative flooring materials have a small share of the market. Hardwood flooring occupies a small, but growing portion of the overall flooring market, with sales increasing at a rate of 10% per year. Currently hardwood flooring has 15% of the residential market, and 2% of the commercial market. This trend is explained both by aesthetics and the technical development and wide acceptance of easy-to-install prefinished grades. Prefinished hardwood volume has increased and now accounts for about 75% of sales. Unfinished hardwood held 75% of a smaller total 10 years ago. Hardwood prices range from \$20/m² for parquet flooring to \$120/m² for high grade plank flooring. Most prices range from \$50 to \$75/m². Installation costs are about 21.50/m².

Rubber flooring, is used mostly in specialty markets, such as transit systems, commercial institutions and sporting facilities (gymnasiums, arenas, golf clubs), where high traffic requires high durability. The Floor Covering Institute (Toronto) estimates that normal butyl rubber, priced at \$30-40/m², has about 2% of the commercial market. In Europe, rubber is used in as much as 10% of the commercial market.

Linoleum, used extensively until the 1960's, is a highly wear-resistant, natural sheet flooring composed of linseed oil, tree resins, wood flour, and filler. Linoleum is

expensive because its production is labour-intensive and it requires 4-8 weeks of curing time at high temperatures. Linoleum cannot be manufactured in white or light pastel colours, which are demanded by about 80-90% of the resilient flooring market. It is now only produced in two plants in the world; one in Scotland, where the product originated, and one in Italy. Linoleum is imported to Canada for use in niche commercial and institutional applications such as airports, schools, and particularly hospitals, where its durability and unique anti-static and anti-bacteria properties are valued. It is priced at \$40-60/m² and has a low market share.

Tarkett Inc. of Germany, reports that a polyolefin-based flooring product, called Supernova™, was introduced to the German commercial and institutional market in August 1996, the first such non-PVC resin flooring product on the market. The material is a homogeneous combination of polyethylene and polypropylene resins (patented formula), with a small amount (<6%) of pigments and processing additives. A thin coating of a non-scuff polyurethane surface provides durability. The current product has not been approved for wet environments, and so it is not sold in the residential market. It is priced at the equivalent of \$32/m² in Europe, but not currently distributed in the North American market.

10.6.2 Technical Characteristics of PVC Flooring and Alternatives

Ceramic tile is more durable than vinyl sheet, which is often thinner, more flexible, and can be much softer, making it less desirable for high traffic applications. PVC also has a higher tendency to tear or deform under sharp stress. New technology has allowed production of very hard ceramic tiles which have high impact resistance and minimal water absorption. The durability of the surface, however, depends on the integrity of the grout material. Cracks can occur over stressed floors if not applied properly. The general perception among consumers is that ceramic tile offers a higher aesthetic appeal than PVC flooring. It is available in a wider variety of sizes and designs and offers a greater opportunity for colour coordination. When visual design is the most important factor for a consumer, ceramic tile tends to be chosen. PVC flooring is generally easier to install than ceramic tile.

Carpeting offers several advantages over PVC flooring, including comfort and noise reduction. The main disadvantage for carpet is the issue of cleaning stains and spills. It is not easy to completely remove stains from carpeting and steam cleaning is necessary over the long term. Although carpeting often has antimicrobial chemicals applied to fibres, it is difficult to fully prevent the trapping and formation of dust, bacteria and other microbes in carpet. However, one marketing manager claims that a tightly woven, high density, solution-dyed carpet tile with a high degree of wear and appearance retention can be as durable as vinyl in the long run. These carpets can be bleach cleaned.

Hardwood flooring is seeing significant growth and recapturing market share due to a combination of aesthetic and technical factors. The polyurethane (PU) finish on a hardwood base gives this alternative a good durability compared to PVC flooring. There are from 3 to 7 PU coats applied in prefinished hardwood. A top-grade PU coating usually carries a 5-year warranty and can last much longer with care using clean and soft footwear. Refinishing may be required after as little as 3 years or as much as 20 years. There is usually a lifetime warranty on the structure of the underlying wood, which is quite durable to impacts if properly installed. The hard PU finish is very resistant to moisture and chemicals and is easy to clean.

Polyolefin sheet flooring has a similar construction to homogeneous PVC sheet flooring, although a much higher level of resin is used. In homogeneous PVC sheet, the resin content is about 30%, with plasticizers and fillers added. The resin content of the polyolefin-based flooring is about 94%, with no plasticizer or filler. At 1.8 kg/m², the polyolefin flooring is lighter than PVC. The polyurethane surface reduces chemical use and cleaning effort. The polyolefin flooring is recyclable.

Table 10-31 summarizes technical factors between PVC and other flooring alternatives.

Table 10-31: Technical Comparison Between Flooring Alternatives

Characteristic	Vinyl Sheet & Tile	Ceramic	Carpet	Polyolefin Sheet Flooring
Aesthetic				
Design	many colours & patterns	many colours & patterns	many colours & patterns	colour tones, no patterns
Walking comfort	sheet soft; tile hard	hard	soft	hard
Service				
Installation	adhesive	difficult	set only	adhesive
Maintenance	tile requires waxing, replacement of tiles possible	replacement of tile	usually replacement of full carpet	sheet replacement; no waxing
Cleaning	easy	easy	more difficult	easy
Physical				
Durability	high	high	wears; some very durable	high
Flexibility	flexible	rigid	flexible; adjusts to subfloor	slightly flexible
Impact resistance	good	medium	good	good
Moisture & stain resistance	very good	good	moderate	not proven
Chemical resistance	good	good	moderate	good

10.6.3 Direct Replacement Cost for PVC Flooring

10.6.3.1 Methodology

The substitution for vinyl flooring uses two models. In the first model, all PVC flooring is assumed to be replaced by polyolefin sheet flooring. In the second model, all vinyl sheet is replaced with ceramic tile, while commercial carpet replaces VCT and homogenous sheet.²⁸ The model assumptions are as follows:

- since material and installation costs for the 3 types of PVC flooring are different, separate cost estimates were made for each;
- the total PVC flooring surface area is calculated from market share and sales estimates to be 26 million m², based on market discussions with two major producers; the estimate uncertainty is likely to be on the order of 20%;
- ceramic tile installation costs are estimated as twice those of vinyl composition tile because of the extra preparation and finishing involved;
- polyolefin sheet flooring is assumed to be able to replace PVC sheet in residential use as well as commercial use.
- no investment costs are assumed for this option, since it is a straight material substitution.

For each flooring alternative, prices were sought from industry sources for total installed cost at the consumer level. Prices of all alternatives ranged widely, because of the variation in quality, but sources were asked to identify the price where the majority of product was sold. The assumptions used for these calculations were based on weighted averages.

Sheet vinyl ranges greatly in price from \$5 to \$50/m², depending on the quality of the patterns and the coating. For example, non-staining, asphalt resistant urethane coating is more expensive than a standard grade acrylic wear layer. The majority is 80 mil gauge (3/32" - 2.0 mm) material sold between \$15 and \$30 per m². Installation costs are assumed to be \$0.25/ft² (\$2.69/m²). Prices quoted for 125 mil gauge (1/8" - 3.2 mm) vinyl composition tile were in a tight range between \$0.55 and \$0.58/ft² (\$5.90-\$6.25/m²) with an installation cost of \$0.50 per ft² (\$5.38/m²). Homogeneous tile costs varied, but \$1.00/ft² (\$10.76/m²) was chosen with a \$0.50/ft² (\$5.38/m²) installation cost.

²⁸ Additional analyses were done based on substitution with hardwood, rubber, and linoleum flooring materials. The additional direct replacement cost with hardwood was \$1715 million; with rubber, \$423 million; and with linoleum, \$808 million.

Polyolefin sheet flooring is priced at the equivalent of \$32 per m². It is assumed that it would be made available at this price if marketed in North America. Installation costs are assumed equal to that of PVC sheet at \$0.25/ft² (\$2.69/m²). The majority of ceramic tile is priced between \$2.50 and \$3.00 per ft² (\$27-32/m²), and requires more labour for installation, assumed at \$1/ft² (\$5.38/m²). Carpet prices were given for densities in the 20-30 oz/yd² range, which makes up the majority of commercial carpet sales. Prices for this category ranged from \$24 to \$39/ m². Carpet installation costs are in the \$2.50-\$3.50/m² range which is similar to vinyl sheeting.

10.6.3.2 Direct Replacement Cost Summary

The additional annual direct replacement cost of PVC flooring with a polyolefin-based sheet flooring is \$338 million per year. The additional costs for replacement with ceramic tile (for sheet vinyl) and commercial carpet (for vinyl tile and homogeneous sheet) are \$426 million per year. Tables 10-32 and 10-33 summarize the cost calculations.

Table 10-32: Direct Replacement Cost using Polyolefin Flooring

	PVC	Polyolefin
Material cost (wtd avg. \$/m ²)	18.00	32.00
Installation (wtd avg. \$/m ²)	3.50	2.70
Total (wtd. avg. \$/m ²)	21.50	34.70
Total flooring area (Mm ²)	25.7	25.7
Total cost (\$millions)	554	892
Cost difference (\$millions)	-	338

Table 10-33: Direct Replacement Cost using Ceramic Tile and Commercial Carpet

	PVC Sheet	PVC VCT	PVC Homog.	PVC Total	Ceramic Tile	Comm. Carpet	Total
Market Share (%)	65%	30%	5%	100%			
Surface Area (Mm ²)	16.7	7.7	1.3	25.7	16.7	9	25.7
• material cost (\$/m ²)	23.90	6.10	10.00		29.60	31.00	
• installation cost (\$/m ²)	2.70	5.40	5.40		10.80	3.00	
• Total cost (\$/m ²)	26.60	11.50	15.40		40.40	34.00	
Total Cost (\$millions)	445	89	20	554	674	306	980
Cost Difference (\$millions)				-	229	197	426

10.6.4 Direct Replacement Cost Compared to End Use Revenues

The domestic sales in this sector are an estimate of the total annual value of installed flooring in Canada based on the average installed prices used in the direct replacement cost section, and the market shares listed above. Total volume of installed flooring in Canada is estimated at 93 million square meters. Based on these numbers, the estimated sales value of flooring installed in Canada in 1993 was approximately \$3 billion.

The extra direct replacement cost involving polyolefin sheet flooring (\$338 million) represents 11% of the total value of flooring installed. The extra direct replacement cost of ceramic tile and commercial carpet (\$426 million) represents approximately 14% of the total value of flooring installed.

10.6.5 Socio-economic Profile

Flooring products in general are sold in Canada through a wide network of distributors to contractors and retail outlets. The distributors will generally but not exclusively market both PVC and alternative forms of flooring. Thus, the distribution chain will not be described.

10.6.5.1 PVC Flooring

Number and Location of Producers: There are four manufacturers of PVC flooring and tile in Canada, three of whom are based in Quebec. The industry is mature and has been stable over many years.

Domco Sommer is the largest Canadian-owned manufacturer of sheet vinyl. The plant is in Farnham, PQ. Domco Sommer is owned by Domco Industries Inc., the oldest flooring company in North America. Domco also operates other divisions producing carpeting and other building materials. Domco owns two U.S. subsidiaries, Nafco and Azrock, which supply tile to Canada. Domco no longer produces floor tile in Canada.

Armstrong World Industries Canada is a subsidiary of Armstrong World Industries Inc., one of largest U.S. producers of vinyl flooring products. In their Montreal plant, Armstrong produces vinyl sheet and tile among other wall, ceiling and pipe building products. Armstrong produces 6-foot wide vinyl sheet and tile. American Biltrite Canada Ltd. produces vinyl tile and a wide variety of rubber and vinyl sheeting products in Sherbrooke, PQ. This subsidiary of American Biltrite Inc. sells flooring under the trade name of Amtico™ Tile. Flexile Ltd. produces vinyl composition floor tiles from its plant in Toronto.

Production and Capacity Levels: Total domestic production of PVC flooring is estimated at 20 million square meters.

Imports and Exports: In 1993 imports are estimated at 16 million m² of PVC flooring, while exports are estimated at 10 million m², for a trade deficit of 6 million m². Large U.S. producers exporting to Canada include: Tarkett, Mannington, Congoleum and Armstrong. American Biltrite supplies some Amtico product from England. More recently, the amount of Asian imports have been increasing. Exports are primarily to the U.S., although export markets have been established in Western Europe, Australia and New Zealand.

Revenues: The value of domestic sales of PVC flooring is estimated at approximately \$468 million based on annual sales of 26 million square meters at a average price of \$18.00 per square metre. Domestic revenues are estimated at \$360 million dollars, based on imports of \$288 million and exports of \$180 million. The trade deficit is estimated at \$108 million.

Number of Employees: Armstrong reports that a total of about 750 people are employed in the company. In their Sherbrooke plant, American Biltrite employees 400 people. Flextile employs 100 people in its Toronto plant. Assuming that approximately one half of total employees are employed in manufacturing PVC flooring generates an estimate of employment of approximately 700 people.

10.6.5.2 Carpet

Carpet production is part of a larger industry aggregation known as the Textiles Products Industries (SIC code 19). Domestic revenues from this larger aggregation are estimated at \$2.9 billion, with employment of 22,466 (Stats. Can, 1993, 31-203). The carpet, mat and rug industry is a specific SIC code; 192. All information on revenues, imports and exports, and employment are taken from Statistics Canada, 1993; cat. 31-203, 65-004, 65-007.

Number and Location of Producers: There are 7 carpet manufacturers operating about 11 plants in Canada, as listed in Table 10-34. Peerless Carpet Corp. of Montreal is one of the largest carpet manufacturers in the world, with subsidiaries in the US, Europe and Australia. National FibreTech of Mississauga recently bought Harding Carpets and runs several plants in Canada. Interface Flooring is the Canadian market leader in carpet tile systems, competing with products from Milliken of Georgia.

Production and Capacity Levels: Total domestic production of carpet in Canada is estimated at 58 million m².

Imports and Exports: The value of imports of Canadian carpet is estimated at \$387 million, while exports are valued at \$122 million in 1993, for a trade deficit \$265 million.

Revenues: Domestic revenues from carpet sales are \$736 million in 1993.

Number of Employees: Employment in manufacturing was 3082 people in 1993.

Table 10-34: Canadian Carpet Manufacturers

Company	Plant Locations
Peerless Carpet Corp.	Acton Vale, Wickham, (PQ)
National FibreTech Inc.	Toronto, Mississauga, Collingwood (ON)
Harding (National FibreTech div)	Brantford, ON
Kraus Carpet Mills Ltd.	Waterloo, ON
Crossley Carpets Ltd.	Truro, NS
Interface Flooring Systems Canada Inc.	Belleville, ON
Venture Carpets Ltd.	Drummondville, PQ
Coronet Carpets Inc.	Farnham, PQ

Source: Canadian Carpet Institute, 1995

10.6.5.3 Ceramic Tiles

Number and Location of Producers: Maple Leaf Ceramics and Windsor Ceramics are the major companies producing glazed ceramic tile in Canada. Both companies are owned by Olympia Tile International Ltd. of Toronto.

Production and Capacity Levels: Estimated production of ceramic tiles is approximately 10% of domestic demand, or 102 thousand square meters.

Imports and Exports: Domestic demand for ceramic tile is met largely through imports. Imports represent 1,016,069 square meters in 1993. Imports are primarily from Italy (55%), Spain (17%) and Brazil (9%). Exports are assumed to be zero.

Revenues: The annual value of domestic sales is estimated at \$33 million dollars, based on an average price of \$29.6 dollars a square meter. Domestic revenues are estimated at \$3.3 million.

Number of Employees: The two major Canadian companies producing glazed ceramic tiles employ about 130 people.

10.6.5.4 Polyolefin Sheet Flooring

There is no domestic or US manufacture of polyolefin sheet flooring. If imports exist at all, they are likely to be very small. Tarkett is the only company known to produce this product in the world. It is manufactured at one plant in Ronneby, Sweden.

10.6.5.5 Hardwood Flooring

Hardwood produced for flooring is part of a larger aggregation known as Wood Industries (SIC code 25). Domestic revenues and employment for this aggregation are described in section 10.4.5. The hardwood flooring industry is part of the four digit SIC code; 2549, other millwork industries. Domestic revenues and manufacturing employment associated with this aggregation are \$985 million and 7424 (Stats. Can., 1993, 31-203).

Number and Location of Producers: The Canadian hardwood industry is concentrated in eastern Canada where the oak, maple and other (birch, beech, ash) hardwood forest tracts are most plentiful. Hardwood flooring mills usually purchase rough lumber from sawmills for conversion into unfinished or prefinished flooring. There are an estimated 25 hardwood flooring mills operated by 14 companies in Canada, as listed in Table 10-35. The majority of Canadian hardwood mills are located in Quebec and they source their lumber from forests along the St. Lawrence, the eastern townships, Vermont and New York. Hardwood is rare in Western Canada.

Table 10-35: Major Canadian Hardwood Suppliers

Company	Location
Canadian Hardwood Suppliers	
Boa-Franc Inc.	St. George de Beauce, QU
Groleau Inc.	Ste. Thecle, Beloeil, Louiseville, Compton (QU)
Satin Finish Hardwood Flooring Ltd.	Weston, ON
Barwood Flooring Ltd.	St. Laurent, Maniwaki, Alma, Chicoutimi, Gatineau (QU); Scarborough, ON
Plancher Beauceville Inc.	Beauceville-Ouest, Laval (QU)
Erie Flooring Ltd.	West Lorne, ON
Plancher Héritage Ltée	Kedgwick, NB
Stanley Knight Ltd.	Meaford, ON
Knights of Meaford	Meaford, ON
Les Entreprises David Lauzon Ltée	Papineauville, QU
Madawaska Hardwood Flooring	Renfrew, ON
P.G. Hardwood Flooring Inc.	St-Edouard, QU
Tembec Forest Products Group	Huntsville, ON
Les Bois de Parquets Valcluse Inc.	St-Gérard-Majella, QU

Source: Canadian Lumbermen's Assoc., CHEMinfo Services

Production and Capacity Levels: Production for 1993 is estimated at 5175 thousand square metres.

Imports and Exports: Imports are estimated at 500 thousand square metres, while exports are estimated at 675 thousand square metres, for a net trade surplus of 175 thousand metres.

Revenues: Domestic revenues are estimated at \$347 million, based on an average price of \$67.00 a square metre. The value of domestic sales of hardwood is estimated at \$335 million, with a trade surplus of \$12 million.

Number of Employees: Employment in hardwood manufacturing is estimated at 2615, based on the ratio of domestic revenues associated with hardwood production (\$347 million), to domestic revenues associated with SIC code 2549 (\$985 million), multiplied by manufacturing employment in SIC code 2549 (7424).

10.7 Food Wrap

Polymers such as PVC, polyvinylidene chloride (PVdC), and the polyethylene (PE), are the principal materials used in the manufacture of food wraps. Food wrap is used to wrap meats, vegetables, or other fresh food for display prior to sale. Food wrap accounts for approximately 14 kT of PVC resin per year, or 3% of total PVC resin production, as well as approximately 1 kT of PVdC resin.

Another packaging film market is pallet wrap, used in industrial applications to wrap large pallets of material. This industrial segment of the market requires over 27 kT of resin per year, and is dominated by PE (26 kT/y). PVC once had a larger share of the pallet wrap business, but lost this position with the development of stronger PE film products. This analysis focuses on the food wrap market, where most PVC film is sold.

10.7.1 Market Description of Food Wrap

The food wrap market splits between the retail segment and the wholesale segment. The wholesale segment serves packagers of fresh foods, principally firms wrapping meats for the grocery chains. Grocery chains are also major customers for food wrap for refrigerated fresh food displays. PVC dominates the wholesale market for food wrap, with 12 kT of resin. PE is also used, with about 1 kT of resin.

Retail household use represents the lower volume segment of the market, accounting for approximately 2 kT of PVC and PVdC resin. The main alternative to PVC and PVdC is PE, which accounts for approximately 3 kT of PE used in this segment.

Brand names in the retail market are *Stretch'n Seal* (PVC), *Saran* (PVdC), and *Handiwrap* (PE). Private labels claim about 25% of the retail wrap market. In the retail market, Saran wrap has an established reputation for its odour and oxygen barrier properties, and high temperature performance. Mass advertising has ensured that premium performance characteristics have been communicated to consumers. The result has been that Saran sells as a high priced product to more discriminating consumers of wraps. Similarly, Stretch'n Seal (PVC) film commands a higher price than polyethylene wraps.

10.7.2 Technical Characteristics of PVC Food Wrap and Alternatives

The major benefit of the PVC and PVdC wraps is aesthetic appeal. This appeal is based on several technical features, including: the abilities of the wraps to retain their shape after handling; their permeability to oxygen which keeps meat looking fresh; and their resistance to fogging in refrigerated conditions. Although these features are not major

overriding technical performance advantages for meat preservation, they do enhance the attractiveness of contained products, especially at the point of purchase from retail shelves. These advantages are important for retailers, who rely on consumer preferences in packaging/product appearance to maintain fast turnover in meat sales. Table 10-36 shows some of the factors used to compare food wrap.

Table 10-36: Technical Comparison of PVC and PE Food Wrap

	PVC	Polyethylene
Stretch capability	Medium - 20%	High (200% to 300%)
Strength to thickness ratio	Low	High
Cling	High	High
Low temperature performance	Medium	High

Source: CHEMinfo Services

10.7.3 Direct Replacement Cost for PVC Food Wrap

The direct replacement cost model for food wrap assumes complete replacement of both PVC and PVdC film by PE wrap. Table 10-37 summarizes the prices for PVC food wrap and alternatives.

Table 10-37: Prices for PVC, PE and PVdC Films
(1988 - 1993 Estimated Averages)

Segment	Price per roll (\$/roll)	Price per area (\$/1000 m ²)
Fresh Food Wrap (1609 m x 43 cm) (65 gauge)		
PVC	\$35.05	\$50.46
Polyethylene	\$34.64	\$49.85
Household Wrap (30 m x 30 cm) (45 gauge)		
Polyethylene	\$1.10	\$122.22
PVC	\$1.65	\$188.33
PVdC	\$3.00	\$333.33

Source: Wrap producers, retailers, CHEMinfo Services

Based on the cost substitution model, the total impact of substitution for PVC and PVdC in the food wrap market is annual cost savings of \$9.4 million, split between \$0.5 million in the wholesale market, and \$8.9 million in the retail market.

Table 10-38: Direct Replacement Cost for PVC Food Wrap

	PVC & PVdC Resin (kilotonne)	Coverage (area) (1000 m ²)	Cost Difference (PE vs PVC per \$/1000 m ²)	Cost Impact (M\$)
PVC Fresh food film	12	851,000	-\$0.61	-0.5
PVC Household film	2	135,000	-\$66.11	-8.9
Total				-9.4

Source: CHEMinfo Services

10.7.4 Direct Replacement Cost Compared to End Use Revenues

The total value of food wrap sales is estimated by adding the value of domestic sales for PVC and PE food wrap documented in the socio-economic profile below. In the wholesale market, the total value of domestic sales is estimated at \$45 million. The direct replacement cost (\$0.5 million) represents a cost savings of approximately 1%. Domestic sales in the retail market are estimated at approximately \$39 million. The direct replacement cost in this sector (\$8.9 million) represents cost savings of approximately 23%. The direct replacement savings for the whole food wrap industry (\$9.4 million) is estimated at 11% of total food wrap sales (\$84 million).

10.7.5 Socio-economic Profile

10.7.5.1 PVC Food Wrap

Number and Location of Producers: There are two producers, operating three plants making PVC food and stretch film in Canada. Borden has plants in Toronto and Edmonton, while Huntsman, the other producer, has a single plant in Toronto. Both companies are involved in other packaging film markets.

Production, Imports and Exports: Production of PVC is equivalent to domestic demand, as there are negligible imports and exports of PVC food wrap. Production is estimated at 986 million m² in 1993.

Revenues: Domestic sales of PVC food wrap are estimated at \$68 million dollars, based on commercial wrap valued at \$43 million, and retail wrap valued at \$25 million.

Number of Employees: Total employment associated with PVC food wrap is estimated at approximately 120 people.

10.7.5.2 Polyethylene Film

Number and Location of Producers: PE food wrap is a minor component of film production, with the major market being pallet wrap film. There are three principal producers of PE pallet wrap film; Mobil, Borden and Huntsman, all located in Ontario. These firms account for over 80% of domestic production. Other producers include Poly tarp (Ontario), Bonar (Quebec), and Western Concord (BC).

Production and Capacity Levels: Resin demand for production of stretch pallet wrap is estimated at 18 to 20 kilotonne or 1 billion metres squared. Food wrap is estimated at 2 kilotonnes, or 100 million metres squared.

Imports and Exports: Imports currently have a major position in this market with 1993 estimates of 500 million metres squared of pallet wrap, and 50 million meters squared of food wrap. Exports are negligible.

Revenues: Total value of domestic sales of PE food wrap is estimated at \$2 million for wholesale wrap, and \$14 million for retail wrap, for total annual sales of \$16 million. Domestic revenues are estimated at approximately \$11 million.

Number of Employees: Employment in PE food wrap is estimated at approximately 30 people.

10.8 Plastic Bottles

Plastic bottles are used as containers for soft drinks, household chemicals, toiletries, and food products. Household chemical products include window cleaners, dishwashing liquids, general purpose household cleaners and waxes. Hair shampoos and conditioners represent the largest products in the toiletry bottle market, which also includes mouthwashes, skin care lotions, baby care products and bath use goods. Food products include edible oils, juices, and salad dressing.

It is estimated that 1.7 billion plastic bottles are produced annually. PVC is used in the manufacture of about 5% (100 million) of these. The volume of PVC consumed for bottle production in Canada in 1993 was 4 kT, or approximately 1% of total PVC resin production.

10.8.1 Market Description of Plastic Bottles

PVC is used primarily in the manufacture of bottles for household chemical, toiletries and edible oils. High-density polyethylene (HDPE) bottles dominate the household chemicals and toiletries markets. Polyethylene terephthalate (PET) appeared in the late 1970s as a substitute for glass soft drink bottles. It has virtually taken over the beverage bottle market and is now appearing in the other consumer bottle market segments.

Over the past ten years, the plastic bottle market has approximately doubled. During this time the market shares of HDPE and PET have been growing at the expense of PVC. Large consumer products companies have invested in PET packaging to address environmental concerns, recycling issues and improve market share.

10.8.2 Technical Characteristics of PVC Bottles and Alternatives

PVC provides a clear bottle with good barrier properties. The principal reason for PVC use in toiletry goods is for its clarity. However, recently there has been a consumer trend away from clear bottles for toiletries. Table 10-39 summarizes some of the factors comparing PVC bottles with alternatives.

Table 10-39: Technical Comparison of Plastic Bottle Materials

Characteristic	PVC	PE	PET (One Stage)	PET (Two Stage)
Blow Mold Process	extrusion	extrusion	extrusion (5%)	injection stretch (95%)
Handle Molding	yes	yes	yes	no
Clarity	clear; good shine	translucent; opaque	clear; glassy sparkle	clear; glassy sparkle
Vapour Barrier	best	poor	good	good
Hot Temp Performance	poor	poor	medium	medium
Impact Resistance	high	medium: can crack	low, more brittle	high
Melt Strength	high	high	medium	high
Recyclable	rare	common	rare	common

HDPE is translucent and can be coloured for product image. It is used for household chemicals and toiletries as translucent or opaque bottles providing non-breakable, lightweight packaging. PET bottles have clear shiny surfaces, good vapour barrier properties, and high impact resistance. Consequently, PET has replaced glass for many bottle types. Both HDPE and PET (two stage) bottles are commonly accepted for recycling while recycling of PVC bottles is rare.

10.8.3 Direct Replacement Cost for PVC Bottles

The direct replacement costs for plastic bottles are estimated for two scenarios, namely: PVC is replaced by HDPE; and PVC replaced by PET. The costs are estimated based on both material and capital costs, with capital costs based on need for new molds and modified extruder machines.

Prices for bottle materials are related to resin costs. Based on average price for bottle material between 1989 and 1993, average PET resin prices were 14% higher than PVC compound prices. HDPE resin prices were 38% lower than PVC compound prices. PET and PVC compound prices remained reasonably stable over the five years. HDPE showed a steady decline through this period. All resin prices have increased markedly

over the last two years as demand has outpaced capacity to supply. Resin prices used are shown below.

Simplifying assumptions are listed below:

- 10% more resin is required to produce PET bottles than to produce PVC bottle;
- PVC bottles are made from 500 different, active molds among all Canadian packagers, with an estimated 20 extruder machines currently dedicated to PVC bottle production;
- mold costs are estimated to be \$20,000/mold for HDPE and \$25,000/mold for PET;
- no extruder modification costs are projected for conversion to HDPE; and
- extruder modification costs of \$60,000/machine are estimated for conversion to PET, with an estimate of 20 machines requiring conversion.

The additional capital cost and operating savings of converting PVC bottles to HDPE is \$10 million and \$2.6 million per year respectively. The annualized capital costs, assuming an 9% interest rate and 20 year equipment life, are \$1.1 million per year. Combining capital and operating costs results in annual direct replacement savings of \$1.5 million per year.

The additional capital and operating costs of converting PVC bottles to PET are \$13.7 million and \$1.7 million respectively. The annualized capital costs, assuming an 9% interest rate and 20 year equipment life, are \$1.5 million per year. Combining capital and operating costs results in annual direct replacement costs of \$3.2 million per year. These costs are summarized in Table 10-40.

The major costs for substituting for PVC with HDPE or PET are new mold costs and extrusion modification costs. Using PET to replace PVC bottles would involve production in the one stage extrusion blowing process since the high mold costs associated with injection stretch blow molding make this process prohibitive for the low volume PVC bottles runs required in the market.

Table 10-40: Direct Replacement Cost for PVC Bottles

	PVC	HDPE	PET
Summary			
Total capital investment costs (\$M)		\$10.0	\$13.7
Annualized capital cost (\$M/yr)		\$1.1	\$1.5
Additional resin cost of option (\$M/year)		-\$2.6	\$1.7
Direct Replacement Cost/(Savings) (\$M/year)		-\$1.5	\$3.2
Assumptions and Calculations			
Total bottle compound (kT/year)	4.0	4.0	4.4
Average resin cost (\$/T)	1670	1025	1909
Total resin costs (\$M)	\$6.7	\$4.1	\$8.4
Additional resin cost of option (\$M/year)		-\$2.6	\$1.7
Number of extruders	20	20	20
Extruder modification cost (\$/machine)			\$60,000
Total extruder modification cost (\$M)		0	\$1.2
Number of molds	500	500	500
Mold modification cost (\$/4-cavity mold)		\$20,000	\$25,000
Total new mold costs (\$M)		\$10.0	\$12.5

Source: CHEMinfo Services

10.8.4 Direct Replacement Cost Compared to End Use Revenues

Based on the information provided in the socio-economic profiles below, the total domestic sales value of plastic bottles in the Canadian market is estimated at \$225 million dollars. The direct replacement savings with HDPE (\$1.5 million) represents 0.7% of the

total costs of plastic bottles, while the direct replacement cost with PET (\$3.2 million) represents 1.4% of the costs of plastic bottles in Canada.

10.8.5 Socio-economic Profile

10.8.5.1 PVC Bottles

Number and Location of Producers: Two companies, Graham Packaging and Monarch Plastics, dominate the PVC bottle market in Canada. Graham Packaging Canada has three plants located in Burlington and Mississauga, ON, and Ville d'Anjou, PQ. Established in 1970, the company produces custom and stock plastic bottles for the food, household, personal care and automotive markets. The company has experience with all major plastic resins and has four extruders dedicated to PVC bottles. Other companies have smaller volumes of PVC bottles in the market. Most have less than 5% of the market.

Monarch Plastics Ltd., is a custom blow molder of plastic bottles. Established in 1972, it operates a plant in Bramalea, Ont. for small volume, high run consumer bottles and has an affiliate company, Swissplas Ltd, with a plant in Concord, Ont. which produces large volume bottles and jugs.

As PVC has a relatively small market, no blow molders produce PVC bottles exclusively. Typically, PVC represents no more than 20% of total bottle production in any bottle plant manufacturing PVC bottles.

Production and Capacity Levels: It is estimated that about 100 million bottles are produced from PVC annually.

Imports and Exports: There are no significant imports or exports of PVC bottles.

Revenues: Based on an average price of \$0.15 per bottle the value of domestic sales is estimated at \$15 million.

Number of Employees: Total employment in PVC bottle manufacture is estimated at approximately 20 people.

10.8.5.2 Polyethylene Bottles

Number and Location of Producers: There are several dozen producers of PE bottles in Canada, as listed in Table 10-41. PE bottles are blow molded in many plants across Canada. Production costs are low and there is a broad base of demand. Plants are mostly located close to end-users due to high unit freight costs.

Table 10-41: Major PE Bottle Producers

Company	Location
ABC Packaging Inc	Vancouver, B.C.
BC Plastics Industries	Richmond, B.C.
Bristol-Myers Canada Inc	St. Laurent, P.Q.
Canada Plastic Containers	Toronto, Ont.
Chanteclerc Bleach	Quebec City, P.Q.
Copak Plastic Products	Boucherville, P.Q.
Cotain Plastic Products	Toronto, Ont.
CRS Plastics Inc.(Vulcan)	Toronto, Ont.
Express Plastics Inc.	Mississauga, Ont.
Graham Packaging Canada	Ville'D Anjou, P.Q.
Graham Packaging Canada	Burlington, Ont.
Lavo Ltee	Montreal, P.Q.
Lavo Ltee	Toronto, Ont.
Lever Detergents Ltd.	Toronto, Ont.
Mirabelle Plastics	Montreal, P.Q.
Monarch Plastics Ltd.	Toronto, Ont.
Myriad Detergents	Quebec City, P.Q.
Olympus Plastics Ltd	Richmond Hill, Ont.
Polybottle Ltd.	Brampton, Ont.
Produits JCV	Quebec City, P.Q.
Vulcan Packaging	Milton, Ont.

Source: CHEMinfo Services

Production and Capacity Levels: Annual production of PE bottles was estimated at 1.2 billion in 1993.

Imports and Exports: Imports and exports of PE bottles are minimal.

Revenues: Based on an average price of \$0.10 per bottle the value of domestic sales is \$120 million.

Number of Employees: Based on discussion with industry representatives, total employment for this subsector is estimated at about 500 people.

10.8.5.3 PET Bottles

Number and Location of Producers: Table 10-42 lists the major PET bottle producers in Canada. PET bottle production in Canada is dominated by one company, Twinpak Inc. They are a national supplier of plastic, paper and composite material packaging, operating 13 plants across Canada. Not all plants are involved with PET bottle production. Their major bottle market is the standard one and two litre soft drink bottles. Other companies are participating in the growth of PET in consumer product packaging. Rexham Containers, was formerly Canada Plastics and has recently taken production of bottles for Pinesol and Kraft salad dressing. Duopac in Montreal produces some packaging for Best Foods.

Table 10-42: Major PET Bottle Producers

Company	Location
Twinpak Inc.	Montreal, PQ
Twinpak Inc.	Mississauga, ON
Rexham Containers	Scarborough, ON
Rexham Containers	Lachine, PQ
Duopac Packaging Inc.	Montreal, PQ
Agra Plastics Inc.	Mississauga, ON

Source: CHEMinfo Services

Production and Capacity Levels: Annual production of PET bottles is estimated at 400 million bottles.

Imports and Exports: Industry representatives report that about 10% of production (150 million units) is exported annually. Bottles are exported world-wide. Growing export markets include South America and Asia. Imports are assumed to be negligible.

All PET melt phase resin used to make PET bottles is imported. Eastman Chemicals imports melt-phase resin from its U.S. PET plants and solid-states in Toronto. Other US suppliers of solid-state resin include ICI Americas, Hoechst-Celanese and Shell Chemicals.

Revenues: Based on an average price of \$0.25 per bottle the value of domestic sales is estimated at \$90 million, with domestic revenues valued at \$100 million.

Number of Employees: Employment for this subsector is estimated at 300 people.

10.9 Rigid Plastic Sheet Products

PVC is the dominant polymer used in the production of both rigid and flexible sheeting. Total PVC sheet production in Canada is estimated to require 42 kT of PVC resin, or approximately 10% of total PVC resin consumption. Of this amount, approximately one-third (15 kT) is consumed in the manufacture of rigid sheeting, and two-thirds in the manufacture of flexible sheeting (27 kT). Flexible sheeting will be discussed in the following section.

Rigid plastic sheeting, comprised of PVC or other polymers, is used in a wide range of retail applications. The major applications of PVC are thermoformed non-food packaging of such products as hardware, batteries, toys, pharmaceutical, medical products and similar products. This application uses 80% of the PVC resin used in rigid sheet. Other uses include credit cards, stationery, clear boxes and collector sport cards.

Alternatives to PVC currently used in this market include oriented polystyrene (OPS) and polyethylene terephthalate (PET) sheet. A different packaging market which is dominated by OPS is the clamshell packaging market, providing packaging for baked goods. There are insignificant quantities of PVC used in this application, and it will not be included in this analysis.

10.9.1 Market Description of Rigid Sheet

Rigid PVC sheeting commands close to 90% of the market in thermoformed non-food applications. PET and OPS share the remaining 10% of the market equally. Rigid PVC sheet is not likely to break into any major new application areas. Producers expect modest 3-4% growth from established applications in packaging.

10.9.2 Technical Characteristics of Rigid PVC Sheet and Alternatives

The production of rigid PVC sheet requires impact modifiers to overcome the brittle nature of the resin. In thermoformed packaging applications, rolled PVC sheet is typically sold to thermoformers, which heat the sheet in custom shaped dies, then cut it to meet specific customer requirements. Less than 15% of the PVC sheet is sold directly to packagers who thermoform and cut for their own needs.

Table 10-43 compares technical properties of PVC and its major alternatives, PET and OPS. In this application, PVC has a number of technical advantages over the alternatives including ease of processing, good sealing capability using existing packaging equipment, and ease of cutting.

Table 10-43: Technical Comparison of Rigid Plastic Sheet Materials

Technical Dimensions	PVC	PET	OPS
Clarity	Good	Excellent	Good
Processability	Broad -easy to process	Narrow-heat causes opacity	Broad
Impact Resistance	Good	Very good	Poor
Sealing Capability	Good - compatible with adhesive existing systems	Poor - incompatible with existing systems	Poor - incompatible with existing systems
Sheet Separability	Ease to separate	Problems in separating	Similar to PVC
Yield	Similar to PET	Similar to PVC	20-25% more per kg
Ease of cutting	Low wear	Hard to cut. Faster wear	Low wear

Source: CHEMinfo Services

10.9.3 Direct Replacement Cost for Rigid PVC Sheet

The direct replacement cost of rigid PVC sheeting used in packaging with alternative materials is estimated at \$6 million annually, as shown in Table 10-44. OPS and PET sheet are assumed to split the thermoformed non-food packaging market. Some applications which require a high impact resistant package may not be able to use OPS. PET would be needed for these applications. The cost calculations also take into account 20% better yield for OPS versus PVC. This reduces the equivalent amount of material that would be required to substitute for the PVC resin. The assumption is made that OPS and PET can be processed on existing thermoforming equipment, with minor modifications.

Table 10-44: Direct Replacement Cost for Rigid PVC Sheet

	Sheet Prices (C\$/kg)	Resin Required (kilotonne)	Total Cost (\$M)
PVC sheet	2.21	15	33.2
OPS	2.42	50% of 12 ¹ = 6.0	14.5
PET (virgin)	3.30	50% of 15 = 7.5	24.8
Cost Difference Relative to PVC			6.1

Source: CHEMinfo Services

¹ 20% yield gain assumed with OPS (10 mil, truckload quantities).

10.9.4 Direct Replacement Cost Compared to End Use Revenues

The total annual value of the rigid sheet market is calculated in the socio-economic profile below as \$104 million, the sum of domestic sales of PVC, OPS and PET sheet. The annual direct replacement cost of \$6 million represents 6% of total sales.

10.9.5 Socio-economic Profile

The socio-economic profile includes information on both the manufacturers of rigid PVC sheet, and those companies that thermoform the PVC sheet into packaging applications. The alternatives described are OPS and PET sheet.

10.9.5.1 Rigid PVC Sheet

Producers: There are two manufacturers of rigid PVC sheet in Canada. Canadian Oxy (Ac. Folien) and Pure Plast Inc., both located in Ontario.

Production: Based on 15 kT of PVC resin used in this application, and assuming negligible weight of additives, total production of rigid plastic sheet in Canada is 15 kT.

Imports and Exports: Imports of plastic sheet are 10 kilotonnes, while exports are 11 kilotonnes. The trade surplus is 1 kilotonne.

Revenues: Based on 15 kT of PVC resin, at a price of \$2.21 a kilogram, the value of domestic sales is estimated at approximately \$31 million. Domestic revenues are estimated at \$33 million, with a trade surplus of \$2 million.

Employment: Employment is estimated at 100 people.

10.9.5.2 Thermoformed Packaging Producers

Producers: There are both merchant and captive manufacturers of thermoformed packaging in Canada. Most production is captive, as manufacturers produce their own thermoformed packaging to meet their own needs. Therefore, thermoformed packaging is undertaken at literally hundreds of manufacturing facilities across Canada.

Production, Imports and Exports, Revenues, Employment: As this market is so fragmented with both merchant and captive producers, no reliable estimates of production, trade, revenues and employment can be presented.

10.9.5.3 OPS Sheet

Producers: No manufacturers of OPS sheet were identified in Canada.

Production: There is no production of OPS sheet in Canada.

Imports and Exports: Imports are estimated at approximately 5 kT. Exports are assumed to be zero.

Revenues: Based on 5 kT of OPS sheet, at a price of \$2.42/kg, the value of domestic sales is estimated at approximately \$12.1 million.

Employment: There is no dedicated manufacturing employment in this sector in Canada.

10.9.5.4 PET Sheet

Producers: No manufacturers of PET sheet were identified in Canada.

Production: There is no production of PET sheet in Canada.

Imports and Exports: Imports are estimated at approximately 18.5 kT. Exports are assumed to be zero.

Revenues: Based on 18.5 kT of PET sheet, at a price of \$3.30/kg, the value of domestic sales is estimated at approximately \$61 million.

Employment: Related employment is associated with distributors of sheet products. These companies are involved with a number of sheet products as well as other businesses, such that the number of employees dedicated (or that can be allocated) to sheet sales is not readily quantifiable.

10.10 Flexible Plastic Sheet Products

PVC is the dominant polymer used in the production of flexible plastic sheeting. Flexibility is attained in PVC sheet by incorporating plasticizers into PVC resin. Total PVC sheet production in Canada is estimated to require 42 kT of PVC resin, or approximately 10% of total PVC resin consumption. Of this amount, approximately two thirds is consumed in the manufacture of flexible sheeting (27 kT). The remainder (15 kT) was analyzed in the previous section on rigid sheet.

Flexible sheet is used in vehicle trim, pool liners, upholstery, luggage, rainwear, vapour barriers, auto accessories and a host of other applications. The amount of PVC resin used in these applications is shown below.

Table 10-45: PVC Resin Used in Flexible Sheet Applications
(kilotonnes)

Applications	1988	1993
Vehicle Trim (headliners, instrument panels, seats)	14	14
Pool Liners	7	6
Furniture, Upholstery	3	3
Footwear, Handbags, Apparel	2	1
Consumer goods (Shower curtains, golf bags etc.)	2	1
Other Applications	2	2
Total	30	27

Source: CHEMinfo Services

Vehicle trim, including headliners, instrument panels and seating are major uses of flexible PVC sheet, accounting for 14 kT of PVC resin consumption in 1993. With an assumed plasticizer and other additive content of 50 parts per hundred resin, the amount of PVC sheet compound is estimated at about 21 kT. The total surface area of flexible PVC sheet used in automotive trim is estimated to be 10 million m². Major alternatives to PVC in this use include: synthetic fabric, leather and other plastics for assorted trim.

Pool liners are the second largest application of flexible PVC sheet, accounting for 6 kT of PVC resin use, or about 9 kT of compound, in 1993. Concrete and fibreglass are

alternatives currently used in this application. All other applications of flexible vinyl sheet use minor amounts of PVC (< 3 kT each) and will not be analysed further.

10.10.1 Market Description of Flexible Sheet

10.10.1.1 Vehicle Trim

Vehicle trim includes headrest liners, seating upholstery, roof coverings and dashboard panels. Along with many small uses, these applications currently represent the largest market area for flexible PVC sheet. In upholstery, PVC market share has dropped from 65% in 1980 to its current level of 20% in 1993. The primary PVC material used is vinyl coated fabric. On average, 5-8 square metres of vinyl coated fabric can be consumed in a typical North American assembled automobile. In 1993, fabrics without vinyl held 75% of the market, and leather held the remaining 5%. Fabrics and leather are also the main alternative for other PVC applications such as apparel, sporting and household goods.

Dashboard and door panels often use PVC sheet laminated into a composite construction using a polyurethane foam backing. There are no obvious current commercial alternatives to the use of PVC sheet in these applications. If a resin alternative were likely to be developed, it would most likely be a material from the family of thermoplastic elastomers, TPEs. These include, among other classes of compounds, thermoplastic olefins (TPO) and thermoplastic polyurethanes (TPU). TPEs account for less than 2% of trim materials used for vehicles made in North America. One application area for TPO is in headrest liners, where they compete with fabric and vinyl materials.

The choice of material used in vehicle trim is highly influenced by consumer aesthetic preferences. Recent trends in cars have favoured plush interiors over vinyl. PVC offers the advantages of being water and salt resistant, and having better durability. Therefore, it is preferred for dashboards, arm rests, door handle coverings, and floor mats. Nylon and polyester fabrics are preferred for seating, and more recently, even for headrest liners. Leather is used for premium interiors. The durability of vinyl ensures stable markets in heavy trucks, transit vehicles and marine upholstery.

10.10.1.2 Pool Liners

Swimming pools are highly discretionary, luxury purchases which vary with demographics, growth, and tastes. Construction peaked in 1989 when as many as 20,000 below ground pools were installed. The number of swimming pool installations jumped in Canada during the late 1980s. New pool construction has been lower in the 1990s. As with most construction materials, housing starts are a good indicator of demand for swimming pools.

In 1993, there were approximately 10,000 below ground pools and upwards of 14,000 above-ground pools installed in Canada. The annual replacement market, is estimated by industry sources to be at least as high as the demand for new pools. PVC lined pools have an estimated 95% of this market. Concrete and fibreglass pools are the main current market alternatives. The dominance of PVC in this market is the result of cost, where the average cost of a vinyl pool is \$15,000, the cost of comparable sized fibreglass pool is \$20,000 and a concrete pool is \$25,000.

10.10.2 Technical Comparison of Flexible PVC Sheet and Alternatives

PVC sheet is a durable, waterproof material which provides flexibility and versatility in design. Fabrics are more esthetically pleasing for automotive seating, but are more difficult to clean, since stains get trapped in the fabric fibres. Leather is durable and smooth and generally easier to clean than fabric when treated with protective finishes.

The family of thermoplastic elastomers combine high impact strength and flexibility of elastomers with the processability of thermoplastics. There are a number of different classes of compounds which can be blended to meet a wide range of physical properties. Thermoplastic olefins (TPOs) are a class of TPEs which are blends of olefin-based thermoplastics and elastomers. TPOs are the lowest priced of the family of TPEs. Thermoplastic urethanes (TPUs) are a class characterized by a high degree of toughness, flexibility, and abrasion resistance. They are at the high end of TPEs in price and performance.

Concrete is a very durable material for swimming pools. Its surface has a higher roughness, and is more difficult to clean than PVC sheet. PVC sheet has a higher degree of design and colour flexibility than concrete.

10.10.3 Direct Replacement Cost of Flexible PVC Sheet

10.10.3.1 Vehicle Trim

The substitution model for PVC use in vehicle trim combines the options of fabric for upholstery applications and thermoplastic elastomers for other sheeting uses. Leather, which is roughly 5 times the cost of nylon or polyester fabric, was not selected for substitution, although a brief socio-economic profile has been included for reference²⁹. It is assumed that half the volume of PVC sheet compound (10.5 kT) is used for upholstery, covering 5 million m². The other half (10.5 kT) is assumed to be used for other trim applications. Two substitution models are developed, to account for the different TPEs that could be used: one for low-cost TPOs and one for higher cost TPUs. A further assumption is that there is no significant extra costs or savings to seat and trim manufacturers by using fabric or TPEs in place of PVC.

Based on these assumptions, the direct replacement cost of flexible PVC sheet in vehicle trim with fabric and TPOs is estimated to be \$25 million/yr. The direct replacement cost for fabric and TPUs is \$60 million/yr. Table 10-46 summarizes the cost models.

Table 10-46: Direct Replacement Cost for PVC Vehicle Trim

	Volume	Price	Value (\$ million)	Difference (\$ million)
Upholstery	(M m ²)	(\$/m ²)		
PVC compound used (kT)	5 (10.5 kT)	5	\$25	
Fabric (nylon, polyester)	5	8	\$40	\$15
Other Trim	(kT)	(\$/kg)		
PVC compound	10.5	1.73	\$18	
1. Thermoplastic Olefin	10.5	2.65	\$28	\$10
2. Thermoplastic Polyurethane	10.5	6.00	\$63	\$45
Low Cost Option				\$25
High Cost Option				\$60

Source: CHEMinfo Services

²⁹ As a point of comparison, if leather were to be used for all upholstery, with TPOs for other trim, the direct replacement cost would increase to \$183 million per year.

10.10.3.2 Pool Liners

Two costing models were used; one assumes that alternative polymer systems would be developed as a substitute to PVC for pool liners, the other assumes replacement with concrete. Although no alternative polymer material was identified in this study, it is probable that these can be developed. PVC competes in similar applications (roof liners, geomembranes, etc.) with other materials such as polyethylene, rubber, thermoplastic olefin, EPDM, and other polymers. For this study, it is assumed that a thermoplastic olefin compound could be developed as a substitute for PVC. This TPO material would be suitably designed to be compatible with existing calendering production and sheet joining equipment used by converters.

As shown in Table 10-47, the direct replacement cost with TPO is \$8 million, and direct replacement cost with concrete is \$100 million.

Table 10-47: Direct Replacement Cost for PVC Pool Liners

	Volume (kT)	Price (\$/kg)	Value (\$ million)	Difference (\$ million)
Total PVC Sheet Compound	9	1.73	16	
Total Thermoplastic Olefin	9	2.65	24	8
Concrete vs PVC [10,000 new pools per year x (\$25,000-\$15,000)]				100

Source: CHEMinfo Services

10.10.4 Direct Replacement Cost Compared to End Use Revenues

10.10.4.1 Vehicle Trim

The total value of sales of vehicle trim in Canada is estimated at \$497 million, based on the value of fabric (\$304 million), PVC (\$93 million), and leather (\$100 million). The direct replacement cost with fabric and TPO (\$25 million) represents approximately 5% of the value of sales, while the direct replacement cost with fabric and TPUs (\$60 million) represents 12% of the domestic sales of vehicle trim.

In comparing these figures to the domestic revenues for automobile sales (\$41.7 billion) the low and high costs are 0.06% and 0.14% of domestic revenues respectively.

10.10.4.2 Pool Liners

Based on installation of 10,000 new pools a year, with a 95% share for PVC, and 2.5% share for fibreglass and concrete respectively, and using prices per pool of \$15,000, \$20,000 and \$25,000, respectively, generates estimated sales of pools at \$154 million per year. The direct replacement costs with thermoplastic olefin (\$8 million) are 5% of the value of pool sales, while the direct replacement costs with concrete (\$100 million) are 65% of the value of pool sales.

10.10.5 Socio-economic Profile

The socio-economic profile will describe the PVC industry manufacturing flexible sheet, and the industries manufacturing fabric and leather automotive trim. For a brief profile on thermoplastic elastomers, see the Wire and Cable section of this chapter, Section 10.5.

10.10.5.1 PVC Sheet

Producers: The top eight producers account for nearly all of the flexible PVC sheet made in Canada. The dominant company in flexible PVC sheet is Canadian General Tower (CGT) of Cambridge, ON, founded in 1946. CGT is the second largest producer of PVC sheet on the continent. The plant at Cambridge has numerous calendaring lines, and at least one plastisol line. While CGT produces a diversified range of products, automotive trim and swimming pool liners constitute the largest product categories.

Morbern Industries, of Cornwall, ON is the leading Canadian competitor to CGT. The company makes supported and unsupported sheet not only expanded but also non-expanded, for use in the upholstery, handbag, luggage, automotive, recreational vehicle, marine, footwear and sporting goods.

Some industrial fabrics are extrusion coated with a vinyl or elastomeric material. Vintex Inc. has been doing this in a Brampton, ON plant after moving from its Candiac, PQ location in 1983. This firm concentrates on vinyl coated textiles for truck covers, tarpaulins, gym mats, boat tops and mine ducting as well as those used in hospitals and other institutions. Stedfast Inc. has the capability of doing the same at Granby, PQ but has emphasized coating with Neoprene and similar elastomeric materials.

Production and Capacity Levels: Based on a use of 28 kilotonnes of PVC resin, with an additional 50% to account for additives generates an estimate of 42 kilotonnes of production of flexible PVC sheet in 1993.

Imports and Exports: Imports are 25 kilotonnes, compared to exports of 22 kilotonnes. (Stats. Can, 1993, 65-004, 65-007).

Revenues: Based on an average PVC sheet price of \$4.10/kg, the value of domestic sales is \$185 million. Domestic revenues are estimated at \$172 million, with a trade deficit of \$13 million.

Number of Employees: Total industry employment is estimated at 1000 people.

10.10.5.2 Fabric for Automotive Trim

This industry forms part of a larger industrial aggregation, the Textiles industry (SIC code 19). Domestic revenues and employment associated with this aggregation are discussed in section 10.6.5.

Production, Exports and Imports: All automotive trim used in Canada is imported, primarily from the United States. Domestic demand is estimated at 38 million square metres of fabric.

Revenues: Based on an average price of \$8.00 per square metre the value of domestic sales is estimated at \$304 million dollars.

10.10.5.3 Leather for Automotive Trim

There are only about 3 to 5 tanneries operating in Canada. Dominion Tanners and A.R. Clarke and Co. Ltd. are the largest firms in the industry. This industry forms part of larger industrial aggregation, Leather products (SIC code: 17). The value of domestic revenues in this industry are \$930 million, with employment estimated at 10,847.

Production: Only one company produces leather for automotive trim in Canada. Dominion Tanners produces about 5 million ft² annually from their Winnipeg plant.

Imports and Exports: Dominion Tanners exports about 90% of their production with the remaining 10% satisfying domestic demand for auto trim. Exports are primarily to the US, with small amounts being bought by Mexican sources. There are only minimal imports.

Revenues: Based on 2.5 million square metres of leather being used for interior trim at a price of \$40 a square metre the value of domestic sales is estimated at \$100 million dollars.

Employment: Dominion Tanners employs approximately 100 people at their Winnipeg plant that can be attributed to the production of leather for automotive trim.

10.11 Contacts and References

10.11.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

ABC Group	Cotain Plastics Products
Agra Plastics Inc.	Crila
Alcan Wire and Cable	Dashwood Industries Ltd.
Alcatel Canada Wire and Cable Ltd.	Daymond Ltd.
American Biltrite (Canada)	Domco
American Waterworks Association	Dominion Plastics Ltd.
Amtico	Duchesne et fils Ltee
Armac	Dupont Dow Elastomers
Armstrong World Industries	Eastman Chemical Co.
Arrow Windows	Emcon
Avenue Interiors	Express Plastic Containers
B.C. Plastics Industries	Express Plastics Inc.
BPCO	Extrusion Plastics
Beckwith Bemis Inc.	Federal Plastics
Belden Canada Ltd.	Flextile Ltd.
Betz Pools	First Brands Canada
Big O Inc.	Foothills Plastics
Borden	Forbo Industries
Burton Rubber	GM Plastics
Canada Brick	Gem Windows
Canada Pipe	General Electric
Canada Plastic Containers	Gentek Building Products
Canada Wood Tape	Graham Packaging Canada
Canadian General Tower	GSW Thermo Plastics
Canadian Oxy	Harding, M. (Industry Canada)
Chemical Resins	Home Siding Co.
City of Toronto	Huntsman Inc.
Cliffside Utility Contractors	Husky Injection Molding
Con-Drain Co. Ltd.	Hydropipe

Hyprescon Inc.
Ideal Drain Tile
ICC Phillips
Imperial Pipe Corp.
Iplex Inc.
KWH Pipe (Canada) Ltd.
Lafarge
LOC Pipe
Manuplast Ltee.
Manville Siding
Mason Windows
Metro Works - Engineering Division
Miceli & Frere Ltee
Mitten Vinyl
Monarch Plastics Ltd.
Mondo America
Morbern Inc.
Noma Inc. (Cable-tech)
Ocean Construction Supplies Ltd
Olympia Tile International
Olympus Plastics Ltd.
Ontario Clean Water Agency
PH Tech Inc.
Philips Cable Ltd.
Pheonix Floor and Wall
Pillar Plastics Ltd.
Pirelli Cables
Plastibec
Plasti-Drain
Plastmo Ltd.
Polybottle Ltd.
Polychor Plastic Industries
Polytubes (West) Ltd.
Prime Poultry Co.
Products JVC
Pure Plast
Quantum Corp.
Rainbow
Rehau Plastics of Canada
Rexham Containers
Rexham Containers
Reynolds Building Products
Richard Packaging Inc.
Royal Plastics

Roytek Vinyl Inc.
Sander Industries Ltd.
Shawflex Inc.
Solen - SPD inc.
Stedfast Inc.
Stelpipe Ltd.
Stradwicks
Surfaces Flooring Journal
Synergistics Industries
Temiskaming Plastics Ind.
Thermoplast
Twinpak Inc.
Union Carbide
Unibell PVC Pipe Association
Vulcan Packaging
Vycan/Gentek
Vytec Corp.
Waterloo Concrete Ltd.
Western Profiles Ltd.

10.11.2 Association Contacts

- Vinyl Council of Canada/SPI Canada
- Canadian Carpet Institute
- Canadian Concrete Pipe Association
- Canadian Plastics Institute
- Canadian Window and Door Manufacturers Association
- Ductile Iron Pipe Research Association
- Electro-Federation Canada
- Plastics Pipe Institute
- Tubecon (Quebec Concrete Pipe Association)

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PART THREE

OTHER CHLORINATED SUBSTANCES

11. Sodium Hypochlorite Used in Household Chlorine Bleach

11.1 Introduction

Sodium hypochlorite is a chemical made by a simple reaction combining elemental chlorine and caustic soda. Sodium hypochlorite has many uses. The major market is household bleach applications where it is used in laundry, general purpose cleaning and disinfecting. With 10 kT of annual demand (on a 100% basis), the household bleach market accounts for more than 60% of all domestic sodium hypochlorite production. Another 2 kT per year of sodium hypochlorite is used as a bleaching additive in cleaning and laundry products. Other important uses for sodium hypochlorite include municipal water treatment, industrial and institutional bleaching and swimming pool disinfecting. Sodium hypochlorite is also produced on site at some pulp mills from chlorine and caustic soda for captive use in the pulp blechery, as described in Chapter 4.

This chapter focuses on the household bleach market. The term "bleaching" refers to the removal of coloured matter through the chemical process of oxidation and decomposition. Chlorine bleach is a solution of sodium hypochlorite (NaOCl) in water. The main alternatives to chlorine bleach are bleaches formulated with sodium perborate or hydrogen peroxide.

This chapter will describe chlorine bleach, and alternatives, in five sections: market analysis, technical description, direct replacement costs, direct replacement costs compared to end-use revenues, and socio-economic profile. The socio-economic profile will investigate production, imports and exports, revenues and manufacturing employment.

11.2 Market Analysis

There are two major uses for household bleach: laundry bleaching and surface disinfecting. One manager reports that household bleach is sometimes used to disinfect swimming pools in summer. Market managers for the two major Canadian branded bleach suppliers both estimate that the consumer bleach usage rate in Canada is about 20 litres/year/household. The total Canadian volume is 240 million litres (ML) of bleach annually, of which laundry use accounts for about 80%. Household bleach usually contains 5.5% sodium hypochlorite by weight in water.

In Canada, chlorinated bleaches dominate both markets, accounting for approximately 80% of all bleach solutions or 200 ML of bleach per year. The remaining 20% is dominated by non-chlorinated laundry bleaching alternatives. The majority of these non-chlorinated bleaches contain sodium perborate, but some contain sodium percarbonate. These non-chlorinated bleaches appeared in the 1980's, and have demonstrated an increasing market share due to their gentleness in cleaning delicate and colourfast fabrics. Only one bleach alternative that covers both markets (laundry, surface disinfectant) is currently marketed in Canada, a stabilized hydrogen peroxide solution. Its product manager claims a 1% market share.

In Europe, the market positions of chlorine and non-chlorine bleaches are reversed. Chlorine bleaches are used almost exclusively as a cleaning disinfectant, while non-chlorinated alternatives (sodium perborate, hydrogen peroxide) dominate the laundry bleach market.

The dominant company in the domestic bleach market is Colgate-Palmolive, which sells both the leading chlorine bleach (Javex), estimated at 50% market share, and the leading alternative "Javex 2 Bleach for the Unbleachables". With Javex brands, Colgate-Palmolive is the leading bleach company in the world. Groupe Lavo Inc. is the other dominant consumer bleach company, marketing the "Old Dutch" (Ontario), "Lavo" and "Parisien" (Quebec) brands. Groupe Lavo brands hold about 20% of the Canadian market, but their production facilities also supply private label packagers. The remaining 30% of the market is held by a variety of private label products. Household bleach is a commodity product that many supermarkets have chosen to include in their private label lines.

Currently, Sunfresh Ltd. (a subsidiary of Loblaws) is the only identified company in Canada that markets general purpose hydrogen peroxide bleach. Kik Corp. blends, packages and distributes the hydrogen peroxide bleach under the "President's Choice GREEN™" label.

11.3 Technical Characteristics of Chlorine-Based Household Bleach and Alternatives

Sodium hypochlorite is a very strong chemical oxidizing agent which also has powerful disinfecting properties. It can also be used in water of all temperatures. The research director of the leading bleach company in Canada claims that despite extensive testing on bleach alternatives, nothing has been able to match the strength of sodium hypochlorite as a stain remover and disinfectant.

Non-chlorinated bleaches such as hydrogen peroxide and perborate formulations are inherently milder in their oxidizing power and require increased dosage or repeated

treatment to match the cleaning power of sodium hypochlorite. The advantage of the mildness of peroxy type bleaches is their effectiveness with delicate fabrics such as nylon and silks and non-colourfast fabrics, which can be damaged or faded by sodium hypochlorite. Non-chlorinated bleaches must also be used in higher temperatures in order to achieve the same cleaning effect. Chemical activators such as sodium nonanoyl oxybenzene sulfonate (SNOBS) or tetra-acetylene diamine (TAED), commonly used in Europe, are often combined with perborates to help cleaning at lower water temperatures. Table 11-1 summarizes the technical comparison of sodium hypochlorite with alternatives.

Table 11-1: Technical Comparison of Chlorine and Non-Chlorinated Bleaches

	Sodium Hypochlorite	Hydrogen Peroxide	Sodium Perborate; Sodium Percarbonate
Stability	stable	unstable; requires stabilizer	stable
Temperature Range	all: cold and hot	more effective in hot water	warm/hot; effective with activators
Fabrics	whites; colourfast; non-delicates	all incl. nylons, silks; dyed colours	all incl. nylons, silks; dyed colours
Chemical Strength	strong	weak; gentle	moderate; gentle
Disinfecting Strength	strong	moderate	moderate
By-Products	chlorinated salts	O ₂ and H ₂ O	H ₂ O ₂ ; per-acids

Source: CHEMinfo Services

11.4 Direct Replacement Cost

The substitution model for sodium hypochlorite household bleach assumes complete replacement by a stabilized hydrogen peroxide bleach solution. The total direct replacement cost is \$56 million per year, as shown in Table 11-2.

Hydrogen peroxide was chosen over sodium perborate formulations because it is positioned in the marketplace as a direct non-chlorinated alternative for liquid chlorine bleach in laundry and cleaning applications. While peroxy bleaches are present in the marketplace, they are positioned solely for laundry use and not disinfecting purposes. The hydrogen peroxide solution sold as a bleach alternative has the same prescribed usage rate as chlorine bleach. It is assumed that the 200 ML/yr. household volume of chlorine bleach could be substituted by an equivalent volume of hydrogen peroxide solution.

Prices were obtained from market managers of the major suppliers who gave list, promotion, and average prices. The major factors influencing bleach prices are packaging costs and marketing promotional practices. In 1988, list prices for chlorine bleach were high (in the \$0.50 - \$0.60/L range), prior to the full market penetration of private label bleaches. By 1993, major chains were selling bleach at or below cost as a loss leader with prices in the \$0.25 - \$0.30/L range. Today, prices have risen due to increases in packaging costs. The average price of \$0.35/L represents an average of the years 1988-1993 and the effect of private label pricing. The hydrogen peroxide alternative is priced at \$0.60/L, which represents the average shelf price of 1993, when it was first introduced.

Table 11-2: Direct Replacement Cost for Household Chlorine Bleach

	Sodium Hypochlorite	Hydrogen Peroxide
Volume (L)	200,000,000	200,000,000
Average price (\$/L)	0.35	0.63
Consumer cost (\$M)	70	126
Difference (\$M)		56

Source: CHEMinfo Services

11.5 Direct Replacement Cost compared to End-Use Revenues

Based on prices per litre of \$0.35 for chlorine bleaches, \$0.49 for sodium perborate bleaches, and \$0.63 for hydrogen peroxide bleaches, with market shares of 80, 19 and 1% respectively, generates an estimate of the value of total domestic sales of bleach of \$94 million. The direct replacement cost (\$56 million) represents approximately 60% of the value of domestic sales of household bleach.

11.6 Socio-Economic Profile

This section includes profiles for the sodium hypochlorite industry and the sodium perborate industry. The complete socio-economic profile of hydrogen peroxide production was provided in Chapter 4, Elemental Chlorine Use in the Pulp and Paper Industry. Domestic sales revenue associated with hydrogen peroxide are \$139 million, with a trade surplus of \$22 million, and domestic revenues of \$161 million. Manufacturing employment is estimated at 300. The amount of hydrogen peroxide

associated with household bleach production is less than 1% of total hydrogen peroxide production, with the majority of hydrogen peroxide going to the pulp and paper industry.

11.6.1.1 Sodium Hypochlorite

Plants and Locations: Sodium hypochlorite is produced in about 10 plants in Canada as listed in Table 11-3.

Table 11-3: Canadian Sodium Hypochlorite Plants
(some facilities may be idle)

Company	Location	Major Market
Colgate-Palmolive Ltd.	Edmonton, AB	Consumer
Colgate-Palmolive Ltd.	Toronto, ON	Consumer
Colgate-Palmolive Ltd.	Moncton, NB	Consumer
Groupe Lavo Inc.	Montreal, PQ	Consumer
Groupe Lavo Inc.	Toronto, ON	Consumer
ICI Canada Inc.	Cornwall, ON	Industrial
ICI Canada Inc.	Becancour, PQ	Industrial
PPG Canada Inc.	Beauharnois, PQ	Industrial
Welland Chemical Inc.	Samia, ON	Industrial
Stanchem Inc.	Winnipeg, MB	Industrial
PrairieChem Inc.	Saskatoon, SK	Industrial
Canadian Miraclean	Vancouver, BC	Industrial

Source: CHEMinfo Services

Only two producing companies are fully integrated into consumer bleach products with production of retail brand names; Colgate-Palmolive and Groupe Lavo. Other bleach companies that are not integrated into consumer brands produce sodium hypochlorite primarily for industrial markets, but can also supply private label consumer bleach packagers, such as Kik or R.W Packaging (See Table 11-4). The largest hypochlorite producing plant is the ICI Forest Products plant in Cornwall, ON.

Table 11-4: Canadian Household Bleach Suppliers

Company	Brand	Plant Location
Colgate-Palmolive	Javex, Javex 2	Edmonton, AB
		Toronto, ON
		Moncton, NB
Groupe Lavo Inc.	Old Dutch	Toronto, ON
	Lavo, Parisien	Montreal, PQ
Kik Corp.	Private Label	Toronto, ON
		Nisku, AB
R.W. Packaging	Private Label	Edmonton, AB

Source: CHEMinfo Services

Production and Capacity: Total capacity for sodium hypochlorite production in Canada is approximately 40 to 50 kT on a 100% basis. Production is estimated at 30 kT and domestic demand 28 kT, with 12 kT going to household bleach production. The remainder is used for industrial and commercial applications. Due to overcapacity, several plants listed in Table 11.3 may be idle. One supplier claims that sodium hypochlorite consumption has been declining at a rate of 5% per year for the last five years, particularly in industrial applications (e.g. pulp and paper).

Imports and Exports: There are negligible levels of trade in household bleach between Canada and other countries. Canadian suppliers estimated imports and exports are approximately 0.1 kT annually.

Revenues: Annual revenues from the 200 ML (12 kT) of sodium hypochlorite used for household bleach are estimated at \$70 million, using an average price of \$0.35/L. Total merchant sodium hypochlorite revenues (from all 30 kT) are roughly \$110 million at the wholesale level.

Employment: Employment attributable to the production, packaging and sales of sodium hypochlorite in Canada is 400, based on information obtained from suppliers. This excludes employment in the retail sector.

11.6.1.2 Sodium Perborate

Plants and Production: There were no producers of sodium perborate identified in Canada. Various chemical blenders and packagers are involved in the manufacturing and sale of bleach products.

Imports and Exports: Based on market shares, approximately 2.4 kilotonnes of sodium perborate used in household bleach is imported annually.

Revenues: Annual revenues from sodium perborate in household bleach formulations are estimated at \$23 million.

Employment: Based on market share information, it is roughly estimated there are 10 people involved with importing, packaging and selling sodium perborate containing bleaches in Canada.

11.7 Summary

The major use of sodium hypochlorite is in the production of household chlorine bleach. Household bleach has two major uses, laundry (70-80%), and surface disinfecting. Chlorine bleach dominates the bleach market with an 80% market share. The alternatives to chlorine bleach are hydrogen peroxide bleach (1% market share) and sodium perborate bleaches (19% market share). The sodium perborate bleaches are used only as laundry bleaches, whereas the hydrogen peroxide bleach is an all purpose alternative.

The substitution model for sodium hypochlorite assumes complete replacement by a stabilized hydrogen peroxide bleach solution. The annual direct replacement cost is estimated at \$56 million. This represents approximately 60% of the total value of bleach sales in Canada (\$94 million).

Table 11-5 compares the size of the sodium hypochlorite, hydrogen peroxide and sodium perborate producing industries, using the variables of sales, trade balance, domestic revenues, and manufacturing employment.

**Table 11-5: Summary Information on Sodium Hypochlorite,
Hydrogen Peroxide and Sodium Perborate**

	Merchant Sodium Hypochlorite	Total Hydrogen Peroxide	Total Sodium Perborate
Value of Domestic Sales (\$ million)	110	139	23
Trade Balance (\$ million)	0	22	-23
Domestic Revenues (\$ million)	110	161	0
Manufacturing Employment	400	300	0
Ratio of Employment to Domestic Revenues	3.6	1.86	n.a.

11.8 Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Chemprox
- FMC
- Dupont Canada
- Kik Corporation
- Groupe Lavo
- Colgate/Palmolive
- R.W. Packaging
- PrairieChem
- Stanchem
- Welland
- Canadian Miraclean

12. Chlorinated Solvents: Tetrachloroethylene Used in Dry Cleaning

12.1 Introduction

Tetrachloroethylene (also known commonly as perchloroethylene, or just "perc") is the chlorinated solvent with the largest domestic use. The other chlorinated solvents discussed in this report are trichloroethylene (TCE) and dichloromethane (DCM).

The major use of perc is within the dry cleaning industry which accounted for approximately 54% of all perc imports in 1993. The other major use of perc is in the production of chlorinated refrigerants, as will be discussed in Chapter 15. Minor uses of perc include industrial degreasing operations and printing operations. This chapter will focus on the use of perc in the dry cleaning industry.

Dry cleaning refers to the practice of using organic solvents to clean clothes and other textile materials at commercial laundries. The alternative to perc used in dry cleaning is hydrocarbon solvents. In contrast to dry cleaning, wet cleaning refers to cleaning clothes traditionally dry cleaned with surfactant technology (i.e., soaps) applied in water. Wet cleaning and dry cleaning with hydrocarbon solvents are the alternatives to perc discussed in this chapter.

This chapter will describe the use of perc in the dry cleaning market through five sections: market analysis, technical description, direct replacement cost, direct replacement cost compared to end-use revenues, and socio-economic profile. The socio-economic profiles will use the variables of plants, production, imports and exports, revenues, and manufacturing employment.

12.2 Market Analysis

The commercial dry cleaning industry uses solvents to remove grease, oil, protein, soil and other stains from textiles and clothing, notably clothes and textiles made of wool, rayon, and silk. Industrial and institutional cleaning requirements may use wet or dry cleaning technologies. For the most part in Canada, institutions such as hospitals, hotels and restaurants have relied on laundries using wet cleaning. In 1994, it was estimated that 95% of commercial dry cleaning plants used perc (Levelton, 1995), accounting for 3,484 plants.

The remaining 5% of dry cleaning plants used other hydrocarbons, CFCs, and/or 1,1,1-trichloroethane¹, and account for 164 plants.

As hydrocarbon based dry cleaning plants are typically large or medium plants, while perc can be used in large, medium and small plants, the amount of clothes cleaned using hydrocarbon solvents may be higher than a 5% market share. An estimated market share can be generated by assuming that the average size of a hydrocarbon plant corresponds to a large sized plant (45 tonnes clothes cleaned annually). Using an estimate of 164 hydrocarbon-based plants generates 7.4 kilotonnes of clothes cleaned using hydrocarbon solvent. Assuming that 85 kilotonnes of clothes are dry cleaned annually (Levelton, 1995) indicates that 9% of all clothes dry cleaned are cleaned with hydrocarbon solvent, 90% of clothes are cleaned with perc, while 1% are cleaned by other methods, including wet cleaning.

The position of wet cleaning among commercial dry cleaning plants was negligible in Canada in 1993. Although many dry cleaning operations had surfactant-based laundry machines, none had the required specialized equipment to conduct wet cleaning. Ordinary laundry machines may be used for shirts, some linens and other items which can easily be finished (steamed, pressed, ironed) after cleaning. There are now several dry cleaning companies which have installed wet cleaning processes, but it is estimated that wet cleaning still represents less than 1% of the clothes traditionally dry cleaned in Canada.

The trend in the use of perc in dry cleaning is decreasing, primarily due to environmental considerations. Perc was declared toxic under the Canadian Environmental Protection Act (CEPA) in 1993. This declining trend in terms of perc use has two components, one being more efficient use of perc in dry cleaning through more modern equipment and better operating practice, the other being displacement of perc by both wet cleaning, and hydrocarbon solvents. Perc use in the dry cleaning industry is estimated to have declined from 7.1 kilotonnes in 1990 to 5.5 kilotonnes in 1994 (Environment Canada, 1996).

12.3 Technical Characteristics of Perc and Alternatives

Perc possesses two principal advantages over the alternatives of wet cleaning and hydrocarbon solvents: its ability to clean most fabrics without damage, and its relatively low flammability compared to hydrocarbon solvents.

¹ CFCs and 111-trichloroethane have been phased out as of the end of 1995 under the Montreal Protocol governing ozone depleting substances.

Wet cleaning (i.e. with soap and water) will swell and potentially distort hydrophilic fibres of fabrics such as wool and rayon, while this does not occur with perc or hydrocarbon solvents (Levelton, 1995). Most of the damage occurs when the moisture content falls below 10% relative humidity. Specialized sizing chemicals applied in the context of careful computer controlled cleaning procedures in suitable equipment can serve to overcome many of the shortcomings of wet cleaning. Estimates of the amount of clothes currently dry cleaned which can be safely wet cleaned vary. One study estimates that wet cleaning may be able to replace about 87% of the current dry cleaning volume (Green Clean, 1995), however a more conservative estimate is from 40 to 50% of the current volume of clothes dry cleaned (Levelton, 1995).

The main problem with hydrocarbon solvents is that they are flammable, with some potential for explosion. This poses a fire hazard, particularly in mixed use buildings currently occupied by perc using dry cleaners. Older hydrocarbon solvents have a low flash point (40°C), but most new hydrocarbon solvents used for dry cleaning have flash points of 60°C, and thus pose less risk of fire. These high-flash point solvents, and the equipment associated with their use, may be able to meet local fire regulations in mixed use buildings. However obtaining the required permits will be dependent on local circumstances. Table 12-1 summarizes the technical comparison of perc and alternatives.

Table 12-1: Technical Comparison of Perc and Alternatives

Characteristic	Wet Cleaning (surfactants and water)	Hydrocarbon Solvents
Shrinkage	High potential	Equal
Dimensions distortion	High potential	Equal
Post drying relax characteristics	Creases lost, shows wrinkles, likely will need ironing	Equal
Feel of clothes	Smoother, softer	Equal
Colour brightness	Superior	Equal
Residual odour	Lower	Equal
Dyes fading	Poor for water soluble dyes	Equal
Allergic response	None or little sensitivity of consumers	Equal
Operational control	Needs high level of process control	Equal
Drying/evaporation times	Longer	Equal or longer
Fire hazard	None	Higher

12.4 Direct Replacement Costs

The total capital cost associated with adopting non-chlorine products in the dry cleaning industry is estimated at \$231 million. The operating cost is estimated at \$18 million. Annualized capital costs, assuming an 9% interest rate and 20-year equipment life, are \$25 million. Total annual costs, including operating costs, are \$43 million/year.

Substituting for perc within the dry cleaning industry would require new wet cleaning equipment or new hydrocarbon solvent machinery. The model of substitution adopted for the purposes of this analysis makes the assumption that 30% of what is currently dry cleaned would be wet cleaned. The remaining 70% would be cleaned with hydrocarbon solvents. All hydrocarbon plants are assumed to be large plants cleaning 45 kilotonnes of clothes per year, while wet cleaning plants are assumed to be medium-sized plants cleaning 25 kilotonnes per year.

The direct replacement cost analysis presented here adopts cost estimates (machinery, chemicals, energy, labour, etc.) taken from (Levelton, 1995). These cost estimates are applied to the substitution model to arrive at the total estimated cost to the dry cleaning industry. Table 12-2 summarizes the results, while Table 12-3 outlines the methodology and costs for 30% substitution with wet cleaning, and Table 12-4 outlines the methodology and costs for 70% substitution with hydrocarbon solvent.

Table 12-2: Summary of Cost Calculations

Cost Components	Costs (\$ million)
Capital cost to replace 30% of existing dry clean machines with wet clean equipment.	\$35
Capital cost to replace 70% of existing dry clean machines with hydrocarbon solvent machines.	\$196
Total capital cost	\$231
Additional annual operating cost to clean 30% of currently dry cleaned clothes with wet cleaning.	\$24/yr
Additional annual operating cost to clean 70% of currently dry cleaned clothes with hydrocarbon solvent.	(\$6/yr)
Total annual operating cost	\$18

Table 12-3: Direct Replacement Cost; 30% Wet Cleaning

Assumptions	Value	Source
Number of plants using perc in Canada	3,484	Levelton
Number of perc machines	4,263	Levelton
Quantity of dry cleaned clothes (tonnes)	85,000	Levelton
Quantity dry cleaned per machine (tonnes/year)	20	Calculated
Capital cost for equipment (25 tonnes/year)	\$27,500	Levelton, Wet Clean machines may not operate at capacity
Total number of wet clean machines required	1,279	Assumed 30% of total perc machines
Total capital cost for wet cleaning (\$ million)	\$35	Calculated
Operating costs versus perc (per machine)		
Labour	\$27,500	Levelton
Electricity savings	(\$650)	Levelton
Chemicals	(\$2,125)	Levelton
Solvent	(\$4,202)	Versus 2nd gen. Machine
Waste disposal	(\$1,950)	Levelton
Total annual cost per machine	\$18,573	Levelton
Total annual operating cost for wet cleaning machines (\$ million/year)	\$24	Calculated (total operating cost * # wet machines)

Table 12-4: Direct Replacement Cost: 70% Hydrocarbon Solvents

Assumptions	Value	Basis
Number of plants using perc in Canada	3,484	Levelton
Number of perc machines	4,263	Levelton
Quantity of dry cleaned clothes (tonnes)	85,000	Levelton
Quantity dry cleaned per machine (tonnes/year)	20	Calculated
Capital cost for medium sized equipment (45 tonnes clothes/year) and drier	\$147,500	Levelton, Large machine
Total number of hydrocarbon machines required at same capacity to perc machines	2,984	Assumed 70% of total perc machines
Total number of 45 tonnes/year machines required	1,326	20/45 * 2984
Total capital cost for hydrocarbon cleaning (\$ million)	\$196	Calculated
Operating costs (savings) versus perc (per machine)		
Labour (training/monitoring)	\$2,900	Levelton
Solvent	(\$6,485)	Versus 2nd generation perc machine
Insurance	\$750	Levelton
Total annual cost per machine	(\$6345)	Levelton
Total annual operating savings for hydrocarbon cleaning machines (\$ million/year)	(\$6)	Calculated (total operating cost * of machines)

12.5 Direct Replacement Cost Compared to End-Use Revenues

Total annual revenues in the dry cleaning industry are estimated at \$740 million (Harris, 1996). The annual direct replacement cost of \$43 million represents approximately 6% of total revenues in the dry cleaning industry.

12.6 Socio-Economic Profile

The socio-economic profile will describe the industries supplying perc, and hydrocarbon solvents. Due to the limited market share of wet cleaning in 1993, a socio-economic profile of soaps and surfactants will not be provided. Interested readers may refer to Chapter 13, "Trichloroethylene Used in Industrial Degreasing" for a socio-economic profile of the soap and surfactant sector.

12.6.1 Perchloroethylene

As with many of the other chlorinated products discussed in Part Three, perchloroethylene is a high value-added product derived from chlorine. Some of the multinational companies who produce chlorine, as discussed in Part One, are integrated forward to manufacture chlorinated solvents from petrochemicals.

Importers/Producers and Distributors: There is no production of perc in Canada. All of the perc in the Canadian market is imported by four main importers, as shown in Table 12-5, who are also producers. There are perhaps about a dozen small importers in Canada.

Table 12-5: Principal Importers/Producers of Perc

Importer	Country
Dow Chemical	USA
Vulcan	USA
PPG	USA
ICI	UK

Source: Harris, 1996

Perc is distributed to dry cleaners through distributors. Some of the major distributors are listed in Table 12-6. The distributors package and distribute perc to dry cleaners, along with other supplies associated with dry cleaning (e.g. machinery, filters, hangers). In general, perc represents a small percentage of revenues for distributors, ranging from 5 to 10% of total revenues (Environment Canada - Harris, 1996).

Table 12-6: Major Distributors of Perc to Dry Cleaners

Distributor	Location
Unisource	New Brunswick
Royal McGoun	Quebec
Groulx-Robertson	Quebec
Dalex	Ontario
Apco	Ontario
Regal Sales	Ontario
Pro Chemical	Ontario
GBA Refineries	Ontario
Comet Chemicals	Ontario
Keats Brothers	Manitoba
George Wertman	BC
B.C. Specialities	BC

Source: Environment Canada: Harris, 1996

Imports and Exports: In 1993, the total quantity of perc imported was 10.2 kilotonnes, of which an estimated 5.5 kilotonnes was used by the dry cleaning industry.

Revenues: The total value of perc imports as registered by Statistics Canada in 1993 is \$6.3 million (Statscan, 1993). Based on a price of \$2.05 per kilogram and an amount of perc use of 5.5 kilotonnes (Levelton, 1995) the value of domestic sales associated with perc sales to dry cleaners are \$11 million. The differences in values reflect a substantial price-mark-up through the distribution chain for perc.

12.6.1.1 Hydrocarbon Solvents

Hydrocarbon solvents are liquid petroleum products distilled from crude oil in special fractionating units within certain oil refineries. Two major categories of hydrocarbon solvents are aliphatic and aromatic solvents, distinguished by their molecular structure.

There are many grades of aliphatic hydrocarbon solvents, but the main product is referred to as "mineral spirits". Two common solvent trade names are: Varsol™, (Imperial Oil Ltd.) and Shellsol™ (Shell Chemical Canada Ltd.). Aromatic hydrocarbon solvents include the chemicals toluene, xylenes and heavy aromatics. The hydrocarbon solvents used as alternatives to perc are generally aliphatic hydrocarbon solvents.

Plants: Major producers of hydrocarbon solvents in Canada are Imperial Oil Ltd., Shell Chemicals Canada Ltd., and Sun Chemical Ltd., all of whom produce solvents in Sarnia, ON. These plants account for over 90% of all hydrocarbon solvents manufactured in Canada. Imperial's major commercial product used in dry cleaning is Varsol 3135. It also imports hydrocarbon solvents suitable for dry cleaning from Exxon's Baytown, TX refinery. One such product, called DF2000, is being promoted as a safe hydrocarbon solvent with a high flash point and no odour due its high iso-paraffinic and extremely low aromatics content. Shell Canada offers Cleansol 34 as its major commercial dry cleaning solvent. Its volume of business in Canada is low.

Production/Use: An estimated 350 kT of hydrocarbon solvents (aliphatic and aromatic) are produced in Canada, but only a tiny fraction are used in dry cleaning. Using an estimated 7.4 kilotonnes of clothes cleaned by hydrocarbon technology, and a use rate of 65 kilograms of solvent per tonne clothes (Levelton, 1995), generates an estimate of 0.5 kilotonnes of hydrocarbon solvent used in for dry cleaning in Canada.

Imports and Exports: The established hydrocarbon solvents (Varsol 3135, Cleansol 34) are produced domestically, while the newer formulations are (DF-2000) are imported. There are no exports of dry cleaning hydrocarbon solvents from Canada, but it is assumed that about 10% of the domestic hydrocarbon solvents used for dry cleaning are imported.

Revenues: Based on an estimate of 0.5 kilotonnes of hydrocarbon solvent used in Canada and a retail price for hydrocarbon solvent of \$1.05 (Levelton, 1995) the estimated value of annual sales of hydrocarbon solvent to dry cleaners is \$0.5 million.

12.7 Summary

The principal solvent used in the dry cleaning industry is tetrachloroethylene, commonly referred to as perc. Perc use in the dry cleaning industry accounts for approximately 54% of all perc imported in 1993; approximately 5.5 kilotonnes. The principal alternatives to perc are hydrocarbon solvents and wet cleaning. Wet cleaning refers to cleaning clothes currently dry cleaned (ex. wool, silk) with special soaps and water, in specialized laundry equipment.

Perc is the dominant cleaning substance used in the dry cleaning industry. Perc is estimated to clean 90% of all clothes dry cleaned. Hydrocarbon solvents are estimated to clean 9% of all clothes dry cleaned, while other methods (including wet cleaning) account for less than 1% of the market. The trend in perc use is declining, primarily due to environmental concerns. Perc has been declared toxic under the Canadian Environmental Protection Act (CEPA).

The total annual direct replacement cost for perc is estimated at \$43 million, based on annual operating costs of \$18 million, and total capital costs of \$231 million. This estimate is based on clothes currently dry cleaned with perc being cleaned 70% by hydrocarbon solvents, and 30% by wet cleaning. The direct replacement costs (\$43 million) represent approximately 6% of total annual revenues in the dry cleaning industry (\$740 million). Table 12-7 summarizes the market for perc and hydrocarbon solvents.

Table 12-7: Summary for Tetrachlorethylene and Hydrocarbon Solvents, 1993

Variables	Tetrachlorethylene for Dry Cleaning	Hydrocarbon Solvents for Dry Cleaning
Value of Domestic Sales (\$ million)	11	0.5
Trade Balance (\$ million)	0	0
Domestic Revenues (\$ million)	11	0.5
Manufacturing Employment	0	n.a.
Ratio of Domestic Revenues to Employment	0	n.a.

12.8 Contacts and References

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Imperial Oil Ltd.
- Careful Hand Laundry and Dry Cleaning
- Buttons and Bows
- Broadkorb, T. (Environment Canada - Pollution Abatement Division)
- Centre for Emissions Control (Washington D.C.)
- Dry Cleaners and Launderers Institute
- Ontario Fabric Care Association

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13. Chlorinated Solvents: Trichloroethylene (TCE) in Industrial Degreasing Operations

13.1 Introduction

This chapter describes trichloroethylene (TCE) used in industrial degreasing operations. Degreasing refers to a cleaning process used in industries manufacturing or processing metal parts. Degreasing operations are found in the pipe and tube, aerospace, automotive parts industries, electrical and electric components industries, plating shops and many other industrial sectors.

Industrial degreasing operations can take a number of different forms with a variety of cleaning agents. Basic operations include manual wipe cleaning and passive immersion cold cleaning using aliphatic hydrocarbon solvents or chlorinated solvents. Vapour degreasing uses heated chlorinated solvents such as TCE, methylene chloride, 1,1,1-trichloroethane (prior to its phase-out) and tetrachloroethylene in batch open-top degreasing tanks or continuous conveyor systems. The alternatives to TCE include hydrocarbon solvents and aqueous and semi-aqueous cleaning systems.

It is estimated that approximately 1.6 kilotonnes of TCE were consumed in Canada in 1993 in degreasing operations, the majority of it in vapour degreasing (1.3 kilotonnes). TCE used in degreasing accounts for approximately 73% of the 2.2 kilotonnes of imports of TCE in 1993 (CHEMinfo, 1996). It is also used in other products as industrial coatings, adhesives and miscellaneous chemical formulations. This chapter will focus on TCE used in industrial degreasing operations.

This chapter will assess the importance of TCE in industrial degreasing through five sections, market analysis, technical evaluation, direct replacement cost, direct replacement cost compared to end-use revenues, and socio-economic profile. The socio-economic profile will use the variables of manufacturing, imports and exports, revenues and employment to describe the economic importance of TCE and alternatives.

13.2 Market Analysis

As shown in Table 13-1, hydrocarbons solvents have the major share of the degreasing market, accounting for over 47% of all solvents used. The chlorinated solvent 1,1,1-

trichloroethane (TCA) which occupies the second largest market share was phased out of use by the end of 1995, as part of the Montreal Protocol on ozone depleting substances.

Table 13-1: Solvents Used in Degreasing Operations
(cold cleaning and vapour degreasing)

Solvents	1993 Use (kilotonne)	
Hydrocarbons (aliphatic, aromatic, etc. - virtually all cold cleaning)	18	56%
111-trichloroethane (methyl chloroform)	3	10%
Oxygenated solvents (i.e., alcohols, esters, etc.)	5	15%
Trichloroethylene (TCE)	2	6%
Other solvents	4	12%
Total solvents for degreasing	32	100%

Source: Energy Pathways Inc., 1993, CHEMinfo Services.

Most TCE is used in the vapour degreasing sub-sector of the industrial degreasing market. Two trends in TCE use have been caused by environmental factors. The first is an increasing trend towards TCE as a replacement for TCA as the latter is being phased out under the Montreal Protocol. The second trend is a declining use of chlorinated solvents in vapour degreasing in general. This trend is generated by TCE being declared toxic under the Canadian Environmental Protection Act (CEPA). This second trend has several components, including market penetration by aqueous and semi-aqueous cleaning or other non-solvent based technologies, as well as a trend toward more efficient use of TCE. Table 13-2 shows the phase-out of TCA in vapour degreasing over 2 years.

Table 13-2: Trends in Solvent Use for Vapour Degreasing

Solvent	1993 (kilotonne)	1995
TCE	1.3	1.6
TCA	1.3	0.5
Other	0.1	0.1
Total	2.7	2.2

Source: CHEMinfo Services, 1996

13.3 Technical Description

There are a variety of degreasing processes employed, including batch cold cleaning, open top vapour cleaning, continuous or in-line cleaning and aqueous and semi-aqueous systems. Hand wiping with solvent containing rags is a common option where it is not feasible to remove parts and place them in degreasing machinery. These processes can be classified into cold cleaning, and vapour degreasing where vapour degreasing refers to some heating of the solvent. TCE is used extensively in vapour degreasing and somewhat in cold cleaning. The main advantages of TCE are that it can clean all types of metals, using little space, without posing a fire hazard. There are two general alternatives to degreasing with TCE, aqueous and semi-aqueous based cleaning systems and non-chlorinated specialty hydrocarbon solvents.

13.3.1 Aqueous Systems

Aqueous systems involve washing, rinsing and drying stages. The wash stages involve the use of an totally aqueous alkaline detergent formulation. These detergents incorporate builders, surfactants and additives for proper and effective functionality. Builders act as saponifiers and pH buffers and include such chemicals as sodium silicate or sodium tripolyphosphate. Various surfactants may be used as wetting and emulsification agents. Sequestering agents, corrosion inhibitors, defoamers, and other specialty chemicals may be added.

Aqueous systems offer good removal of contaminants for most metal parts, but complex, and intricate parts may present problems. A drawback with some alkaline cleaners is an incompatibility with aluminum components. With at least three stages required in the cleaning process, aqueous systems usually require much more space, equipment and energy.

13.3.2 Semi-aqueous Systems

Semi-aqueous systems use soluble organic solvents in a first stage followed by water washing and drying in subsequent stages. Terpene-based systems generally provide good cleaning power. However these products do produce strong odours and can present toxicity problems. Terpeneol offers an alternative with lower odour, higher flash point and lower toxicity. N-methylpyrrolidone is a polar solvent used in semi-aqueous acidic or basic formulations. At higher temperatures it is often blended with other solvents, and functions well as a degreasing agent. Drawbacks to this technology include material incompatibility with plastic and rubber equipment, and potential waste water disposal problems. In addition, some techniques (i.e. using a spray) can generate flammability problems.

13.3.3 Hydrocarbon Solvents

Hydrocarbon solvents were extensively employed prior to the widespread use of chlorinated solvents. The main problem with hydrocarbon solvents in vapour degreasing is one of safety related to flammability. Hydrocarbon solvent degreasing operations need to be designed to eliminate the risk of vapour release, ignition and possible explosion. Specialty aliphatic hydrocarbon solvents for degreasing applications are often synthetically produced to offer low odour, low volatility, narrow boiling range, and higher flash points (as high as 93°C). Some of these more expensive solvents are likely to be suitable in situations replacing TCE.

In cold cleaning, hydrocarbon solvents are relatively simple substitutes for TCE. Hydrocarbon solvent alternatives in simple batch dip degreasing operations include: toluene, xylenes, naphthas and various grades of mineral spirits. Other related solvents include oxygenated solvents (such as alcohols, ketones and glycol ethers) and perfluorocarbons. Each solvent has its own unique properties which must be matched with the cleaning application. Table 13-3 summarizes the technical comparison.

Table 13-3: Technical Comparison of TCE and Alternatives

Technical Feature	TCE	Semi-Aqueous & Aqueous Systems	Hydrocarbon Solvents
Functional			
Non-polar contaminant removal	Excellent	Moderate	Good
Polar contaminant removal	Excellent	Good	Good
Broad range of metal and other materials compatibility	Excellent	Moderate	Very good
Operational			
Drying time	Short	Longer (may need drier)	Moderate
Space limitations	Low	High	Low
Energy Requirements	Low	High	Low
Compatibility with existing machinery		Very low	Moderate
Safety, Other			
Flammability	Very low	None; Low for semi-aqueous only	Very high
Waste water, sludge generation	Low	High	Low
In-plant recycling capability	High	Moderate	Very high

Source: CHEMinfo Services.

13.4 Direct Replacement Costs

The direct replacement costs for TCE in degreasing operations in Canada assumes that all vapour degreasing is replaced by aqueous systems, and that all cold cleaning applications are replaced by hydrocarbon solvents. The total capital costs for conversion to the two options are estimated at \$52 million (\$6 million annualized at 9%, 20 years). The total increase in operating costs are estimated at \$6.7 million per year, generating a total annualized cost of \$13 million. The vapour degreasing calculation is shown in Table 13-4, and the cold cleaning calculation is shown in Table 13-5.

Table 13-4: Direct Replacement Costs - Vapour Degreasing
(Substitution with Aqueous Cleaning Systems)

Type of Machines	Number of Machines	Capital Cost per Machine (\$ thousand)	Total Capital Cost (\$ million)	Op Cost Diff per Machine (\$ thous/yr)	Total Op Cost Difference (\$ million/yr)
Small	86	15	1	7.7	1
Medium	132	40	5	10.7	1
Large	95	150	14	16.7	2
Very Large	106	300	32	28.5	3
Total	419		52		7

Source: CHEMinfo Services, 1996.

Table 13-5: Direct Replacement Costs - Cold Cleaning

	TCE	Hydrocarbon Solvents	Operating Cost Saving
Volume (kT)	0.3	0.3	
Average Price (\$/kg)	2.00	1.00	1.00
Value (\$ million/yr)	0.6	0.3	0.3

Source: CHEMinfo Services, 1996.

All costs and estimates of machines by size, and costs, are taken from "Profile of Industrial Solvent Degreasing with Trichloroethylene and Perchloroethylene in Canada" (CHEMinfo Services, 1996).

The model for vapour degreasing includes replacement of both TCE- and TCA-using machines by aqueous systems, since both chlorinated solvents were still being used in 1993.

The principal operating cost increases from this substitution come from higher labour, utility and maintenance costs, despite the lower material costs of aqueous solutions. The replacement of TCE by hydrocarbon solvents assumes no new machines are required. Operating savings are expected due to the lower cost of hydrocarbons. However, due to the low volume (0.3 kT/yr), the overall savings are very low.

13.5 Direct Replacement Costs Compared to End-Use Revenues

Three industries account for approximately 56% of all vapour degreasing chlorinated solvent demand, the steel pipe and tube, aeronautics, and automobile parts industries (CHEMinfo, 1996). Multiplying the total direct replacement cost by the percentage of each industries use of TCE generates an estimate of the annual direct replacement cost for each industry. In all industries the annual direct replacement costs are less than 1% of domestic revenues. Table 13-6 shows the ratios for the 3 industries.

**Table 13-6: Direct Replacement Costs Compared to
End-Use Revenues**

Industry	TCE Use (kilotonnes)	% Total TCE Use (1.6 kT)	Direct Replacement Cost (\$ million/yr)	Domestic Revenues (\$ million/yr)	Direct Replacement Cost/ Domestic Revenues
Steel Pipe and Tube	0.4	25%	3	1563	.19%
Aeronautics	0.3	19%	2	4796	.04%
Auto and Auto Parts	0.2	12%	1	54734	.00%
Total	0.9	56%	6	61093	.01%

Source: CHEMinfo Services, 1996; Stats Can, 1993, 31-203.

13.6 Socio-Economic Profile of TCE and Alternatives

13.6.1 TCE

Importers/Producers: There are no producers of TCE in Canada. All TCE is imported, with the majority of imports coming from the same four importers/producers listed in Chapter 12; Dow Chemical (U.S.), ICI (U.K), PPG (U.S.) and Vulcan (U.S.).

The TCE is then distributed through a number of major distributors, who may sub-distribute to another level of sub-distributors for companies using smaller quantities of TCE. The major distributors offer a wide range of other chemical products as well as TCE. The major distributors are Van Waters and Rogers, Ashland Chemicals, Stanchem and Canada Colors and Chemicals.

Imports and Exports: Total imports of TCE into Canada in 1993 were 2.2 kilotonnes, of which 1.6 kilotonnes were used in degreasing.

Revenues: Total imports of TCE are valued at \$2 million in 1993 at the level of the importers (Stats. Can., 1993, 65-007). The annual value of sales to degreasing end-users is estimated at \$5.1 million (CHEMinfo Services, 1996).

13.6.2 Aqueous and Semi-Aqueous Cleaning Compounds

Aqueous and semi-aqueous cleaning compounds are available from several suppliers of surfactant products to industrial and commercial accounts. Cleaning compounds are usually chemically based on surface-active agents (surfactants) and may or may not incorporate solvents, bleaching agents, alkalies, emollients, chelating agents or other additives. The Canadian formulators of such compounds report to Statistics Canada as part of SIC 376; soaps and cleaning compounds. In 1993 domestic revenues for this code were \$1.6 billion, with manufacturing employment of 3679 (Stats Can., 1993, 31-203). In 1993 the trade deficit for this classification is estimated at \$222 million (Stats. Can., 1993, 65-004, 65-007), generating an estimated value of domestic sales of \$1.8 billion.

Plants: There are only a few companies in Canada making basic surfactant molecules. These include Rhone-Poulenc in Oakville, Huntsman Chemicals in Guelph, Witco in Oakville and Stepan in Longford Mills, Ontario. Procter and Gamble and Lever also make surfactants, mostly for internal requirements as part of their consumer product lines.

Table 13-7 lists the major surfactant suppliers and formulators. The formulated products manufacturers can be divided into two groups, cleaner products for industrial and commercial applications, and consumer products firms. The largest firms are in the

consumer products group which produce household laundry products, consumer cleaners and the like. Almost all of the consumer detergent products group also sell products in many of the other categories of this industry (i.e. industrial, commercial), and many of the smaller cleaner producers also have some consumer products. A large number of smaller companies exist as suppliers of industrial cleaners, but also service commercial laundries, restaurants as well as providing janitorial supplies.

Table 13-7: Major Cleaners & Detergents Manufacturers

Company	Location	
Cartier Chemicals	Lachine	PQ
Choisy Laboratories Ltd.	Louiseville	PQ
Deb Swarfega Inc.	Toronto	ON
Diversey Inc.	Mississauga	ON
Ecolab Ltd.	Toronto	ON
Huntsman Chemicals	Guelph	ON
Lilly Products	London	ON
Magnus Chemical	Boucherville	PQ
Procter & Gamble Inc.	Hamilton	ON
Rhone-Poulenc Specialties	Mississauga	ON
Stepan Chemical Inc.	Longford Mills	ON
Savolite Corp.	Delta	BC
West Penetone Inc.	Ville d'Anjou	PQ
Witco Chemical Canada Ltd.	Oakville	ON

Source: CHEMinfo Services

There are not many Canadian companies supplying aqueous degreasing equipment systems. Most systems are supplied by major US companies. The major Canadian supplier is Proceco Industrial Machinery Ltd. of Montreal, which employs about 150 people.

Production: Production quantities for aqueous cleaning compounds are not routinely tracked by industry participants or Statistics Canada. One problem is the level of active ingredients versus water in the products.

Imports and Exports: There is very little international trade in aqueous cleaning products. The transportation costs for products containing water are expensive.

Revenues: In 1993 the total volume of aqueous degreasing was low, but has experienced high growth rate from 1993 onwards, possibly ranging as high as 10% per year (CHEMinfo Services, 1996). Assuming a 10% market share of vapour degreasing in 1993, and that

aqueous cleaning solutions are valued at 20% of the value of TCE (CHEMinfo Services, 1996) generates an estimate of domestic sales of \$0.5 million.

Number of Employees: Based on the ratio of domestic sales from aqueous cleaning solution to total domestic revenues in SIC code 376, multiplied by employment in SIC code 376 (3726) manufacturing employment related to aqueous cleaning solution for degreasing is 1 person.

13.6.3 Hydrocarbon Solvents

Number and Location of Producers:

The four major producers of hydrocarbon solvents in Canada are Imperial Oil Ltd., Shell Chemicals Canada Ltd., Sun Chemical Ltd., and Petro-Canada Ltd. The majority of cold degreasing solvents are aliphatic solvents made by Imperial Oil and Shell at Sarnia, ON.

Hydrocarbon solvents are distributed in Canada by large chemical distributors such as Van Waters & Rogers, and Ashland Chemicals, many of the same companies that distribute TCE. Safety-Kleen Inc is established as a full service distributor to degreasing operations. It installs degreasing machines at customer sites (sometimes free) and supplies a range of clean hydrocarbon solvents while also removing spent material for recycling. It dominates the low volume degreasing market. Another company recently offering this service is Laidlaw.

Production Levels: The domestic market for hydrocarbon solvents in degreasing operations is estimated at 18 kT, primarily for cold cleaning applications.

Imports and Exports: Imports of hydrocarbon solvents to Canada are estimated at less than 10 kT, and most are specialty solvents. Virtually none of this is used for degreasing. Although exports of aliphatic solvents are estimated at 60 kT, a very low percentage would be used for degreasing. The trade balance for degreasing solvents is assumed to be 0.

Revenues: The total domestic market for aliphatic and aromatic hydrocarbon solvents is estimated to be about 280 kT, with an average price of about 0.50/kg. The total domestic sales are about \$140 million. The domestic sales associated with the estimated 18 kT of degreasing solvents is about \$9 million.

Manufacturing Employment: There are approximately 100 people employed in the manufacture of hydrocarbon solvents at 4 plants in Canada.

13.7 Summary

The main use of trichloroethylene (TCE) is to degrease metal parts in various industries, primarily the steel pipe and tube, aeronautics, and auto parts industries. Degreasing applications account for 73% (1.6 kilotonnes) of imports of 2.2 kilotonnes. The major use of TCE is in vapour degreasing applications, where vapour degreasing applications refers to applications where the solvents must be heated. In 1993 TCE and 111-trichloroethane (TCA) had roughly equal market shares in this degreasing application. TCE also has a small market share in cold cleaning degreasing markets, where the major market share is held by hydrocarbon solvents.

Two factors are influencing the trend in terms of TCE use. The first is that TCA is being phased out as part of the Montreal Protocol on ozone depleting substances, where TCE is being used as a replacement for TCA. The second factor is that TCE has been declared toxic under CEPA. This second factor has led to a decline in chlorinated solvent based vapour degreasing in favour of aqueous and semi-aqueous cleaning systems, as well as hydrocarbon solvents.

The costs of substitution for TCE were based on replacement of TCE by aqueous cleaning systems in vapour degreasing, and by hydrocarbon solvents in cold cleaning. Total capital costs are estimated at \$52 million, with annual operating costs of \$7 million, generating total annual costs of \$13 million. These costs represent less than 1% of domestic revenues in the main industries which use vapour degreasing (steel pipe and tube, aeronautics, and auto parts). Table 13-8 summarizes the socio-economic data of TCE and its alternatives.

Table 13-8: Socio-Economic Profiles of TCE and Alternatives

Variables	TCE	Soaps and Surfactants	Hydrocarbon Solvents
Value of Domestic Sales (\$ million)	2	1822	140
Trade balance (\$ million)	(2)	(222)	30
Domestic Revenues (\$ million)	0	1600	170
Manufacturing Employment	-	3679	100
Manufacturing Employment/Dom. Revenues	-	2.29	0.6

13.8 Contacts and References

13.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Gerrard Manufacturing Company Limited
- Imperial Oil
- Proceco Industrial Machinery Limited
- Shell Canada Limited
- Statistics Canada (Soap and Cleaning Compounds Industries)
- Sun Petrochemical Company

13.8.2 References

CHEMinfo Services Inc., Profile of Industrial Solvent Degreasing with Trichloroethylene and Perchloroethylene in Canada and Economic Impacts of Applying End-Use Quotas to Reduce Solvent Use. For Environment Canada. 1996

Energy Pathways Inc./Quinn Associates. 1995. VOC Emissions from Solvent Degreasing, for Environment Canada.

Statistics Canada. 1993. Imports by Commodity, 67-004.

Statistics Canada. 1993. Exports by Commodity, 65-004.

Statistics Canada. 1993. Manufacturing Industries of Canada, 31-203.

14. Chlorinated Solvents: Dichloromethane in Paint Stripper and Polyurethane Foam

14.1 Introduction

Dichloromethane (DCM) is a chlorinated hydrocarbon solvent which is commonly known as methylene chloride. DCM is not produced in Canada. Net imports into Canada have been in the range of 7 to 8 kilotonnes per year¹ over the last 5 years. As shown in Table 14-1, two major domestic applications for DCM are in paint stripper products, and as a blowing agent in flexible slabstock polyurethane foam production. It is estimated these applications accounted for nearly 60% of DCM net imports² in 1993. Other uses include aerosol products, adhesives, pharmaceutical tablet production, industrial cleaning, chemical synthesis, and application in laboratories as an extraction solvent. This chapter focuses only on DCM used in paint stripping and as an auxiliary blowing agent in polyurethane foam production.

Table 14-1: Canadian DCM Consumption

End Use	1993 (kT)	
Paint Remover	2.8	40%
Blowing Agent	1.3	19%
Other applications	2.9	41%
Total	7.0	100%

Source: CHEMinfo Services. Note: Total domestic consumption in 1995 was 7.4 kT.

The alternative to DCM in paint stripper is a combination of n-methyl pyrrolidone and di-basic esters. The alternative to DCM used as an auxiliary blowing agent in polyurethane foam production is carbon dioxide injection.

¹ Stats. Can., 65-007 reports 8.7 kT of DCM imports for 1993. This total import level is incorrect and 1993 total imports were 7.4 kT (personal conversation with Statistics Canada by CHEMinfo Services). Net imports estimated at 7 kT.

² Net imports are total imports less exports. Some DCM is exported by distributors of offshore supplies.

14.2 Market Analysis

In the paint stripper market, DCM-based formulations have a dominant market share. Most sales of commercial formulations contain 50 to 90% methylene chloride, and a mixture of less expensive organic solvents. A few products contain less than 10% DCM by volume, and rely more on other active ingredients for functionality. The paint stripping market is composed of industrial, commercial and consumer paint stripper applications, with most volume going to the consumer and commercial segments. Commercial operations include the many furniture stripping and refinishing operations, spread across Canada.

There are a few non-chlorinated alternatives commercially available but their market share is low. Some alternatives include oxygenated solvents such as n-methyl pyrrolidone and dibasic esters, solvents blends (i.e., acetone, toluene and methanol blends), and caustic-based solutions.

DCM's high market share in paint stripper is primarily due to its technical characteristics, notably its ability to strip paint quickly and effectively. One negative factor which may influence the market share for DCM in both markets is that DCM has been declared toxic under CEPA. Environment Canada classifies DCM as a Group II substance, "Probably Carcinogenic to Humans" (CEPA 1993).

As a result of its high solvency and vapour pressure, DCM has replaced chlorofluorocarbons (CFCs) as an auxiliary blowing agent in the production of flexible polyurethane slabstock foam, which is used in some automotive applications, residential furniture and bedding products. Roughly 25% of all polyurethane slabstock foam (low density, soft grades) requires auxiliary blowing with DCM. In replacing CFC-11 as the leading blowing agent, it yielded savings due to its lower molecular weight and lower cost per kilogram. CFCs have been phased out under the Montreal Protocol on ozone depleting substances.

There are a few non-chlorinated alternative auxiliary blowing agents in North America, but their use is limited; probably to no more than 5-10% of applications. No chemical alternatives to DCM were identified as being used in Canada in 1993. Some foam producers have used HCFCs, predominantly in California. However there is a realization that HCFCs are only a temporary alternative solution, as HCFCs may also be phased out as ozone depleting chemicals. Acetone is used in one US foam plant and pentane is used by one company in two plants. Foam producers seem to agree that the most likely long term alternative is the installation of a system for the external generation and injection of carbon dioxide (CO₂) gas. Three European companies have developed process patents on CO₂ systems, which are now being licensed in 10 plants. Although the technology is new

and problems are being debugged, this alternative will be selected for comparison with DCM.

14.3 Technical Comparison of Alternatives

14.3.1 Paint Stripper

Paint strippers are composed of a solvent or combination of solvents strong enough to penetrate a polymerized paint or finish film. They act on that film in one of three ways, depending on how the particular solvents in the stripper react with the film being stripped. They either dissolve the film into a "gunk" that can be wiped off; they swell the film so it blisters and can be scraped off; or they break the bond of the film to the substrate so the film lifts off in sheets. An article in Wood Magazine³ rates 59 different consumer and commercial products available in USA. They are grouped by type of solvent that is the basis of the product formulation: DCM-based (21 products), acetone/toluene/methanol (ATM) based (12 products), DCM/ATM based (12 products), nMP based (8 products), dibasic esters (DBE) based (4 products), and caustic alkalies (2 products). Other solvents are available for industrial applications. For example, benzyl alcohol is used for stripping paint from aircraft.

For the purposes of this study, a combination of n-methyl pyrrolidone (nMP) and dibasic esters (DBEs) is selected as the option to DCM for paint stripping formulation. Alkaline benzyl alcohol formulations are selected as the option for stripping small aircraft and dry media blasting is selected for medium and large aircraft. Aircraft paint stripping accounts for less than 10% of DCM used in all paint strippers in Canada.

DCM is claimed to be the most powerful paint stripper solvent available in common use. Since it is too volatile to be used in pure form, it is blended with special ingredients (i.e., wax) as well as polar organic solvents such as methanol, ethanol, acetone, methyl ethyl ketone or isobutyl ethyl ketone to reduce vapour pressure and lower costs. Despite its organic content, methylene chloride paint strippers are non-flammable. This is not the case for hydrocarbon based organic solvents.

A major technical factor favouring DCM is the time required to effectively strip a paint surface. It is claimed that most paint jobs are ready after only about 1 hour of treatment with methylene chloride. By comparison, nMP may take as long as 20 hours to remove the paint surface. The performance of nMP depends in part on the type of coating being removed.

³ "Getting Under The Surface Of Today's Finish Removers", Wood Magazine, August, 1992, pp.54-57.

Table 14-2 summarizes the technical comparison of alternative paint strippers.

Table 14-2: Technical Comparison of Paint Strippers

Characteristic	Methylene Chloride	n-methyl pyrrolidone, dibasic esters	Benzyl Alcohol
Flammability	None	High	High
Volatility	High; blend required	Medium	Medium
Polarity	High	Medium	High
Reactivity	Low	Low	Medium
Removal Time	Low (2-60 min)	Medium (0.1-15 hours)	Medium (2-20 hours)

Some formulations are blends of nMP, DBE and solvents. Other are blends with terpenes. All products sold in Canada are imported. nMP is believed to be readily absorbed through the skin and is used in medical applications to transmit drugs to the body through this method.⁴ This property has led to two health concerns about the use of nMP as a replacement stripper.

One concern is the use, for lower cost, of recycled nMP (obtained from extraction and pharmaceutical processes, paints). These have been found to contain potentially harmful impurities such as n-propylamine, pyrrolidone and vinyl pyrrolidone. The hazards presented by these compounds are exacerbated by the skin absorption characteristics of nMP. Another concern that has been expressed is that nMP may act as a conduit for the absorption of heavy metals and other toxins present in the coatings being removed, e.g. lead which was still used in architectural coating in recent times.⁵

Alkaline benzyl alcohol solutions are effective paint strippers but work more slowly than DCM. Dry media blasting using wheat starch is a fast paint stripping method requiring a heavy capital investment in application and exhaust recovery equipment.

14.3.2 Polyurethane Foam Blowing Agents

When a polyol and an isocyanate react, they form a tough, solid polyurethane elastomer. When water reacts with an isocyanate, urea and CO₂ gas are generated. When all three materials are combined in correct proportions, a flexible polyurethane foam (driven by

⁴ Information provided by industry representatives participating in the Meeting of the Technical Working Group - Paint Stripping, Consumer and Commercial, held on October 23, 1996.

⁵ It was significant, however, that nMP was still the product of choice for the largest manufacturer of consumer paint strippers, Swing Paints, in the event of a ban on the use of DCM.

CO₂ expansion) is produced. There is an upper limit to the amount of foam expansion that can be generated by CO₂ because the reaction is exothermic and too much heat can create undesirable resin conditions (i.e., scorching or auto-ignition). DCM is used as an auxiliary blowing agent for three reasons: providing extra softness to foam (for pillows, etc.); lowering the density of foam (for low-quality inexpensive grades); and to provide extra cooling required for certain firm surface foams. DCM is not used for blowing of moulded polyurethane foams, which are higher density, harder and smaller in size.

Hydrocarbon and oxygenated auxiliary blowing agents are not attractive to the industry because of the extensive equipment and process modifications required due to the flammability of the materials. Injection of CO₂ is a capital intensive operation requiring a generator, piping and controls and modifications to the exit of the foam mixing head to control CO₂ frothing. Also, modifications may have to be made to ensure that foams not requiring auxiliary blowing agents can still be produced properly by the machine.

14.4 Direct Replacement Costs

The substitution model for methylene chloride assumes complete replacement in paint remover applications by n-methyl pyrrolidone (nMP), dibasic esters (DBE), benzyl alcohol, and media blasting (wheat starch). In polyurethane foam auxiliary blowing agent applications, the substitute technology is CO₂ generated by on-site equipment⁶. Total annualized capital and operating costs in adopting these options are estimated at \$29 million/yr, as shown in Table 14-3. The models for consumer and commercial paint strippers are shown in Table 14-4 and Table 14-5, respectively.

Table 14-3: Direct Replacement Costs for DCM Use
Paint Strippers and Polyurethane Foam Production

	Technical Option	Capital (\$ million)	Annual Operating (\$ million/yr)	Annualized Capital Plus Operating (\$ million/yr)
Paint strippers				
- Consumer	nMP, DBE		5.4	5.4
- Commercial	nMP, DBE		16.4	16.4
- Aircraft	media blasting, benzyl alcohol	30.0	-1.2+3.1	5.2
PU foam	carbon dioxide	8.8	0.8	1.8
Total		38.8	24.5	28.8

Note: The above costs are based on the report: Dichloromethane Uses in Canada: Review of Options and Regulatory Requirements - DRAFT, Produced by CHEMinfo Services. For Environment Canada, Feb. 1997. Capital costs in that study were annualized at 10% over 15 years.

⁶ Dichloromethane Uses in Canada: Review of Control Options and Regulatory Requirements - DRAFT, CHEMinfo Services Inc., February, 1997. For Environment Canada.

The replacement model assumes DBE/nMP strippers are suitable for the consumer and commercial market and that plastic containers can be handled on filling lines.

**Table 14-4: Direct Replacement Costs for DCM
Consumer Paint Strippers**

Reduction of DCM emissions	100%, or 1200 tonnes
Annual DCM stripper sales	1500 tonnes
Total volume of DCM stripper sales, assuming SG=1.2	1.25 million litres
Package size distribution: ½ litre: 1 litre: 4 litre for the purpose of cost comparison	35%:50%:15%
Assume use of equal amounts of nMP and DBE	0.625 ML nMP and 0.625 ML DBE
Price for ½ l can of DCM, nMP, DBE	\$14.00, 30.00, 14.00
Price for 1 l can of DCM, nMP, DBE	\$11.00, 20.00, 11.00
Price for 4 l can of DCM, nMP, DBE	\$6.00, 15.00, 6.00
Additional cost of using DBE	nil
Additional cost of using nMP	\$5.4 million
Total cost of DCM reduction	\$5.4 million

**Table 14-5: Direct Replacement Costs for DCM
Commercial Paint Stripping**

No. of commercial paint stripping shops in Canada using DCM	1400
Reduction of DCM emissions in all commercial shops	1260 tonnes
Annual volume of DCM-based stripper in commercial shops	1.46 million litres
Annual cost of DCM-based stripper, assuming that on average most of the stripper is sold in 20l containers at ~\$75/20l.	\$5.5 million
Assume: 1 L of nMP/DBE blend for 1 L of DCM stripper	
Assume that DCM strippers will be replaced by a blend of DBE/nMP based stripper at about 60% higher cost ⁷ .	\$3.3 million
Additional cost for nMP/DBE strippers is	
Container cost	no additional cost for plastic containers
Waste disposal cost	no additional waste disposal cost
Productivity, time to strip	~20% longer
Total number of employees in furniture refinish shops	2800
Assume that 50% of the time they do paint stripping	1400 man-years
Additional time required to strip with nMP/DBE blends	280 man-years
Annual cost of an employee in a furniture refinish shop	\$30,000
Annual cost to eliminate emissions of DCM from furniture refinish shops (900 tonnes)	\$11.7 million (8.4+3.3)
Annual cost to eliminate emissions of DCM from all other commercial paint stripping facilities (1260 tonnes)	\$16.4 million (1260/900*11.7)

⁷ Clark's Antiques Specialty Supply Ltd. Supplies a 50/50 nMP/DBE blend manufactured by Fielding U-Safe which sells for \$26.40/4 litres or ~60% over the price of a DCM based stripper.

The substitution costs for aircraft stripping are based on different options for large/medium and smaller aircraft. In the model shown in Table 14-6, it is assumed that for 5 locations stripping large and medium size aircraft, the use of DCM strippers will be eliminated by the use of wheat starch blast stripping. The two commercial airlines operate 4 locations and the Department of National Defense operates 1 location), The total volume of DCM used at these locations is 70 tonnes and the releases are 56 tonnes.

**Table 14-6: Direct Replacement Costs for DCM
Large/Medium Aircraft Paint Stripping**

Reduction of DCM emissions (80% of 70 tonnes)	56 tonnes
Number of large aircraft	18
Average area of large aircraft	10,000 sq. ft.
Number of medium aircraft	44
Average area of medium aircraft	5,000 sq. ft.
Total area of large and medium aircraft	400,000 sq. ft.
Annual cost of DCM stripping at \$6000/1000 sq.ft.	\$ 2.4 million
Automated starch media blasting operating costs	\$3000/1000sq.ft.
Automated starch media blasting operating costs	\$1.2 million
Foregone revenue as a result of slower turnaround	nil
Net Operating Cost Difference	\$(1.2) million
Capital cost, US\$4-5 million for 5 locations, C\$1=US\$0.75	\$30 million
Annualized capital cost of media blasting (@ 9%, 20 years)	\$3.3 million/yr

For smaller aircraft (the other 17 locations), the model shown in Table 14-7 assumes benzyl alcohol strippers as alternatives for DCM strippers, possibly combined with some use of dry media blast stripping for some off aircraft components. The total DCM volume used at these locations is 130 tonnes and the releases is 80% or 104 tonnes.

**Table 14-7: Direct Replacement Costs for DCM
Small Aircraft Paint Stripping**

Reduction of DCM emissions in commercial shops (80% of 130 tonnes)	104 tonnes
Number of small aircraft	600
Average area of small aircraft	2,000 sq. ft.
Annual cost of DCM stripping at \$6000/1000 sq.ft.	\$ 7.2 million
Assume that cost of benzyl alcohol stripping is 20% less	\$ 5.8 million
Lost net revenues from longer turnaround time	\$15,000/day
Average delay in stripping a small aircraft	½ day
Cost of delay in stripping small aircraft, 600x½x\$15,000	\$4.5 million
Total operating cost of benzyl alcohol	\$10.3 million
Net Operating Cost Difference	\$3.1 million

Source: CHEMinfo Services

The substitution of DCM as a blowing agent involves the installation of carbon dioxide generation and distribution equipment for each slabstock foam plant. It is assumed that each plant will require one system. Prices will differ according to plant layout. Two installed cost estimates of \$300,000 and \$1,000,000 per system were mentioned by foam producers studying this technology. A cost of \$800,000 per system was assumed. The DCM price used for foam blowing is an average delivered bulk price for high volume purchases. These direct replacement costs are shown in Table 14-8, based on CarDio technology by Cannon.

Table 14-8: Direct Replacement Costs for DCM
Polyurethane Foam

100% Reduction of DCM emissions	1300 tonnes
Volume of carbon dioxide to replace DCM, 1:3.1	420 tonnes
Saving in eliminating 1300 tonnes of DCM @ \$1100/tonne	\$1.43 million
Cost of Carbon dioxide @ \$150/tonne	\$63K
Lease cost of liquid carbon dioxide tank, \$1000/month, 11 tanks	\$132K
Total cost of carbon dioxide	\$195K
Net savings	\$1.23 million
Total weight of raw materials: assumes ~5pphp of DCM is used	45,000 tonnes
Total raw material cost (at \$2.00/lb), excluding DCM.	\$200 million
Foam Chemical Royalties: 1% assumed	\$2 million
Net Operating Cost Difference	\$0.77 million/yr
Capital cost per plant, US\$0.6 million (CarDio technology)	\$0.8 million
Total capital cost for 11 plants	\$8.8 million
Annualized capital cost (9%, 20 years)	\$1.0 million/yr
Total annualized costs	\$1.8 million/yr

14.5 Direct Replacement Costs Compared to End-Use Revenues

Paint stripper is primarily an end-use good bought by consumers and commercial shops, while DCM used as a blowing agent is an intermediate good in the production of polyurethane slab. Polyurethane slab will be considered as an end use product for this analysis, though polyurethane slab is also an intermediate good used in the production of bedding, automobiles, and furniture. The direct replacement costs for paint stripper are 73% of end use revenues, largely driven by the replacement cost in aircraft paint stripping. The direct replacement cost of polyurethane foam is 1.2% of foam end use revenues. Table 14-9 summarizes the ratios of direct replacement costs to revenues.

**Table 14-9: Direct Replacement Costs Compared to
End-Use Revenues**

Market	Direct Replacement Cost (\$ million)	End-Use Revenues (\$ million)	Direct Replacement Cost/ End-Use Revenues (%)
Paint Stripper	27.0	37	73%
Polyurethane Slab	1.8	150	1.2%
Total	28.8	187	15%

14.6 Socio-economic Profile

Due to the low market shares of alternatives, the socio-economic profile will describe solely DCM. Chapters 12 and 13 provide information on hydrocarbon solvents.

14.6.1 DCM

Plants and Production: All DCM consumed in Canada is imported from the four companies identified in chapter 12 and 13; Dow Chemical (U.S.), ICI (U.K.), PPG (U.S.), Vulcan (U.S.). The five major Canadian distributors who handle methylene chloride include Van Waters & Rogers, Apco, Canada Colors and Chemicals, Stanchem and Chemcentral, again the same companies as distribute trichloroethylene.

Over 80% of paint remover volume is supplied to the consumer market by three companies which formulate and package the DCM blends. The largest is Swing Paints Ltd. of Montreal, who supply over 50% of the market with their Circa 1850™ brand. LePage's is likely second with their Polystrippa™ brand. Recochem also supplies paint stripper to mass merchandisers, but paint strippers make up a minor portion of their wide range of packaged chemicals. There are many (perhaps 25-50) small formulators and packagers (e.g. Trend and Denalt). Some of these smaller producers supply private label products and industrial markets.

Imports and Exports: In 1993 total net imports of DCM were nearly 7 kilotonnes, with an estimated 2.8 kilotonnes going into paint stripper, and 1.3 kilotonnes into the polyurethane slab production.

Revenues: In 1993 the total value of DCM as registered at the import level was \$4.5 million (Stats. Can., 1993, 65-007). The estimated value of the 4.1 kT of domestic sales of DCM to paint stripper formulators (2.8 kT) and polyurethane foam producers (1.3 kT) is \$4.5 million, assuming a distribution price of \$1100/T. The value of DCM-based paint stripper is estimated at \$37 million and polyurethane foam sales is \$150 million.

14.6.2 nMP/DBE Solvents

Production and Imports: There is no known production of n-methyl pyrrolidone, dibasic esters and benzyl alcohol in Canada. All nMP, DBE, benzyl alcohol used in paint stripper formulation are imported from the US.

Revenue: At an estimated 5% market share of all paint strippers, the total domestic sales generated by these alternative chemicals sold to formulators is roughly \$0.4 million.

14.6.3 CO₂ Injection

Production, Imports and Revenue: There are no current installations of CO₂ injection technology in Canada. The technology is manufactured in the US, so any domestic sales would be imported. Industrial gas companies supply CO₂ throughout Canada.

14.7 Summary

No commercial quantities of dichloromethane (DCM) are manufactured in Canada. In 1993, approximately 7 kilotonnes of DCM was consumed in Canada. Two major applications were paint stripper formulations and use as a blowing agent in slabstock polyurethane foam production. These applications accounted for approximately 2.8 and 1.3 kilotonnes consumption in 1993, respectively, and represent approximately 60% of total consumption. In both applications, DCM has a dominant market share. A factor that may generate a declining trend in use is that DCM has been declared toxic under CEPA.

The options to DCM analyzed were a combination of solvents (nMP, DBE, benzyl alcohol) and mechanical stripping technology for paint stripper and carbon dioxide injection for polyurethane slab production. The total direct capital replacement costs were \$30 million, with additional annual operating costs of \$25 million, generating total annual costs of \$29 million. The direct replacement costs for paint stripper represent 73% of the value of domestic sales of DCM based paint stripper (\$37 million). The direct replacement cost for polyurethane foam is only 1.2% of foam sales.

14.8 References

Statistics Canada. 1993. Imports by Commodity: Cat. 65-007.

Statistics Canada. 1993. Manufacturing Industries of Canada, Cat. 31-203.

CHEMinfo Services Inc., Review of Regulatory Environment and Control Options for All Uses of Dichloromethane (DCM) in Canada, DRAFT REPORT, February 1997.

15. Chlorinated Flame Retardants

15.1 Introduction

There are over 60 commercial flame retardant products available from nearly 60 suppliers in North America. The matrix of these compounds and where they can be used has thousands of possibilities. Flame retardants are used primarily in rubber and plastics, although there are other applications (e.g., textiles). Some flame retardants are only suited to specific polymers, while others have broad application and can be incorporated in practically all plastic materials. Several hundred different flame retardant mixes are used in the plastics industry. Polymers in which flame retardants are routinely incorporated include polyolefins, polystyrenes, ABS resins, urethanes, acrylics, polyesters, PVC, and styrene-butadiene (SB) rubbers.

Flame retardants can be organic or inorganic compounds containing halogens (such as chlorine or bromine), phosphorus, alumina or antimony. The compounds are also grouped according to their binding mechanism: reactive compounds bond chemically with the substrate material while additive compounds are only mixed in. Commercial grades are available in liquid, paste, and waxy solid forms, although liquid forms predominate since they are easier to blend. Different types of flame retardants are often combined to improve performance. Flame retardant additives can be incorporated at levels of a few percent to as much as 60% by weight of the formulation. The dosage depends on the compound, properties of the plastic, and the application in which the final product will need to perform. There are often requirements to meet established technical standards of performance for many critical applications. Specific examples of chlorinated flame retardants and possible non-chlorine based alternatives are shown in Table 15-1.

Table 15-1: Examples of Flame Retardants

Type	Examples
Chlorinated	chlorinated hydrocarbons; chlorendic acid; chlorendic anhydride
Brominated	brominated organics; brominated hydrocarbons
Chlorinated Phosphorus	chlorinated polyphosphates; chlorinated organic phosphonates; chloro-alkyl phosphates tris (chloropropyl) phosphate; tris (dichloropropyl) phosphate
Brominated Phosphorus	halogenated organic phosphates
Phosphorus	isopropyl triphenyl phosphate; octylphenyl phosphate; triphenylphosphate; ammonium polyphosphates; triethylphosphate;
Inorganics	alumina trihydrate; antimony oxide; magnesium hydroxide; magnesium carbonate; zinc borate; tin compounds; molybdc oxide; sodium antimonate

In Canada, approximately 30 kilotonnes of flame retardants are consumed annually. The total quantity of all chlorinated flame retardants used in Canada is estimated at approximately 6 kilotonnes per year, with another 1.8 kilotonnes being accounted for by chlorinated paraffins. Chlorinated paraffins are plasticizers with fire retardant properties, largely used in PVC products. Alternatives to chlorinated flame retardants, and chlorinated paraffins, are phosphorus compounds, aluminum trihydrate and brominated compounds.

This chapter examines chlorinated flame retardants through five sections; market analysis, technical description, direct replacement cost, direct replacement cost compared to end-use; and a socio-economic profile. Two substitution models are assumed: one for chlorinated flame retardants and one for chlorinated paraffins. The socio-economic profile will include analysis of production, imports and exports, revenues and manufacturing employment.

15.2 Market Analysis

Since flame retardants are often blends of more than one type of compound, it is difficult to effectively segment the total market. However, as shown in Table 15-2, alumina trihydrate (ATH) has by far the greatest volume share with broad coverage of the flame retardants market. Halogenated compounds are the next most prevalent group, with brominated compounds having a slightly larger quantity than chlorinated compounds. Phosphorus is often combined with these compounds.

Table 15-2: Estimated Market Share of Flame Retardants

Type	Quantity (kT)	Percent
Alumina trihydrate	12	40%
Brominated phosphorus	4.5	15%
Chlorinated hydrocarbons	4	13%
Brominated hydrocarbons	3	10%
Chlorinated phosphate esters	1.5	5%
Antimony oxide	2	7%
Non-halogenated phosphorus	1.5	5%
Others	1.5	5%
Total	30	100%

Source: CHEMinfo Services

Environmental pressures are resulting in a trend away from halogenated flame retardants. Most of the concern is related to potential generation of toxic by-products of combustion resulting in the case of fire. The European industry has moved away from halogenated flame retardants, especially poly-brominated phenyl oxide types, faster than North America. Halogenated flame retardants are still widely used in Canada.

15.3 Technical Characteristics of Halogenated Flame Retardants and Alternatives

It is difficult to characterize the complex technology of flame retardants because individual chemical groups often simply contribute only a specific function to a designed mixture. However, each of the major alternative classes (brominated, phosphorus, inorganic metal hydrates) will be discussed in terms of their dominant flame retardant mechanism to illustrate some technical differences between compounds. Table 15-3 below summarizes the technical properties of non-chlorinated flame retardants relative to chlorinated flame retardants.

Table 15-3: Technical Comparison of Non-Chlorinated Flame Retardant Types to Chlorinated Flame Retardants

Characteristic	Brominated	Phosphorus	Inorganic Metal Hydrates (ATH)
Flame retardant Efficacy	equal, better	equal	lower (for equal dosage)
Loading	equal	higher	higher
Polymer mechanical properties	equal	some worse	reduces tensile
Need for antimony	yes	none	none
Halogen gas release	yes	none	none
Smoke densities	equal	lower	low
Processing compatibility	equal	equal, better	poor

Source: CHEMinfo Services

15.3.1 Halogenated Flame Retardants; Chlorine and Bromine

Halogenated flame retardant compounds work by releasing halogen ions into the fire zone when heated. In a fire zone, a high concentration of hydrogen ions are released, which are responsible for breaking down large organic molecules into smaller, volatile radicals. The halogen ions act mainly to bind up free hydrogen (as HCl) and secondarily to react with

and deactivate free radicals. Halogen compounds are called free-radical scavengers because of this action of binding up loose molecules and suppressing the spread of combustion.

An effective halogen flame retardant must be stable under normal conditions, yet be able to release halogens into the fire zone when heated. Fluorine, the lowest atomic weight halogen, bonds strongly with carbon and does not breakdown easily. At the other end of the scale, iodine has such a weak carbon bond that it is unstable, easily decomposing from the compound to form iodine gas. Chlorine and bromine are the only halogens having appropriate bond strength to be stable. However, brominated compounds, with weaker carbon bonds, tend to have lower thermal stability and are more reactive than equivalent chlorinated compounds.

Brominated flame retardants provide much the same functionality as chlorinated flame retardants. Two common brominated flame retardants are: decabromodiphenyl oxide and tetrabromobisphenol compounds. They are used in a range of applications including: solid thermoplastic resins, wire and cable compounds, thermoset resins, and adhesives and coatings. They are generally not used in foamed polymer products. While brominated compounds provide a close technical substitute for chlorinated compounds, it must be recognized that they may also have similar health and environmental issues.

15.3.2 Chlorinated Paraffins

Chlorinated paraffins are a group of hydrocarbon-based compounds used as plasticizing flame retardants. They are chlorinated derivatives of the straight-chain paraffin class of hydrocarbons. The chlorine content ranges from about 30% to 70% by weight.

Chlorinated paraffins are classified according to their molecular chain length. Medium-chain compounds (C_{14} - C_{17}) are used extensively as flame retardants and provide a plasticizing function in resin compounding. Resin applications include ABS, acrylics, cellulose resins, epoxies, phenolic resins, polyesters, polyethylene, polypropylene, polystyrene, PVC and urethanes. The largest volume of medium chain chlorinated paraffins goes into PVC compounds. Long-chain compounds (over C_{18}) are a minor portion of the market and short chain compounds (C_9 - C_{13}) are used primarily in extreme pressure metal working fluids (see Chapter 16).

The main functions of plasticizers are to increase the flexibility, softness and extension properties of thermoplastic resins, thermoset resins, rubbers, coatings and other compounds. Common phthalate ester plasticizers fulfil these functions, but also tend to increase flammability of the polymer in which they are compounded. Chlorinated paraffins are part of a small subgroup of additives which offer flame retardancy as well as resin flexibility. Chlorinated paraffins are similar in structure to PVC resin and

chemically bind to the resin to form an integral complex structure. A maximum chlorinated paraffin loading level of 10% of the additive package is permitted.

15.3.3 Phosphorus Flame Retardants

Phosphate esters are the largest class of phosphorus flame retardant compounds. They are usually composed of a phosphate core to which is bonded alkyl (straight chain) or aryl (aromatic ring) groups. The most common type of phosphate flame retardant is isopropyl triphenyl phosphate. Others include tricresol phosphate and a variety of alkyl diaryl phosphates. The majority of these compounds are used as plasticizers in flexible PVC products. They do not function as well with other polyolefins such as polyethylene or polypropylene. Phosphate esters provide plasticizing function with flame retarding capability due to a tendency of phosphorus to react with the organic material to form a protective, impermeable "char" layer when heated. This layer insulates against heat transmission, prevents volatile organic compounds from being released as gas, and prevents oxygen from reaching underlying combustible material. Phosphate esters impart good flame resistance performance but some industry sources claim that their presence detracts from some physical and electrical performance characteristics of modern materials.

Phosphate esters are often combined with chlorinated flame retardants in additive packages. These compounds generate higher smoke levels than chlorinated compounds and decrease the tensile strength of the resin. For example, phosphate esters could not be used as additives in automobile dashboards because of code requirements. A combination of phosphate esters with brominated compounds may be a possible option for many of the applications.

Borate compounds are a small chemical class of flame retardants that have a mechanism similar to phosphates. These are inorganic powdered additives which when heated, decompose in a solid-phase reaction releasing boric acid and water vapour. The boric acid forms a "melt", a glass-like barrier which functions in a similar fashion to the phosphate "char". The most common compound in this class is zinc borate, but others include boric acid and calcium borate.

15.3.4 Inorganic Metal Hydrates Flame Retardants

Alumina trihydrate (ATH), also known as alumina hydroxide, is added to compounds as an ignition inhibitor. ATH is a white, inorganic solid with a typical particle size of about 1 micron. It chemically decomposes at about 200°C to alumina and water vapour to promote "zone cooling". The endothermic reaction absorbs heat from the area, while the released superheated steam dilutes volatile organic combustion fragments and blankets the area from oxygen access. Once exhausted, the material no longer serves any function.

ATH is used with unsaturated polyester, epoxies, urethanes and polyolefins, but because of its thermal instability and solid form, it can be incompatible with many thermoplastic resins which are heated and processed. Since ATH is a fine solid, the tendency is to use it in situations where the formulation can tolerate high flame retardant loadings while the mechanical performance of the polymer is not adversely affected. It is reported that ATH can contribute to colouration of white polymers. ATH can also destabilize PVC since the alumina can react with the chlorine to form alumina chloride.

ATH is very inexpensive compared to hydrocarbon-based flame retardants, and is often used at high loadings. For example, levels of chlorinated flame retardants range from 1-20 parts per hundred parts of resin, while ATH levels range from 10-100 parts per hundred.

Two similar products to alumina trihydrate are: magnesium hydroxide, which also gives off water vapour; and alumina carbonate, which gives off carbon dioxide gas. These products can appear in blends with ATH.

15.4 Direct Replacement Cost

Two cost models of substitution are used in this study, one for chlorinated flame retardants, excluding chlorinated paraffins (see Table 15-4), and one for chlorinated paraffins (see Table 15-5). The model of substitution for chlorinated flame retardants used for the purposes of this study assumes replacement in equal proportions by three non-chlorinated chemical classes. The annual direct replacement cost is about \$8 million. The cost for chlorinated paraffins is estimated at \$5.4 million/year. The total cost for both flame retardants is \$13 million.

In order to compare the relative magnitudes of the alternatives, the direct costs of complete substitution of chlorinated flame retardants were first calculated. However, to reflect the fact that not all products can substitute for all applications the simplifying assumption was that each of the alternatives would substitute for one third of the chlorinated flame retardants volume. The approach adopted to obtain an order of magnitude cost for direct material substitution is to assume an average price level for chlorinated, brominated, phosphorus and ATH flame retardants. Price information for several commonly used products were obtained from industry suppliers and used for comparison purposes. Two respondents indicated that phosphorus compound loading levels are higher than chlorinated compounds and so a 33% increase in levels was assumed. Also, it was assumed that ATH loading would be three times that of chlorinated compounds.

One major company supplying chlorinated flame retardants claimed that their price ranged from \$2.66 to \$5.31 per kg. for common grades and reached as high as \$16.94 per kg. for specialty compounds. Most of these were chlorinated phosphorus compounds. Some more basic chlorinated hydrocarbons sell for less; between \$1.60 and \$2.40 per kg. A weighted average of \$3.30/kg is assumed to represent the class. The same company offered phosphorus compounds in their line as non-halogenated substitutes that cost from \$4.00 to \$12.00/kg. A weighted average of \$6.50/lb is assumed. The list prices of brominated chemicals from the largest supplier in this class range from \$2.90 to \$5.55/kg. A weighted average of \$4.00/kg is assumed. ATH sells between \$300 and \$360 per tonne for basic grade, but Alcan reports that most flame retardant material sells for \$480 per tonne. This level was chosen as an average.

Table 15-4: Direct Replacement Cost for Chlorinated Flame Retardants

(excluding chlorinated paraffins)

Fire Retardants Class	Volume (kT)	Average Price (C\$/kg)	Total Cost (\$ millions)
Chlorinated	6	3.30	20
Alternatives:			
Brominated	6	4.00	24
Phosphorus	8	6.50	52
ATH	18	0.48	9
Combined (33% each)	11		28
Difference			8

Source: CHEMinfo Services

The substitution model for chlorinated paraffins makes broad simplifying assumptions about the ability of alternatives to completely replace chlorinated paraffins in all flame retardant applications. As alternatives to chlorinated paraffins, phosphate esters are about 4 times more expensive than chlorinated paraffins and generally have higher loading levels. Brominated compounds are not as widespread and cost about 20% more than equivalent chlorinated compounds. The assumption is that a slightly higher loading level for this alternative package (33% more) is required on account of the phosphate ester. The annual direct replacement cost is approximately \$5.4 million.

Table 15-5: Direct Replacement Cost of Chlorinated Paraffins in Flame Retardant Applications

PVC Flame Retardant Additives	Volume (kT)	Average Price (\$/kg)	Cost (\$M)
Chlorinated Paraffins	1.8	1.00	1.8
Phosphate Ester/Bromine	2.4	3.00	7.2
Cost Difference			5.4

Source: CHEMinfo Services

15.5 Direct Replacement Cost Compared To End-Use Revenues

As most flame retardants are used in plastics, the direct replacement cost will be compared to domestic revenues generated by SIC code 16: Plastic Products Industries. The annual direct replacement cost (\$13.4 million) represents 0.2% of domestic revenues associated with plastic products (\$6.2 billion). (Stats. Can., 1993, 31-203).

15.6 Socio-economic Profile

15.6.1 Chlorinated Flame Retardants

Plants and Suppliers: All chlorinated flame retardants used in Canada are imported from the US. Five large companies, listed in Table 15-6 are the major suppliers.

Table 15-6: Major Chlorinated Flame Retardant Suppliers

Company	Location
Occidental Chemical Corp.	Dallas, TX
Albright & Wilson Americas	Richmond, VA
Akzo Nobel Chemicals Inc.	Dobbs Ferry, NY
Elf Atochem	Philadelphia, PA
Ferro Corp.	Hammond, IN

Imports and Exports: Imports are estimated at 6 kilotonnes in 1993.

Revenues: Based on an average price of \$3.30 per kg. the value of domestic demand is estimated at \$20 million.

15.6.2 Chlorinated Paraffins

Number and Location of Producers: The only Canadian producer of chlorinated paraffins is ICI Canada. ICI manufactures medium-chain chlorinated paraffins and long-chain liquid chlorinated paraffins at its plant in Cornwall, Ontario.

Production Levels: Annual production of chlorinated paraffins at the Cornwall plant is estimated at 3 kilotonnes.

Imports/Exports: The volume of medium and long chain chlorinated paraffins imports is estimated at approximately 0.1 kT. Exports are estimated at 1.5 kT, and are sold primarily in the U.S. PVC market.

Revenues: Based on a price of \$1.00 per kilogram, domestic revenues are estimated at \$3 million, with a trade surplus of \$1.4 million, and a value of domestic sales of \$1.6 million.

Number of Employees: ICI's plant at Cornwall employs approximately 115 workers in manufacturing. It is estimated that about 5 are directly related to manufacture of chlorinated paraffins.

15.6.3 Phosphate Esters

Plants and Suppliers: Phosphate esters are manufactured in Canada by Rhone-Poulenc which manufactures phosphate esters at two plants in Canada; Mississauga, ON and Valleyfield, PQ. The main importer is FMC Corporation, with other importers being Monsanto, and Albright and Wilson. Nearly all imports come from the United States.

Production Levels: Total production of phosphate esters by Rhone Poulenc is estimated approximately 1 kT in 1993.

Imports/Exports: Exports are negligible, and imports are estimated at 1.3 kT in 1993 (Stats Can, 1993, 65-004, 65-007).

Revenues: Based on a price of \$6.50 a kilogram the value of domestic sales is estimated at \$15 million. Domestic revenues are estimated at \$6.5 million, with a trade deficit of \$8.5 million.

Manufacturing employment. Rhone-Poulenc currently has 150 full-time equivalent manufacturing personnel. Employment in phosphate production is estimated at 5 people.

15.6.4 Alumina Trihydrate Flame Retardants

Plants and Suppliers: Alcan Chemicals Ltd. is the only company that manufactures alumina trihydrate in Canada. Alcan only produces alumina trihydrate at its plant in Saguenay, PQ. Alcan Chemicals Ltd., a subsidiary of Alcan Aluminum Ltd., manufactures a variety of chemical products including alumina trihydrate, activated alumina, calcined alumina and other chemical products, primarily for the water treatment and cement industries.

Production Levels: Production of aluminum trihydrate (ATH) at Alcan is split between internal consumption and sales to third parties. Alcan produces approximately 2,000 kilotonnes of ATH annually, over 90% of which is used internally for aluminum metal production. Alcan produces upwards of 160 kT per year of alumina trihydrate for non-aluminum metal uses. Production of ATH flame retardants is estimated at 3 kT.

Import and Exports: One industry source states that most of the alumina trihydrate used in the production of flame retardants is actually being imported from production facilities in Europe. It is assumed that 75% of aluminum trihydrate used in flame retardants is imported (9 kT), while exports are negligible.

Revenues: Based on a price of \$0.48 per kilogram, domestic sales as fire retardants are estimated at \$6 million. Total revenues from third party sales of ATH are estimated at \$77 million.

Manufacturing employment: Alcan Chemicals employs approximately 1,000 workers in production of ATH in Canada. Two people can be allocated to the production of aluminum trihydrate used in flame retardants.

15.7 Summary

Flame retardants are generally complex combinations of numerous compounds. Their principal use is in plastics and rubber products. The three principal types of flame retardants are halogenated flame retardants (chlorinated and brominated compounds), phosphorus compounds (phosphate esters), and inorganic metal compounds (alumina trihydrate). Aluminum trihydrate has the largest market share followed by chlorinated and brominated compounds. Halogenated compounds are experiencing a declining market share due to environmental concerns associated with potentially toxic by-products released when halogenated compounds are burned.

The annual direct replacement costs for chlorinated flame retardants are estimated at \$13 million based on substitution with phosphate esters, alumina trihydrate, and brominated compounds. The direct replacement cost represents 0.2% of domestic revenues associated with plastic products (\$6.1 billion).

A summary of the key socio-economic information allowing a comparison of the economic importance of chlorinated flame retardants and alternatives is presented in Table 15-7.

Table 15-7: Summary Table for Chlorinated Flame Retardants, and Alternatives

	Chlorinated Flame Retardants	Chlorinated Paraffins	Phosphate esters	Aluminum Trihydrate
Value of Domestic Sales (\$ million)	20	1.6	15	6
Trade Balance (\$ million)	(20)	1.4	(8.5)	4.5
Domestic Revenues (\$ million)	0	3	6.5	1.5
Manufacturing Employment	-	5	5	2
Manufacturing Employment/Domestic Revenues	-	1.7	1	1.3

15.8 Contacts and References

15.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- ICI Canada
- Alcan Aluminum Ltd.
- Rhone-Poulenc
- Hoechst Canada
- FMC
- Van Waters and Rogers

15.8.2 References

Statistics Canada. 1993. Manufacturing Industries of Canada: National and Provincial Areas, Cat. 31-203.

Statistics Canada. 1993. Exports by Commodity, Cat. 65-004.

Statistics Canada. 1993. Imports by Commodity, Cat. 65-007.

16. Short Chain Chlorinated Paraffins Used in Metal Working Fluids

16.1 Introduction

Metal working fluids comprise the broad range of hydrocarbon-based lubricating oils, emulsifiable oils (soluble oils) and synthetic formulations used in a wide range of metal processing operations such as cutting, grinding and forming. Chlorinated paraffins are used as extreme pressure (EP) additives in these lubricants and applications. They are the chlorinated derivatives of the straight-chain paraffin class of hydrocarbons. The chlorine content ranges from about 30% to 70% by weight.

Chlorinated paraffins are classified according to their molecular chain length. The short chain chlorinated paraffin class (C_9 - C_{13}) accounts for about 25% of all chlorinated paraffins, and are the group most commonly used as extreme pressure (EP) additives. No short chain chlorinated paraffins (SCCP) are made in Canada and all are imported. Medium and long chain chlorinated paraffins are produced domestically. Most demand for SCCP is soluble oil metal working fluid formulations. Lower volume applications for SCCPs include additives for rubber, adhesives and sealants, and flame retardants. Medium-chain chlorinated paraffins are used primarily in flame retardant applications (See Chapter 15), while the use of long-chain chlorinated paraffins is limited. Table 16-1 lists the estimated quantity of SCCPs used in Canada by application, during 1994.

Table 16-1: Short Chain Chlorinated Paraffins Used in Canada

Applications	1994 (tonnes)	
Metal Working, Soluble oils	288.5	54%
Metal Working, Straight oils	87.7	16%
Other uses	162.3	30%
Total	538.5	100%

Source: (Abt, 1995)

There are two main functions of metal working fluids. First, they are used to lubricate or reduce friction between the tool and the work piece at the point of contact. Second, they act as a coolant by rapidly removing heat generated at the interface. Consequently, they are used to extend tool life in severe (extreme pressure) metal working operations. Metal

used to extend tool life in severe (extreme pressure) metal working operations. Metal working fluids are used in a wide range of industries, primarily fabricated metal products (SIC 30), but also machinery industries (SIC 31), and transportation equipment industries (including auto parts) (SIC 32). A more exact breakdown of quantities used in these different industries is not available (Abt, 1995).

The alternatives to SCCP are principally other chlorinated products, such as medium and long chain chlorinated paraffins, or sulphur-based chlorinated compounds. The non-chlorinated alternative discussed in this chapter will be a compounded blend of overbased sulphonate (OBS) of calcium or sodium with sulphurized fats or olefins.

This chapter describes SCCP used in metal working applications through five sections; market analysis, technical description, direct replacement cost, direct replacement cost compared to end-use revenues and socio-economic profile. The socio-economic profile will compare SCCP and alternatives using the variables of production, imports and exports, revenues and manufacturing employment.

16.2 Market Analysis

According ICI, based in the UK, the major manufacture of SCCPs (outside of Canada), there are no commercially available non-chlorinated alternatives to chlorinated paraffins as extreme pressure agents in metal working fluids, currently. Chlorinated alternatives (e.g. chlorinated esters and chlorinated fatty acid compounds) are being used to replace short chain chlorinated paraffins in less extreme environments.

Short-chain chlorinated paraffins have been declared toxic under CEPA, and are being considered for virtual elimination under the federal Toxic Substances Policy. These environmental concerns have generated a declining trend in the use of SCCPs in metal working fluids as formulators have attempted to replace them with non-toxic compounds. It is estimated that annual Canadian consumption of SCCPs will decline from 538 tonnes (1994) to 200 tonnes (1996) and be phased out by 2004 (CPIA, 1995), though this trend may be exaggerated (Abt, 1995). In Europe and the US, the major manufacturers have developed medium chain paraffin products which have successfully displaced some short chain compounds in metal working formulations. These products are now being introduced to Canada.

Industry formulators report that new non-chlorinated additives based on sulphur compounds are being developed and are in early market trial stages. Until recently, sulphur compounds have been considered as complementary additives to chlorinated paraffins, and not substitutes. Phosphate esters are being tested and look promising in several formulations,

but are not used commercially. The current favoured alternative is a compounded blend of overbased sulphonate (OBS) of calcium or sodium with sulphurized fats or olefins.

16.3 Technical Characteristics of Metal Working Fluid Additives

16.3.1 Short Chain Chlorinated Paraffins

In heavy duty metal working applications, a great amount of force is required between the tool (die, saw, grindstone, drill, etc.) and the metal work piece. As the metal is heated, the fluid acts to remove heat. Above 150°C (300 F) at the point of contact, chlorine is released from the chlorinated paraffin and reacts with the bare metal surface to form a metal chloride layer on the surface. This surface has a lower friction factor than an untreated surface and helps the metal to expand (particularly in stamping and forming operations). Sulphur (present in emulsifiers) performs a similar function, but usually at higher temperatures and more severe conditions. SCCPs are effective as an additive in severe operations between about 150°C and 260°C (300 F and 500 F) with hard metals or tough alloys such as ferrous and nickel/cobalt mixtures.

SCCPs are preferred to the available alternative for several technical reasons. Most importantly, since they are transparent, metal working fluids with chlorinated paraffins do not diminish the visibility of the workpiece. Chlorinated paraffins are also odourless, have a lighter viscosity, and are easier to handle.

16.3.2 Over-Based Sulfonates (OBS)

OBS compounds are viscous, dark, cloudy fluids. They typically involve the use of phosphorus/nitrogen or sulphur/calcium combinations where the sulphonate base provides water solubility. One form of overbased sulphonate is prepared by reacting sulphonic acid with calcium carbonate in pressurized carbon dioxide gas. There is some synergy between the OBS and the sulphur components, which are effective at temperatures above 400°F. Calcium is preferred over sodium, since sodium has a higher tendency to react with the fatty acids to form a pasty, soapy residue. A fat/olefin OBS combination having non-active sulphur is used for aluminum and magnesium processing, while active sulphur can be used for common ferrous metal processing.

OBS compounds are more difficult to formulate and have a distinctive odour. A senior chemist at one major formulator claims that OBS compounds can also cause acute skin sensitization in contrast to a more chronic form of skin sensitization from chlorinated paraffins.

16.4 Direct Replacement Cost

The model of substitution for short-chain chlorinated paraffins in metal working fluids is based on the use of an overbased sulphonate extreme pressure additive package. This model makes an assumption that OBS packages have the ability to completely replace SCCPs in all metal working fluid applications. Metal working industry sources report that there are some specific cases where a chlorine molecule must be present and no other application works.

Lubrizol, a major additive supplier, outlined a typical OBS package with current costs. The Lubrizol package consists of three components: an overbased sulphonate, a sulphurized olefin with 40% active sulphur and a sulphurized fat with 10% inactive sulphur. It is assumed that an one third additional volume would be required to substitute for SCCPs. This would be blended with a 100 neutral lubricating oil in the formulation outlined in Table 16-2.

Table 16-2: Cost and Components of an OBS Package

Additive	Loading (%)			Price (\$/kg)
	Low	High	Average	
Overbased Sulphonate	2.5	4.0	3.2	3.47
Sulphurized Olefin	1.0	2.5	1.8	3.16
Sulphurized Fatty Acid	1.0	5.0	3.0	2.50
Total/Average	4.5	11.5	8.0	3.04

Source: CHEMinfo Services

The annual direct replacement cost for SCCPs in metal working fluids is estimated at \$1.1 million, as shown in Table 16-3.

Table 16-3: Direct Replacement Cost in Metal Working Fluids

Metal Working Fluids	Quantity (tonnes)	Average Price (\$/kg)	Cost (\$ million)
Chlorinated Paraffins	376	1.00	0.4
Overbased Sulphonate Package	500	3.04	1.5
Cost Difference			1.1

Source: CHEMinfo Services

16.5 Direct Replacement Cost Compared to End-Use Revenues

No information is available on the specific industry sectors, or sub-sectors, which are the principal users of SCCP metal working fluids. However, it is probable that the majority of SCCPs are used in the fabricated metal products (SIC 30), machine equipment (SIC 31), and transportation equipment industries (SIC 32). In order to be conservative and account for sub-sectors in these industrial sectors which do not use metal working fluids, the direct replacement cost will be compared to domestic revenues in the fabricated metal products industry alone. The direct replacement cost (\$1.1 million) represents 0.007% of domestic revenues associated with fabricated metal products (\$15,404 million) (Stats. Can., 1994, 31-203).

16.6 Socio-Economic Profile

16.6.1 Short Chain Chlorinated Paraffins

Producers and Suppliers: Internationally, there are four manufacturers of SCCPs, listed in Table 16-4. No SCCPs are manufactured in Canada. ICI Canada reports that all short-chain chlorinated paraffins used as additives in extreme pressure (EP) metal working fluids are imported from the United Kingdom.

ICI is the world's largest producer of SCCPs, and the dominant supplier and distributor in the Canadian market. Beyond ICI, each of the other competitors affiliates themselves with a Canadian distributor to market their products. Dover Chemical is assumed to have the second largest volume, selling through Van Waters & Rogers. Occidental Chemical ships product from Texas to Chemroy Chemicals in Toronto for distribution. The smallest share is likely Ferro which sells through Bartek Chemicals. Table 16.5 lists the SCCP suppliers in Canada.

Table 16-4: Chlorinated Paraffin Suppliers

Company	Plant Location	Canadian Distributor	Location
ICI Corp.	Cornwall, ON; UK	ICI Canada Inc.	Toronto, ON
Occidental Chemical Corp.	Deer Park, TX	Chemroy Canada	Mississauga, ON
Ferro Corp. (Keil Chemical Div.)	Hammond, IN	Bartek Chemical	Toronto, ON
Dover Chemical Corp.	Dover, OH	Van Waters & Rogers	Toronto, ON

Source: CHEMinfo Services Inc.

There are an estimated 30 formulators of metal working fluids operating in Canada (CPIA, 1995). The market is dominated by about seven firms, listed in Table 16-5, which probably account for over 80% of volume. SCCPs are used by most of the major firms.

Table 16-5: Major Metal Working Fluids Formulators

Company	Location
D.A. Stuart Inc.	Scarborough, ON
Fuchs-Montgomery	Cambridge, ON
Elf Atochem	Oakville, ON
Houghton Canada Inc.	Toronto, ON
Cromac	Brampton, ON
Magnus	Montreal, PQ
CNC Lubricants	Georgetown, ON

Source: CPIA, 1995

Imports and Exports: Total imports of SCCPs are estimated at approximately 0.5 kilotonnes in 1994.

Revenues: Based on a price per kilogram of \$1.00 the value of domestic sales of SCCPs is approximately \$0.5 million.

16.6.2 Over-Based Sulphonate (OBS)

Producers and Suppliers: The major Canadian suppliers of OBS are Witco Canada Inc. and Lubrizol Canada Ltd. Witco is the only company producing overbased sulphonate. Witco's production facility is located in West Hill, Scarborough. Lubrizol imports its supplies of overbased sulphonate from the United States.

Production Levels: Witco manufactures modified overbased sulphonate at its West Hill plant. Approximately 90% is used in motor oil with the remaining 10% being used in the production of other coatings, grease and as an EP additive.

Imports and Exports: Exports are estimated at 1,380 tonnes annually. Lubrizol imports all of its overbased sulphonate from the U.S., however the amount of imports is not available.

Revenues: Based on a average price of \$3.04 per kilogram domestic sales associated with OBS are \$7 million.

Manufacturing Employment: Manufacturing employment associated with OBS production is estimated at 5 people.

16.7 Summary

The main use of short chain chlorinated paraffins (SCCPs) is in extreme pressure metal working fluids. Out of total imports of 538 tonnes in 1994, approximately 70% was used as metal working fluids (376 tonnes). The main alternatives to SCCPs are other chlorinated compounds (ex. medium-chain chlorinated paraffins). Non-chlorinated alternatives being developed are generally over based sulphonate (OBS) compounds. OBS compounds are currently used primarily as gasoline additives.

The metal working market for SCCPs is being driven by environmental pressures. SCCPs have been declared toxic under CEPA, and are being considered for virtual elimination under the federal Toxic Substances Management Policy. The market for SCCPs is expected to decline from 538 tonnes in 1994, to 200 tonnes in 1996, and to 0 in 2004, though this trend may be exaggerated.

The direct replacement cost for SCCPs in metal working fluids is estimated at \$1.1 million annually, based on substitution with an OBS compound. This cost represents approximately 0.007% of domestic revenues in SIC code 30, metal product fabricating industries. Table 16-6 summarizes the socio-economic profile, and compares the relative importance of SCCPs, and over based sulphonate products to the Canadian economy.

Table 16-6: Summary Table for Metal Working Fluid Additives

	Short Chain Chlorinated Paraffins	Overbased Sulphonate Compounds
Value of Domestic Sales (\$ million)	0.5	7
Trade Balance (\$ million)	(0.5)	0
Domestic Revenues (\$ million)	0	7
Manufacturing Employment	-	5
Manufacturing Employment/Domestic Revenues	-	1.4

16.8 Contacts and References

16.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- ICI Canada
- Witco Canada Inc.
- Lubrizol Canada Ltd.

16.8.2 References

Abt. 1995. Analysis of Options to Eliminate Release to the Environment of Short Chain Chlorinated Paraffins, Phase I Report, for Environment Canada.

Chlorinated Paraffins Industry Association. 1995. Short Chain Chlorinated Paraffins, Canada Survey Report.

Statistics Canada. 1993. Manufacturing Industries of Canada: National and Provincial Areas; 31-203.

17. Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) in Refrigerants

17.1 Introduction

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have had wide application as refrigerants. They have also been used as aerosol propellants, plastics blowing agents, cleaning solvents, and other industrial applications. This section describes only refrigerant uses of CFCs and HCFCs, as these account for approximately 73% (11 kT) of estimated domestic demand of 15 kT in 1993.

Refrigerants include a broad range of chemicals, termed working fluids, that are used in refrigeration systems. These chemicals must have suitable physical and chemical properties to efficiently perform with compression, condensation, distribution and heat exchange equipment components of refrigeration systems. Compatible chemicals may also be blended to provide working fluids with functionality over a broad range of operating conditions, than would be offered by a single substance. Product types include CFCs, HCFCs, hydrofluorocarbons (HFCs) and non-fluorinated products such as ammonia, propane, isobutane and other hydrocarbons (HC). The principal alternatives selected for CFCs and HCFCs are HFCs, as shown in Table 17-1.

This chapter describes CFCs, HCFCs, and HFCs used as refrigerants in five sections: market analysis, technical description, direct replacement cost, direct replacement cost compared to end-use revenues, and socio-economic profile. The socio-economic profile will describe production, imports and exports, revenues and manufacturing employment.

Table 17-1: Alternatives to CFCs and HCFCs

CFC, HCFC	Alternatives
A/C, Industrial refrigeration	
CFC-11	HFC-134a, HFC-152a, HC, blends
CFC-12	HFC-134a, HFC-152a, HC, blends
CFC-13	HFC-23, HC
HCFC-22	blends HFC-32 & 134a, HFC-23/152a/125/32
R500, R502	blends of FC, HFC-134a, HFC-152a, HC
Heat Pumps, Chillers	
CFC-11	HFC-134a, HFC-152a, HC, blends
CFC-12	HFC-134a, HFC-152a, HC, blends, water
CFC-114	blends of FC, HFC-134a, HFC-152a, HC
HCFC-22	blends HFC-32 & 134a, HFC-23/152a/125/32
R500, R502	blends of FC, HFC-134a, HFC-152a, HC, ammonia
Transport	
CFC-11	HFC-134a, PF
CFC-12	HFC-134a, HFC-152a, HC, blends, water
CFC-114	blends, FC, HFC-134a, HFC-152a, HC
HCFC-22	blends HFC-32 and/or 134a, HFC-23/152a/125/32
R500, R502	blends of FC, HFC-134a, HFC-152a, HC
Commercial refrigeration	
CFC-11	HFC-134a, PF
CFC-12	HFC-23, HFC-134a, HFC-152a, PF, glycol
CFC-114	blends, FC, HFC-134a, HFC-152a, HC
R500, R502	blends of FC, HFC-134a, HFC-152a, HC, ammonia
Domestic refrigeration	
CFC-11	HFC-134a
CFC-12	HFC-125, HFC-134a
CFC-114	blends, FC, HFC-134a, HFC-152a, HC
R500, R502	HFC-125, ammonia, blends of HC, FC, HFC
Low temperature refrigeration, Dehumidifiers	
R500, R502	HFC-125, HCFC-134a, blend of HFC-125, HFC-134a, blend HFC-125/143a/134a, ammonia, HFC-23
R503	HFC-32
Deep Freeze	
HCFC-22	blend HC, FC, HFC
R502	HFC-125, HFC-134a, HFC-143a

Source: Ozone Depleting Substances Alternatives and Suppliers List, Environment Canada, Ozone Protection Programs, Commercial Chemical Evaluation Branch, December 1994

17.2 Market Analysis

Fluorocarbons dominate the market for refrigerants. In 1993, the three principal types of fluorocarbons were CFCs, HCFCs and HFCs with CFCs holding the largest market share. The market share of each of these groups is shown in Table 17-2.

Table 17-2: Consumption of CFC, HCFC and HFC Refrigerants

Refrigerant	1993 (kT)
CFC (chlorinated product)	7.5
HCFC (chlorinated product)	3.5
HFC (non-chlorine alternative)	1.0
Total	12

Source: Environment Canada, CHEMinfo Services

Domestic demand for refrigerants has two components. A large portion is used to replenish fluid that has leaked from existing systems, with the remainder required for new equipment installations. There are many applications for many different types of refrigerants. Table 17-3 shows some of the applications for refrigerants, while Table 17-4 estimates the 1993 inventory of refrigerants used in Canada.

Table 17-3: Domestic Sales of CFC, HCFC Refrigerants, 1993

Application Segment	Total (kT)	New Equipment (kT)	Service (kT)	Major Products
Commercial refrigeration, A/C	3	1.5	1.5	HCFC-22, CFCs
Mobile Air Conditioners	2.7	.8	1.9	CFC-12
Chillers	0.3	0	0.3	CFC-11
Domestic refrigeration	0.1	0.1	0	CFC-12
All other applications	4.9	0.9	4	CFC-11, CFC-12
Total	11	3.3	7.7	

Source: Environment Canada, CHEMinfo Services

Table 17-4: CFC and HCFC Inventory in Canada, 1993

Application	CFC-12	CFC-11	R500, R502	HCFC-22	All other	Total
Mobile air conditioning	18.1			0.3		18.4
Mobile refrigeration	4.6		7.2			11.8
Commercial installations	0.5	1.7	0	2.5		4.7
Residential	4.2		0	6.6	0.1	10.9
Commercial refrigeration and A/C	2.7	0.5	2.4	4.1		9.7
Automotive	3					3
Food Producers	1	0.1	0.2	1.6	0.1	2.9
All other	0.4	1	0.1	1.4		3
Total	34.5	3.3	9.9	16.5	0.2	64.4

Source: Environment Canada, Chemical Industries Division, A National Inventory of CFC and HCFC Installations in Canada, February 1995

The Montreal Protocol on Ozone Depleting Substances has been a major factor influencing trends in the refrigerants market, and directly affecting CFCs and HCFCs, two principal refrigerants used in Canada. As a result of the Protocol, CFCs are not permitted to be sold or imported as of 1996, while production ceased in 1993. Existing stockpiles can continue to be used. As HCFCs have an ozone depleting potential of 0.05 relative to CFC (1.0), HCFCs have been accepted by the signatories of the Montreal Protocol as an interim substitute for CFCs. HCFCs are expected to be phased out by 2020.

The principal alternatives replacing CFCs are HCFCs, while HFCs are coming into the market as a replacement for both chlorinated fluorocarbons. For example, HCFC-123 was developed as an alternative to CFC-11 for low pressure industrial refrigeration. HFC-134a is now used in almost all of the automotive air conditioners for new cars produced in North America. HFC-143a is used in a blend with HFC-125 for commercial refrigeration applications in transportation storage, retail food displays and ice machines as a replacement for the CFC, R-502. HFC-32 is to be used in several blends with HFC-125 for new residential and commercial air conditioning and in refrigeration applications, with an expected market date in 1996.

As a result of the Montreal Protocol, there have been substantial shifts in the market for CFCs and HFCs over the last several years, as seen in Table 17-5. As the deadline for phase-out of CFCs has approached, prices for CFCs have shot up dramatically, reflecting stockpiling of CFCs. As of 1995 prices were approximately four times what they were in the early 1990s. HCFC-22 has not increased in price to the same degree as CFCs, due to the longer phase-out period. Prices have increased by 15% over the last several years. By contrast, HFCs prices have declined over the last several years as capacity has expanded in the industry. There is an expectation that HFC prices will continue this slow decline.

Table 17-5: Wholesale Price Trends for Selected Refrigerants

Refrigerant	1988-1993 Average (\$/kg)	1995 (\$/kg)
CFC-12	11	44
CFC-11	16	44
HCFC-22	13	15
HFC-134a	44	36
HFC 404a	70	62

Source: CHEMinfo Services

Ammonia and light hydrocarbons such as propane and butane have been used as working fluids in industrial refrigeration compressors in the US and Canada. Propane is used as a refrigerant in natural gas processing in Alberta and BC.

In Germany, refrigeration systems using propane/butane mixtures were developed for domestic refrigerators starting in 1993¹. These compounds have a lower material cost and are not ozone depleting or global warming substances. By 1997, the use of these hydrocarbons has almost completely displaced HCFCs and HFCs in the European domestic refrigeration market, having over an 80% market share. The technology has spread to Eastern Europe, China, Latin America and Australia. The use of hydrocarbons in the much larger commercial refrigeration market has been slower to develop, but is growing as well. The penetration of hydrocarbons into the large mobile air conditioning segment is very low. The key substitution issues that are being faced are: the compressor design for energy efficiency, and fire safety concerns with storage, handling and leaks.

¹ Greenpeace, The Greenfreeze story, 1995.

17.3 Technical Description

There are many types of chlorinated fluorocarbons, and alternatives depending on the specific application for refrigerants. Which alternative is best depends on the specific application and the operating requirements of the refrigeration system. The major technical advantage of CFCs over other fluorocarbons is their thermodynamic performance. Table 17-6 shows some of the technical characteristics of alternatives.

Table 17-6: Technical Summary Comparison of Fluorocarbons

Characteristic	CFC-12	HFC-134a	HFC-152a
Formula	CF ₂ Cl ₂	CH ₂ FCF ₃	CH ₃ CHF ₂
Safety (flammability)	non-flammable	non-flammable	flammable
Thermal stability	stable	stable	stable
Chemical compatibility with contacting materials	compatible with most oils, metals, plastics, elastomers	compatible with most oils, metals, plastics, elastomers	compatible with most oils, metals, plastics, elastomers
Thermodynamic efficiency	higher than HFC-134a, HFC-152a	efficiency, volumetric capacity loss	loss comparable to HFC-134a
Miscellaneous problems	none	sludge formation may occur	operating data not well developed

Source: CHEMinfo Services

A brief analysis of alternatives to CFCs and HCFCs is provided below for some of the major application areas. For a thorough technical analysis of alternatives, the reader is referred to the report published by the United Nations Environment Programme (UNEP, 1991).

17.3.1 Domestic Refrigeration

The majority of refrigerator-freezer systems have employed CFC-12. Two refrigerants dominate current substitution implementation efforts. HFC-134a is the preferred alternative in North America for new systems. The expectation is that CFC-12 will continue to be used for servicing, until stocks are depleted. HFC blends may represent alternatives for servicing or retrofit situations.

17.3.2 Industrial Refrigeration

Industrial refrigeration covers many sectors of the economy, but systems are primarily used in chemical, petrochemical, and pharmaceutical operations. Other uses are found in industrial ice-making, metallurgical, oil and gas industries.

Technology to retrofit existing CFC-12 systems to use HFC-134a is available, while the technology to move from R-502 to HFC blend or HFC-404a is still under development. Proven HFC blend technology may be available towards the end of the decade according to the UNEP Technical Options Committee. Retrofits to use of ammonia may be feasible in some cases. Change-over to ammonia will normally imply improved energy efficiency, while reference cycle efficiency will be lower with some of the new fluids. This may be compensated for by system optimization with computer based regulation and control.

17.3.3 Commercial Refrigeration

Commercial systems range considerably in size. They are employed in the food industry, hospitals, hotels, retail stores, schools, and many other application areas. Use of CFC-123 and R-502 for new equipment has been reduced in favour of HCFC-22 and to a much lesser degree HFCs. Operating problems have resulted. There has been concern in using HFCs, especially with small unitary equipment with hermetic compressors and in high temperature environments.

The phase-out of CFC has increased the requirement for HCFCs in this application. Use of HFC for new equipment is contingent on more development and testing by manufacturers. The increased adoption of working fluids such as ammonia, hydrocarbons and HFC require experienced skilled engineers.

17.3.4 Transport and Automotive Air Conditioning

This application area includes ships, containers, truck, railcars, and passenger vehicles. There are a variety of refrigerants used. CFC-12 has been used for passenger vehicles, but it has now been replaced with HFC-134a. This refrigerant has also largely taken over the demand in new refrigerated containers. Although retrofit procedures have been developed for containers they are not widely used. Drop-in replacements for automobiles have yet to be developed.

17.3.5 Cold Storage and Food Processing

Dairy products, fish, meat, fruit and vegetables are stored and distributed in huge quantities in a chilled condition. Frozen foods are generally stored in the temperature range -18 to -50 degrees Celsius.

The principal CFC used in this application is R-502, but alternatives include blends of HFC (and some cases HCFC-22). There has been a slight trend to increased use of ammonia in large scale freezing and cold storage systems. HCFC-22 has been adopted as a temporary option, while some systems have employed HFC-134a as a replacement for CFC-12. However, CFC-12 has not been widely employed in deep food processing and cold storage. Carbon dioxide, water, and hydrocarbons have been employed, but are not expected to make inroads in these applications.

Retrofits in this sector, while possible are difficult to actually implement. Generally, ammonia cannot be used as a direct substitute in equipment not designed for its use. HFCs or blends of HFC require redesigned systems for efficient operation. The high cost to retrofit, ranging from hundreds to tens of thousands of dollars, encourages operators to extend the life of the refrigerant. This is done by stockpiling, improving recovery and recycling activities or undertaking leak prevention activities.

17.3.6 Chiller Systems

HFC-134a has been a suitable drop-in replacement in some R 500 systems. HFC-134a became available in the late 1980s, for retrofit in centrifugal chillers. Its use requires about 15% higher tip speeds than CFC-12. The implication is that propeller and gearbox replacement may be necessary. For equipment using HCFC-22, some HFC mixes are suitable, but more blends are being developed.

17.4 Direct Replacement Cost

The substitution model for CFC and HCFC refrigerants assumes HFCs and HFC blends are replacements for all applications. It is realized this is an oversimplification in terms of selecting the technically best or least cost effective alternative. However, detailed assessment of which specific chemical replacement is optimal for each application area and each operating temperature range, is beyond the scope of this study.

As activities generated by the Montreal Protocol have distorted this market, it is difficult to estimate the direct replacement cost. Theoretically, a substitution model would be based on some of the following components:

- drop-in replacement which reflects only the material costs;
- redesign of original manufactured equipment to accommodate substitution; and
- retrofit or redesign of existing equipment to accommodate substitution.

The phase-out of ozone depleting substances has spurred most equipment manufacturers to redesign their products. Redesigning to accommodate non-CFC or HCFC working fluids has become a requirement for manufacturers to remain competitive and to survive in the marketplace. This redesign cost is not considered as part of the substitution costs for the purposes of this study.

The cost to retrofit existing equipment to accommodate a substitute material ranges significantly, depending on the size, materials used, operating conditions, and substitute materials. Retrofitting costs range from \$100 to \$10,000 or more for large complex systems. The population matrix for refrigeration systems in Canada, categorized by the type of refrigerant used, capacity (size), operating conditions (temperature, range, etc.) and age of capital is not available. The portion of systems that would require retrofit in any given year is also unknown. Due to these data limitations the cost of retrofitting cannot be calculated. However, this assumption of zero retrofitting costs may be roughly accurate given that this cost would be zero if existing stockpiles were sufficient for the expected life of current equipment.

The substitution cost estimates for refrigerants will include only the drop-in replacement component. This is estimated by calculating the annual materials cost to substitute HFC for CFC and HCFC. The simplifying assumptions used to calculate these costs include:

- average 1988 to 1993 price for CFC and HCFC is \$13.30/kg (estimate based on CFC-12, CFC-11 and HCFC-22); and
- average 1988 to 1993 price of HFC is \$57/kg (estimate based on average of HFC-134a and HFC-404a).

The resulting annual direct replacement cost reflects material costs in substituting HFC for CFC and HCFC and is calculated as: the total 1993 chlorinated refrigerants demand (11 kT) times the average price difference between chlorinated fluorocarbons and HFC, ($57.00 - 13.30 = 43.70$ \$/kg). The estimated annual direct replacement cost is \$481 million annually. This cost estimate incorporates the market distortions (i.e. higher volume of CFCs purchased in 1993, higher HFC costs in 1993) generated by the Montreal Protocol, and may thus somewhat compensate for the lack of information on retrofit costs.

17.5 Direct Replacement Cost Compared to End Use Revenues

Three sectors which can be identified as end-uses are manufacturers of new equipment. These three sectors are commercial refrigeration (SIC 312), major domestic appliances (SIC 332), and transportation equipment (SIC 32). Based on Table 17-3, and a cost of \$43.70/kg., a comparison can be made for these three equipment manufacturing sectors.

Table 17-7 shows that although the ratio of total direct replacement cost to total end use revenues is 0.01%, the ratio is much higher (19%) for commercial refrigeration.

Table 17-7: Direct Replacement Costs Compared to End-Use Revenues for Chlorinated Fluorocarbons

Type of Equipment	CFC, HCFC use in New Equipment (kT)	Direct replacement cost (\$ million)	Domestic Revenues (\$ million)	Direct replacement cost/ Domestic Revenues (%)
Commercial Refrigeration	1.5	66	342	19%
Domestic Appliances	.1	4	917	.04%
Transportation Equipment	.8	35	64113	.005%
Total	2.4	105	65372	.01%

Source: Stats Can, 1993, 31-203

17.6 Socio-Economic Profile

17.6.1 Chlorinated Fluorocarbons

Number and Location of Producers: Fluorocarbon refrigerants were manufactured in Canada by DuPont Canada Inc. in Maitland Ont., and AlliedSignal Canada Inc. in Amherstburg Ont.. Allied phased out production of CFC-11, CFC-12 and HCFC-22 in August 1992. They are no longer producing any refrigerants in their Canadian plants. Production of CFC-113 and CFC-114 was phased out in late 1991 at DuPont. DuPont also stopped producing CFC-11 and CFC-12 in February, 1993. DuPont is still producing HCFC-123 in Canada. Both companies are importing HCFCs and HFCs from United States operations. Table 17-8 lists some of the major suppliers of refrigerants.

Table 17-8: Suppliers of CFCs, HCFCs and HFCs in Canada

Company	Location
Major Importers	
AlliedSignal Canada Inc.	Mississauga, ON
Dow Chemicals Canada	Mississauga, ON
DuPont Canada Inc.	Mississauga, ON
Elf Atochem	Oakville, ON
ICI Canada Inc.	North York, ON
Major Wholesalers and Distributors	
DS Frazer (Division of Carrier)	Vancouver, BC
Eastern Refrigeration	Toronto, ON
Marshall, WT Refrigeration	Toronto, ON
Southern Supplies	Oshawa, ON
United Refrigeration	Markham, ON
Westburn Electric	Montreal, PQ
Warner Wholesale	Toronto, ON

Source: CHEMinfo Services

Production and Capacity Levels: The capacity for the DuPont plant is 18.0 kT of HCFC-123 with production in the area of 4.5 kT. The main feedstock used in the production of HCFC-123 is tetrachloroethylene, a chlorinated solvent whose major use is in dry cleaning (See Chapter 12).

Imports and Exports: Canada exported 3.9 kT of chlorinated fluorocarbons in 1993. Canadian imports of chlorinated fluorocarbons were almost 14 kT in 1993. Table 17-9 lists the estimated imports of chlorinated fluorocarbons, by type, in 1993 and 1994. These imports reflect all uses of fluorocarbons including aerosols, and blowing agents.

Table 17-9: Canadian CFC and HCFC Imports in 1993, 1994
(kilotonnes)

Substance	1993	1994
CFCs	8.47	10.44
HCFCs	5.25	6.86
Total	13.7	17.3

Source: Camford Information Services, 1995

Revenues: Based on an average price of \$13.3 for chlorinated fluorocarbons, domestic revenues are estimated at \$60 million. The value of domestic sales is estimated at \$146 million, with a trade deficit of \$86 million.

Manufacturing Employment: Manufacturing employment at the only remaining Canadian producer of refrigerants is estimated at 70 people.

17.6.2 HFCs

Number and Location of Producers: HFCs are not produced in Canada. The entire Canadian market is met through imports from U.S. manufacturers and distributors, as listed in Table 17-10.

Table 17-10: Major North American Suppliers of HFCs

Distributor	Location
AlliedSignal	Morristown, NJ
DuPont Chemicals	Wilmington, DE
Elf Atochem North America	Philadelphia, PA
La Roche Chemicals	Atlanta, GA

Source: Camford Information Services, 1995

Imports and Exports: In 1993 imports of HFCs are estimated at 1.0 kT.

Revenues: Based on an average price of \$57 per kg, the value of domestic sales of HFCs are estimated at \$57 million in 1993.

17.7 Summary

The chlorinated fluorocarbons (CFC, HCFC) are used primarily as refrigerants, with refrigerant uses accounting for 73% of domestic uses. There are many different types of refrigeration systems using CFCs and HCFCs, with the major users being commercial refrigeration, and mobile air conditioners used in transportation equipment.

Chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) have the dominant market share as refrigerants, with domestic consumption in 1993 of 7.5 kT (CFCs) and 3.5 kT (HCFCs). The major alternative to these compounds is hydrofluorocarbons (HFCs), with approximately 1 kT consumed in 1993.

The main factor driving the trend in the refrigerant market is the status of CFCs and HCFCs as ozone depleting chemicals under the Montreal Protocol on ozone depleting

substances. CFCs are to be phased out (sale, import) by 1996, while HCFCs have an expected phase-out date of 2020.

The estimated direct replacement cost for chlorinated fluorocarbons with HFCs or HFC blends is \$481 million annually, based solely on material substitution costs. The relevant direct replacement cost represents 0.01% of total domestic revenues in the three equipment manufacturing sectors of commercial refrigeration (\$342 million), domestic appliances (\$917 million), and transportation equipment (\$64 billion). However the direct replacement costs in the commercial refrigeration sector (\$66 million) are 19% of domestic revenues.

Table 17-11 summarizes socio-economic data for CFCs, HCFCs, and HFCs.

Table 17-11: Summary Socio-Economic Data, 1993

	CFCs, HCFCs	HFC
Value of Domestic Sales (\$ million)	146	57
Trade Balance (\$ million)	(86)	(57)
Domestic Revenues (\$ million)	60	0
Manufacturing Employment	70	-
Manufacturing Employment/Domestic Revenues	1	--

17.8 Contacts and References

17.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Allied Signal Chemicals
- BASF Canada
- CXY Chemicals Canada
- Chinook Group
- Boehme Filatex Canada
- Cytec Canada Inc.
- Dow Chemicals
- DuPont Canada Inc.-
Fluorocarbons Division
- Eastern Refrigeration
- ICI Canada Inc.
- Marsulex Inc.
- Rhone-Poulenc Canada Inc.
- Tembec Chemical Products
Division
- Witco Canada Inc.

17.8.2 References

- Camford Information Services. 1995. Product Profile - Fluorocarbons.
- Oak Ridge National Laboratory. 1994. Energy and Global Warming Impacts of Not-in-Kind And Next Generation CFC and HCFC Alternatives. Prepared for U.S. Department of Energy and Alternative Fluorocarbons Environmental Acceptability Study (AFEAS).
- Statistics Canada. 1994. Monthly Survey of Manufacturing. Cat. No. 31-001.
- Statistics Canada. 1992. Manufacturing Industries of Canada: National and Provincial Areas. Cat. No. 31-203.
- Statistics Canada. 1994. Exports by Commodity. Cat. No. 65-004.
- Statistics Canada. 1994. Imports by Commodity. Cat. No. 65-007.
- United Nations Environment Program (UNEP) Economic Options Committee. 1991. Economic Assessment Report.

18. Polychloroprene

18.1 Introduction

Polychloroprene is an elastomeric polymer, first produced from chloroprene monomer (2-chloro-1,3 butadiene) in the 1930s by DuPont. Today, polychloroprene is widely recognized by its original trade name Neoprene. As shown in Table 18-1, this synthetic rubber polymer is used in a wide variety of applications including hoses, gaskets, adhesives, wire and cable, coatings, footwear, belts and conveyers.

Table 18-1: Canadian Applications for Polychloroprene

Application Area	1993 Consumption (kilotonnes)
Molded and extruded products i.e., gaskets, etc.	1.0
Hydraulic hose, including automotive	0.9
Adhesives	0.9
Industrial hose	0.7
Wire and cable	0.4
Belts and belting	0.4
Miscellaneous	0.1
Total Canadian Consumption	4.4

Source: Camford Information Services

Nitrile butadiene (NBR) and a variety of thermoplastic elastomers (TPE), notably ethylene propylene elastomers (EPDM) are possible substitutes in some application areas. NBR has the necessary properties for use in products where heat resistance is not as critical. Hydrogenated NBR is a much higher priced polymer which overcomes some of the technical limitations of NBR. TPEs, including ethylene propylene elastomers and copolyesters (COPE) also offer a possible substitute material in applications requiring higher temperature tolerance.

This chapter describes polychloroprene and alternatives, through five sections; market analysis, technical description, direct replacement cost, direct replacement cost compared to end-use revenues, and socio-economic profile. The socio-economic profile describes production, imports and exports, revenues and manufacturing employment.

18.2 Market Analysis

Polychloroprene has a minor position in the context of the overall synthetic rubber and elastomers industry. As a rough estimate, polychloroprene represents only 3% of synthetic rubber and elastomeric products consumption in Canada. This position is not significantly different from that in the United States. The percentage would be even lower if natural rubber and plasticized PVC, which compete for some applications with polychloroprene, were included as part of the industry total. Table 18-2 summarizes the relative position of polychloroprene in North America. Ranking excludes natural rubber and flexible PVC.

**Table 18-2: Estimated Market Position of Polychloroprene
in North America in 1993**

Products	North American Demand (kT)	North American Demand Shares (%)	Major Applications
Synthetic Rubber Products			
Styrene Butadiene Rubber (SBR)	950	40	tires
Polybutadiene Rubber (PBR)	500	21	tires
Butyl Rubber (BR)	195	8	tires
Nitrile butadiene rubber (NBR)	90	4	hoses, belting
Polychloroprene	74	3	gaskets, hose, belting
Thermoplastic Elastomers (TPE)			
Ethylene Propylene Elastomers (EPDM)	265	11	Injection molded parts, sheet
Styrene Block Copolymer (SBC)	170	7	Injection molded parts, misc
Thermoplastic Olefins, Vulcanates (TPO, TPV)	93	4	Injection molded parts, misc
Thermoplastic urethane (TPU)	30	1	Injection molded parts, misc
Copolyester (COPE)	16	1	Injection molded parts, misc
Other Thermoplastic Elastomers	15	1	Injection molded parts, misc
Total	2398	100	

Source: CHEMinfo Services, Chemical Marketing Reporter, Modern Plastics Encyclopedia, 1995

Domestic consumption varies with general economic activity. Demand is stable, and has varied between 4 and 6 kilotonnes per year over the last decade.

18.3 Technical Comparison of Polychloroprene and Alternatives

Polychloroprene offers very good abrasion resistance, high tear and tensile strength, and very good resistance to chemicals and hydrocarbon solvents. The material has good weather capabilities, reasonable oil resistance and a good recovery factor. Polychloroprene bonds better and easier to various metal and other substrates in comparison to NBR or EPDM. This can be a key advantage when the rubber needs to be attached to such components as motors, pumps and the like. As a result of these properties polychloroprene finds use in many under-the-hood auto applications, such as gaskets, belts, etc. Table 18-3 summarizes some of the technical characteristics of polychloroprene and alternatives.

Table 18-3: Technical Comparison of Polychloroprene and Other Rubber Compounds

Characteristic	Polychloroprene	NBR	EPDM
Abrasion resistance	Very good	medium	good
Tear resistance	Very good	medium	medium
Tensile strength	Very good	good	medium
Bonding to metals, other substrates	Very good	good	medium
Chemical resistance	Very good	good	medium
Oil resistance	good	Very good	medium
elongation	good	medium	Very good
weathering	good	medium	Very good
Cold temperature performance	medium	medium	Very good
High temperature performance	medium	medium	Very good
Processability (extrusion, injection molding)	medium	good	Very good

Source: Rubber compounders, CHEMinfo Services, Modern Plastics Encyclopedia, 1995

No one alternative polymer will match or exceed the properties and functional performance of polychloroprene. NBR has very good oil resistance with reasonable abrasion resistance such that it may substitute for some lower quality belts, gaskets and conveyors. EPDM may be more suited as a substitute in applications which require performance at temperature extremes. However, EPDM does not have great oil and hydrocarbon solvents resistance. EPDM does offer very good weathering capabilities and consequently the material has taken a large share of the outdoor household rubber business.

18.4 Direct Replacement Cost

The cost model for polychloroprene involves direct polymer substitution by the compounder. Compounders are able to incorporate alternative rubber materials on behalf of their fabricated rubber products customers. The prices used for comparison are shown in Table 18-4. The rough estimate for the direct replacement cost of polychloroprene is \$45 million per year, as summarized in Table 18-5. Although substituting a NBR, EPDM or more expensive rubber material for polychloroprene is technically viable, the performance of the final product is likely to be compromised in some manner.

The cost of reduced service life, or the implications of reduced performance is not considered here. However, some technical difficulties associated with the substitute materials may be overcome with proper incorporation of additives or rubber blends.

The substitution cost model for polychloroprene adopts the following assumptions:

- ratio of compound to polymer consumed in Canada is 2:1;
- polychloroprene that can be substituted with NBR is 33%;
- polychloroprene that can be substituted with EPDM is 33%;
- polychloroprene that needs to be substituted with more expensive rubber is 33%; and;
- price of more expensive performance rubber compounds such as hydrogenated NBR, fluoropolymers, COPE etc is \$22/kg.

Table 18-4: Typical Prices for Rubber Compound 1988-1993

	Polychloroprene	NBR	EPDM	Hydrogenated NBR, COPE etc.
Compound price (\$/kg)	4.40	3.75	2.75	22.00
Compound cost wrt polychloroprene (\$/kg)		(0.65)	(1.65)	17.60

Source: CHEMinfo Services

Table 18-5: Annual Direct Replacement Cost Calculation

Assumptions	Annual Quantities (kT)	Direct Replacement Cost (\$ tonne)	Total Direct Replacement Cost (\$ million)
Quantities of polychloroprene consumed	4.4		
Corresponding quantity of compound	8.8		
33% replacement with NBR	2.93	(650)	(2)
33% replacement with EPDM	2.93	(1650)	(5)
33% replacement with high performance compounds	2.93	17600	52
Total	8.8	5110	45

Source: CHEMinfo Services

18.5 Direct Replacement Cost Compared to End-Use Revenues

The principal use of polychloroprene is in automobiles (i.e., belts, hoses, gaskets). This application takes up 2.3 kilotonnes of polychloroprene polymer, or approximately 53% of all imports. Multiplying the direct replacement cost by 53% generates a cost of \$24 million dollars. This represents 0.04% of domestic revenues associated with automobile and automobile parts manufacture (\$54,734 million) (Stats. Can., 1993, 310-203).

18.6 Socio-Economic Profile

Practically all rubber polymer must be custom compounded to provide suitable performance for specific end-uses. Merchant compounders also handle SBR, NBR, EP elastomers, natural rubber and other rubber products. Generally, compounders are not active in making fabricated rubber products, such as gaskets, hoses, belts, etc. Their customers are a host of manufacturers serving a broad range of industries including automotive, transportation, electrical, electronic, aerospace and appliances. The socio-economic profile will focus on the rubber polymers with the most market overlap, polychloroprene, and nitrile butadiene rubber.

18.6.1 Polychloroprene

Number and Location of Producers: There are no polychloroprene producers in Canada. Compounders handling polychloroprene include Biltrite Industries with two Toronto locations, and Burton Rubber Company in Tillsonburg.

Imports and Exports: The entire supply of polychloroprene polymer used by Canadian industry is imported from the United States. The major supplier of polychloroprene to Canada is a Dupont plant in Wilmington, Delaware. Imports for 1993 were estimated at 4.4 kT, generating compound of 8.8 kT.

Revenues: Based on a price of \$4.40 a kilogram the value of domestic sales of compound is \$39 million.

18.6.2 Nitrile Butadiene Rubber (NBR)

Number and Location of Producers: Bayer Rubber of Sarnia produces a variety of rubber products in Canada (see 1.7). The company is owned by German based Bayer Corp. and has both manufacturing and distribution facilities in the United States. The Canadian operation makes PB rubber polymer, BR and NBR.

Production and Capacity Levels: Bayer Rubber has estimated capacity of 210 kT for butyl, polybutadiene and butadiene rubber. Most of existing capacity is devoted to Butyl rubber at 120 kT per year. Production of NBR is estimated at 15 kT. Table 18-6 shows Canadian capacity for rubber products. Using a ratio of 2:1, this translates into 30 kT of NBR compound.

Table 18-6: Canadian Capacity for Rubber Polymer
(Bayer Rubber in Sarnia, ON)

Products	Canadian Capacity (kT)
Butyl rubber	120
Polybutadiene rubber	63
Nitrile butadiene rubber	30
Total	213

Source: CHEMinfo Services and Camford Information Services, 1995

Imports and Exports: Exports of NBR totalled 12 kT in 1993 (24 kT compound equivalent). Imports of NBR totalled approximately 2 kT (4 kT compound equivalent), for a trade surplus of 10 kT (20 kT compound equivalent).

Revenues: Based on a average price of \$3.75 per kg. of compound and 30 kt of NBR compound produced (from 15 kT NBR), domestic revenues are estimated at \$112 million, with a trade surplus of \$75 million, and value of domestic sales of \$37 million.

Manufacturing Employment: Although employment statistics for Bayer Rubber were not available, industry experts estimate that manufacturing employment at Bayer is 75 people. Employment associated with NBR is estimated at 5 people.

18.7 Summary

Polychloroprene has a small share of the synthetic rubber market (less than 3%). It is mostly used by the automotive industry for gaskets, belts and hoses. The principal alternative to polychloroprene is nitrile butadiene rubber, as well as a thermoplastic elastomers such as EPDM. The market share of polychloroprene is relatively stable.

Substitution costs are estimated at \$45 million, assuming direct substitution by the compounder. The model assumes that the polychloroprene market will be divided equally between NBR, EPDM and high performance compounds. The principal end use for polychloroprene products is the automobile industry, which accounts for approximately 53% of polychloroprene demand. The direct replacement cost for this sector (\$24 million) represent .04% of domestic revenues associated with automobiles and automobile parts (\$54,734 million). Table 18-7 summarizes the socio-economic profiles of polychloroprene and nitrile butadiene rubber alternative.

**Table 18-7: Socio-Economic Summary of
Polychloroprene and NBR**

	Polychloroprene Compound	Nitrile Butadiene Compound
Domestic Sales (\$M)	39	37
Trade Balance (\$M)	(39)	75
Domestic Revenues (\$M)	0	112
Manufacturing Employment	-	5
Manufacturing Employment/Domestic Revenues (people/\$M/yr)	-	.04

18.8 Contacts and References

18.8.1 Industry Contacts

The following organizations were contacted during the course of this study. Data was collected from these organizations using fax surveys and telephone interviews. In some cases, more than one interview was undertaken within each company.

- Dupont - Neoprene Division
- Canadian Biltrite Industries
- American Biltrite Company
- Bayer Rubber
- Burton Rubber Co.

18.8.2 References

Camford Information Services. 1995. Product Profile - Rubber.

Statistics Canada. 1993. Manufacturing Industries of Canada: National and Provincial Areas. Cat. No. 31-203.

Statistics Canada. 1994. Exports by Commodity. Cat. No. 65-004.

Statistics Canada. 1994. Imports by Commodity. Cat. No.65-007.

19. Pesticides

19.1 Introduction

This chapter will describe chlorine use in pesticides, outline some alternatives, and profile the Canadian pesticide industry. No attempt has been made to quantify the direct replacement cost of chlorine in pesticides.

Pesticides include herbicides, insecticides, fungicides and specialty products (e.g., fumigants and nematocides). The pesticide industry produces chemicals for use in agriculture, forestry, other industrial and household use. In the late 1980s, there were at least 500 different pesticide active ingredients manufactured in the U.S. for a wide variety of applications. Over 85% of pesticides are used for crop protection in the agricultural sector. The overall Canadian pesticide usage rate is less than 1 kg per hectare -- one of the lowest rates in the developed world -- and is primarily due to Canada's relatively dry climate, short growing season and domination of cereal crops over a wide geographic area.

The manufacture of pesticides is a two-stage process. In the first stage, the active chemical ingredient is produced. In the second stage, active ingredients are combined with carrier substances to formulate the final product. The total quantity of active pesticide ingredients used in North America is estimated at 400 kilotonnes in 1993, with 32 kilotonnes used in Canada, as shown in Table 19-1 (Crop Protection Institute of Canada, 1995). Uniroyal Chemical Ltd. is the only Canadian manufacturer of active ingredients, identified in this study. Most Canadian companies import finished pesticide product or import the active ingredients and conduct the second-stage formulation at regional plants. Approximately half the pesticides used in Canada are formulated in Canada, with the other half being imported as finished products.

Table 19-1: Estimated Pesticide Usage in Canada, 1993

Type of Pesticide	Use ¹ (kT)	Portion of Total	Portion of Type Chlorinated ³
Herbicides	25	78%	65%
Insecticides	2	6%	37%
Fungicides	2	6%	50%
Specialty ²	3	10%	80%
Total	32	100%	64%

Source: Crop Protection Institute of Canada; CHEMinfo Estimates.

¹ Active ingredient only. ² Includes fumigants and nematocides

³ See Table 19-2.

Table 19-2: Estimation of Chlorinated Chemicals in Pesticides

Category	Use (%)	Chlorinated Chemicals (%)	Examples Common Chemical Names (Brand Names)
HERBICIDES			
Amides	32	100	alachlor (Lasso®); propachlor (Ramrod®); metolachlor (Dual®)
Carbamates and Thiocarbamates	5	0	butylate (Sutan+®)
Carboxylic Acids and Derivatives	17	70	Chlorinated: chlorophenoxys (2,4-D) (many); triclopyr (Garlon®); chlorimuron (Classic®); clomazone (Command®) Non-chlorinated: glyphosate (Roundup®)
Dinitroanilines	11	0	trifluralin (Treflan®)
Heterocyclic Nitrogen (Triazines)	30	70	Cl'd: atrazine (several); cyanazine (Bladex®); simazine (several) Non-chlorinated: bentazon (Basagran®); metribuzin (Sencor®)
Other	5	0	
Average Chlorinated Chemical		65	
INSECTICIDES			
Carbamates	15	0	carbaryl (Sevin®); carbofuran (Furadan®)
Chlorinated Hydrocarbons	3	100	
Organophosphates	72	40	Chlorinated: Class IV (Counter®, Dyfonate®) Non-chlorinated: Class I-III several
Synthetic Pyrethroids	10	50	barthrin; permethrin (several)
Average Chlorinated Chemical		37	
FUNGICIDES			
Aniline/Anilides	15	0	
Dithiocarbamates	22	0	mancozeb; maneb; zineb
Halogenated	22	100	several (Bravo®; Terraclor®)
Heterocyclic Nitrogen	37	70	Chlorinated: captan (unknown) Non-chlorinated: several (Phaltan®)
Inorganic	4	0	sulfur; copper
Average Chlorinated Chemical		50	
FUMIGANTS/NEMATOCIDES			
Halogenated	75	100	
Carbamates and Dithiocarbamates	13	0	
Organophosphates	3	20	
Other	9	50	
Average Chlorinated Chemical		80	

Source: Chemical Economics Handbook - SRI International; CHEMinfo Estimates;
Weed Science Journal

Relatively little chlorine is contained in active ingredients of pesticides manufactured in Canada (1-2 kilotonnes). The low usage of chlorine by the pesticides producing industry reflects the fact that there is very little production of active ingredients in Canada. However, the calculation in Table 19-1 estimates that 64% of all pesticides used in Canada contain chlorine within their molecular structure. Estimates of the chlorine content of some pesticides is shown in Table 19-2. Chlorine and chlorinated derivatives (e.g. HCl, DCM, EDC) can also be used in the synthesis of active ingredients.

19.2 Alternatives to Chlorine-Based Pesticides

There are three main alternatives to the use of chlorine-based pesticides:

- 1) direct substitution of an existing, non-chlorinated chemical for a chlorinated chemical in a particular product;
- 2) re-engineering or reformulation of the molecule of a product to provide the identical, unique functionality using a non-chlorine based chemical group; and
- 3) use of non-chemical methods known as alternative agricultural methods, which include practices such as organic farming, crop management practices, physical pest barriers and use of biological products.

It is beyond the scope of this study to undertake an analysis of direct replacement costs for the pesticides industry. Therefore, the comparison below provides a qualitative discussion of the technical and economic characteristics of chlorine-based pesticides and the alternatives.

While some pesticides have broad applicability, most are unique and their effectiveness is determined by the type of crop, stage of growth when applied, climatic conditions, and previous history of pesticide application. Consequently, it can be difficult to find an equally effective substitute. The active ingredient molecule can be designed to react to specific applications through adjustment of chemical properties such as solubility, volatility, partitioning, local electrophilicity and ability to bind to specific types of receptor sites. Chlorine has historically provided a low cost tool used in molecular design to adjust some of these properties. On the order of 10,000 different molecular structures are tested for every chemical that is commercialized. This development process involves examining leading chemical species and progressively testing against other promising species. As a result of this process, the commercialized chemical is usually the most effective for a certain application.

However it is also important to recognize that the process of re-formulation and re-design of pesticides is continual in the industry, particularly in regards to insecticides. As pests become resistant, re-engineering takes place in order to develop new types, or variations of pesticides in order to combat the new strains of pest. This re-engineering process is slower in the case of herbicides, the most common type of pesticide.

19.2.1 Direct Substitution of Non-Chlorinated Chemicals

A trend in product development and substitution over the last 10 years has been the development of certain chemicals which are many times more potent than their predecessors and which have dosage rates many times less for the same coverage area (e.g., synthetic pyrethroids). This trend is typically accompanied by increased use of liquid formulations to ensure more complete product distribution. The trend has also involved chlorine-based chemicals, but often in smaller quantities due to the requirement for a lower amount of the active ingredient. Also, due to environmental and health concerns, many chlorinated pesticides have been banned or restricted in use, and several are under review.

The effectiveness of direct substitution of one chemical for another in a particular application depends on the ability of the chemical to perform the task required in the application. There may be some chemical classes where a substitute from one chemical to another can be accomplished without much penalty. However, in many cases, when one product is substituted for another, performance may be affected with respect to dosage rates, crop area coverage under certain weather conditions, degree of pest resistance and pest kill, crop yields, or crop quality.

19.2.2 Re-engineering Using a Non-Chlorine Based Chemical Group

Two Canadian pesticide industry sources agree that it is possible to re-engineer a molecule to remove chlorine, but that it is time consuming and costly. One scientist with Ciba-Geigy claimed that substitution of chlorine by another functional group (e.g., a methyl, bromine, or trifluoro group) would result in a large change in electrophilic properties for which an entire molecular re-design would be required. Any change to a chemical structure requires new registration with Health Canada, a process which includes efficacy studies (about two years), acute and chronic toxicology studies (about three years) and environmental studies. One industry source estimates that the entire process typically costs \$10 to 15 million per commercialized chemical and can require between five to ten years of effort. Other industry sources claim the costs are higher.

19.2.3 Alternative Agriculture Methods

The third alternative to the use of chlorine-based pesticides is the use of non-chemical methods, known as "alternative agriculture". Alternative agriculture uses natural processes, reduces off-farm inputs, makes use of the biological and genetic potential of plants and animals, improves the match between cropping patterns and land, and increases conservation of soil, water, energy and biological resources. Alternative agricultural practices are also used in conjunction with a pesticide program, rather than replacing one. Some of the more common alternative agricultural practices currently in use include:

- integrated pest management (IPM) programs, such as timing of planting, monitoring weather, biological pest controls, and planting resistant strains;
- adoption of tillage and planting practices designed to reduce insect damage, weed growth, improve crop health and decrease soil erosion.

IPM programs can reduce overall pesticide use through crop rotations that disrupt the reproductive cycle, habitat and food supply of many crop weeds, and insect pests and diseases. Fruit and vegetable growers can dramatically decrease pesticide use with an IPM program, particularly in northern, dry climates such as those characterizing much of Canada. Resistant strains of crops are continually being developed and some biological products, while not widespread, are as effective as pesticides in certain low-volume agricultural applications. The installation of physical barriers to weeds (e.g., plastic ground coverage, suspended film or enclosures) and the use of insects to control pests are commonly used in the southeast U.S. Well managed alternative systems virtually always use less synthetic chemical pesticides per unit of production than conventional farms. Organic farming is one variation of alternative agricultural practices which completely eliminates pesticide use.

There have been a number of recent reports comparing the performance of alternative agriculture systems with conventional ones. Summaries of five case studies of alternative agricultural systems are provided below. These studies suggest that, in general, a price premium is currently required in order to encourage organic management practices due to the combined effect of higher costs and lower yields.

However, there are also cases where alternative farming methods have resulted in cost savings, and reduced pesticide use. Examples include fifteen farmers participating in the Northeast Wisconsin Sustainable Farmers Network project to grow corn without herbicides who reduced their costs by \$53 per acre, and Campbell's soup company farmers in Ohio who reduced pesticide use by 80% and lowered costs by \$26 an acre in 1990 and 1991 (World Wildlife Fund, 1995).

I. Conventionally-Managed versus Organically-Managed Vineyards

White (1995) reports the results of a five-year study in New York state, that compared the economic results of growing three varieties of grapes using conventional and organic management practices. Growing costs were 69-91% higher, depending on the variety, each season under organic management practices. Yield per acre for the organic system was between 5 and 35% lower than the conventional system, depending on the variety.

The report did not provide a comprehensive description of the organic management practices, although the following were mentioned: fertilization using pelleted chicken manure, tillage operations which replaced the herbicides used in the conventional system, and hand hoeing to control weeds. Four tillage operations were required, including plowing, taking out, digging and disking.

Operations which were expensive in the organic system included:

- fertilization (using the pelleted chicken manure);
- extra labour and machinery required to handle the (bulky) fertilizer;
- tillage operations; and
- hand hoeing as a means of weed control.

Tillage operations were found to be the most expensive, given the requirement for significant expenditures for labour and machinery, and given their contribution to soil compaction which created a need for more weed control (relative to herbicides).

Profitability was measured by average annual returns to management. Returns were higher in every year for the conventional management practices for all varieties. The difference in returns between the conventional and organic systems was due to the combined effect of higher costs and lower yields for the organic system for all three varieties. Yields were thought to be lower for at least two reasons: from the additional competition from weeds, and from the soil compaction arising from the tillage operations. For one of the three varieties, the calculated variable costs were greater than the total receipts, indicating that the grower would not choose to grow that variety of grape organically even in the short run.

The report also surveyed U.S. producers marketing wine to determine whether they distinguished their products (e.g., using an organic label) and whether the retail price of organic wine was different than regular wine. The majority of producers did not distinguish that their grapes were grown organically, and some indicated that they feared that if organic wines were promoted, consumers might wonder what was "wrong" with their non-organic wines. The results also suggested that it is unlikely that organic wines bring a price premium, except for some producers in selected markets.

II. Conventional versus Organic Apple Production

Vossen *et al.* (1994) report the results of a four-year study comparing organic and conventional apple production systems in California. The study compared three varieties of apples under the two systems according to the following parameters: tree growth, yield, fruit quality, biological and chemical nutrient supply systems, disease and insect pest damage, and economic performance. The study concluded that the price premium for organically-grown apples was insufficient to justify the losses, the need for increased management, and the additional risk involved in organic apple production.

The organic system received an annual spring application of 2 tons/acre of compost, equivalent to 52, 35, 39 and 30 pounds/acre of nitrogen for 1990, 1991, 1992 and 1993 respectively. Phosphorus additions were 47, 66, 53 and 48 pounds/acre for each of the four years. The system also incorporated a bell bean/vetch mixed cover crop and a supplemental (foliar) application of kelp and fish meal for the first three years. Hand thinning was conducted to manage fruit size. Cross-cultivation, rotovating and hand hoeing were used as a means of weed control. Sulphur compounds, insecticidal soap, oil, molasses and a UV inhibitor were applied to control pests.

The conventional system received spring applications of granular calcium nitrate at a rate of 100 pounds/acre of nitrogen in 1990 and 1991, and the same rate for ammonium nitrate in 1992. No fertilizer was applied in 1993. Two or three (foliar) applications of chelated micronutrients (e.g., boron, zinc, copper, iron, molybdenum) were made each year. Chemical thinning followed by supplemental hand-thinning was conducted to manage fruit size. Cross-cultivation, rotovating and chemical sprays were used as a means of weed control. Conventional fungicides and insecticides were applied to control pests.

Over the four year period, the organic system yielded an average of 40% less than the conventional system for the three varieties. In three out of four years, the organic system yields were lower for all three varieties, and the variability in yield was higher for organic systems. Most of the yield loss was attributable to pest damage, particularly damage arising from codling moth and apple scab. Pest damage also resulted in organic apples failing to achieve fresh market quality in three out of the four years. Although prices were higher for organically grown apples, costs were also higher, resulting in lower overall returns/acre in comparison to conventionally grown apples. Plant nutrient levels and soil fertility levels were essentially the same for the organically and conventionally treated plots.

III. Conventional, Organic and Low-Input Livestock and Crop Farming

Cain *et al.* (1994/1995) estimate the effect on farm incomes of adopting organic and low-input farming systems for livestock and crops. The study was conducted in the U.K., and found that the adoption of both organic and low-input systems would require a price premium for livestock and crops to offset the consequent fall in farming incomes.

The main features of the low-input system were a maximum application of inorganic nitrogen to crops of 100 kg/ha, a limit on the number of cereal crops within an arable rotation, adoption of an integrated pest management (IPM) program and use of straw-based livestock housing. The requirements of the organic system additional to the low-input system were the prohibition of the use of inorganic fertilizers and pesticides, the restricted use of permitted ingredients in animal feedstuffs and restricted use of animal health products. The most restrictive feature of the organic system was the limitation on applied inorganic nitrogen.

The adoption of the organic system was estimated to have a significant adverse effect on farm incomes in most cases, with some variation by farm type. While upland farm incomes increased with organic farming, significant declines in income were experienced by cropping, lowland livestock and dairy farmers. On average, a price premium on the order of one-third of the conventional product price was required to compensate farmers for the additional costs and risks associated with organic farming. Low-input farming also required a price premium, although this was lower than that required by organic farmers.

IV. Financial Performance of Organic, Low-Input and Conventional Farming

Klonsky and Livingston (1994) report the results of a four-year study comparing the profitability of whole farm and individual crops under organic, low-input and conventional management systems. The study was conducted in California. The study concludes that neither organic nor low-input systems were able to show equivalent profits to the conventional systems without organic price premiums. The study does not provide a description of the organic, low-input and conventional farming practices associated with each system.

The study provides an analysis of whole farm and individual crop results, which is helpful in developing an appreciation for the variation in results that can be achieved with different crops. For all years, the total costs for low-input and organic tomato systems were higher than for conventional systems, due primarily to high hand hoeing costs. Yields were only slightly below those achieved under conventional systems, due mainly to certain high-cost practices included in the low-input and organic systems. For corn, the low-input and organic systems were less costly than the conventional systems. For

beans, the operating costs of all three systems were fairly close. Gross income (i.e., cash proceeds before costs are deducted) was higher for low-input and organic tomatoes, mainly because of the significant price premiums for organic tomatoes. The study also noted that the price premium for organic tomatoes fluctuated significantly over the four-year period, and that the price premiums for other crops were lower because the organic market for these products was less well developed. A break-even analysis showed that low-input and organic systems are economically viable overall, although they have greater year-to-year fluctuation than conventional systems.

The most critical factors determining profitability of low-input and organic farming were found to be fertility management and weed management. The study found that, particularly in the early years, lower yields should be expected with low-input and organic farming. Since costs are typically either higher or comparable to conventional farming, farm profits can only be maintained if a price premium is obtained.

V. Energy and Labour Efficiency for Conventional versus Alternative Farming

Nguyen and Haynes (1995) report the results of a study comparing three pairs of conventional and alternative mixed cropping farms in Canterbury, New Zealand. Over the entire rotation, the mean annual energy input was considerably lower under alternative than conventional management systems, and the mean annual labour input was slightly lower. Yields of organic crops were typically found to be lower than those of conventional crops.

Organic systems relied on biological pest and disease control measures, mechanical cultivation, mineral-bearing rocks, crop residues, animal and green manures and crop rotations. Conventional systems received annual inputs of various synthetic fertilizers and pesticides.

The total energy input was found to be higher for most conventional systems mainly due to the manufacture and application of synthetic nitrogen-containing fertilizers. For selected crops, however, the total energy input of organic and conventional systems were quite similar, due to the balanced effect of higher chemical inputs for conventional farming and weed/pest control operations for biological farming. Total labour input varied considerably among the three pairs of farms. In some cases, the labour input under organic farming was significantly higher than under conventional farming, because of the higher manual labour associated with weed control. Yields of organic crops were between 58% and 75% of conventional yields, due to the interaction of a number of factors, including disease and pest damage, competition with weed species and an inadequate nutrient supply.

19.3 Socio-Economic Profile of the Pesticides Industry

Plants and Locations: The Canadian pesticide industry is dominated by several multinational companies. Many of these companies are listed in Table 19-1. Since the market in Canada is relatively small compared to that in the U.S. and Europe, there is an insufficient revenue base to sustain large, dedicated research and development activities required for continual product development to meet the limited needs of the Canadian marketplace.

Table 19-3: Major Canadian Pesticide Companies

Company	Location	Activity
BASF Canada Ltd.	Rexdale, ON	Distribution
Chemagro Ltd.	Concord, ON	Formulation
Ciba-Geigy Canada Ltd.	Cambridge, ON	Distribution
Cyanamid Canada Ltd.	Markham, ON	Distribution
Dow Elanco Canada Ltd.	Ft. Saskatchewan, AB	Formulation
Du Pont Canada Inc.	Mississauga, ON	Distribution
Hoechst Canada Ltd.	Regina, SK	Formulation
ICI Canada Inc.	Woodstock, ON	Distribution
Interprovincial Co-op Ltd.	Winnipeg, MB	Formulation
Later Chemicals Ltd.	Richmond, BC	Formulation
Monsanto Canada Inc.	Morden, Manitoba; La Salle, PQ	Formulation
Plant Products Co. Ltd.	Bramalea, ON	Formulation
Rhône-Poulenc Canada Inc.	Calgary, AB	Formulation
Rohm and Haas Canada Inc.	West Hill, ON	Formulation
Sandoz Canada Inc.	Port Perry, ON	Formulation
Uniroyal Chemical Ltd.	Elmira, ON	Manufacturing
United Agri Products		Distribution

Source: CHEMinfo Services Inc.

In this study, only one company -- Uniroyal Chemical Ltd. -- was identified as a producer of active ingredients in Canada. Their single manufactured product, Vitavax®, is a carboxin (an aniline/anilide fungicide) and is sold for grain and oil seeds in over 60 countries. Other companies have plants set up for regional formulation using imported active ingredients. Some multinationals have only distribution facilities in Canada. The pesticides industry is similar to the pharmaceuticals industry, with some companies participating in both (e.g., Cyanamid, Ciba-Geigy, Hoechst, Eli Lilly and Rhone Poulenc).

With respect to herbicides, production of active ingredients in North America is very concentrated, with no more than half a dozen firms accounting for over two thirds of the production. Regional pesticide distributors play a significant role in the business, particularly for herbicides. There are several hundred pesticide distributors across North America, many of whom also carry fertilizer products.

Revenues: In North America, the total value of pesticide sales at the retail level is about \$26 billion. Domestic revenues in Canada are \$1.7 billion (Statistics Canada, 1993).

Employment: There are approximately 2,900 people employed in the Canadian pesticides industry¹, the majority of whom are involved in formulation of the imported basic ingredients and distribution of the finished product (since most of these companies market directly to farming centres). Few are involved in the actual manufacture or production of active ingredients. In addition, approximately 60 people are involved specifically in research and development activities in association with Uniroyal operations.

19.4 Contacts and References

19.4.1 Industry Contacts

- Crop Protection Institute of Canada
- IMS Canada
- Industry Canada

¹ Statscan, Annual Census of Manufacturers (44-250; SIC 3721), 1993 (employment estimate is 2,888)

19.4.2 References

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20. Pharmaceuticals

20.1 Introduction

This chapter will describe chlorine use in pharmaceuticals, outline some alternatives, and profile the Canadian pharmaceutical industry. No attempt has been made to quantify the direct replacement cost of chlorine in pharmaceuticals.

Pharmaceuticals currently represent the most widely used technology for addressing illness and the burden it imposes on society. This burden was valued by Health Canada (1991) at almost \$100 billion, including the loss of future earnings, lost productivity arising from lost work time, and net payments under various disability programs such as government disability pensions, survivors' benefits, death benefits, and worker's compensation.

As with pesticides, the manufacture of pharmaceuticals is a multi-stage process. One stage involves the production of the active chemical ingredient and another the formulation of the pharmaceutical. In Canada, there is only a minor amount of manufacturing of active chemical ingredients for pharmaceuticals, with most companies importing active ingredients and undertaking the formulation at regional plants.

In Canada, there are currently about 1,000 patent medicines on the market. The Patent Medicine Prices Review Board (PMPRB) estimates that the top-selling 200 medicines account for about 85% of sales, with the top 25 accounting for about 30% of sales (PMPRB, 1995). Of the top-selling 12 drugs in Canada, as listed in Table 20-1, only one contains chlorine in the active ingredient and four are formulated as a hydrochloride salt.

Table 20-1: Top Selling Medicines in Canada 1992

Rank	Brand Name	Common Name	Patent Company	Cl Content	HCl Content	Function
1	Total ¹ Cardizem	Diltiazem HCl	Marion Merrell Dow	No	Yes	cardiovascular calcium ion influx inhibitor
2	Vasotec	Enalapril maleate	Merck Frosst	No	No	anti-hypertensive
3	Total Adalat	Nifedipine	Bayer (Miles)	No	No	anti-hypertensive
4	Mevacor	Lovastatin	Merck Frosst	No	No	cholesterol lowering agent
5	Total Ventolin	Salbutamol	Glaxo	No	No	bronco-dilator (asthma)
6	Losec	Omeprazole	Astra	No	No	gastric enzyme inhibitor (antiulcer)
7	Total Voltaren	Diclofenac sodium	Ciba-Geigy	Yes	No	non-steroidal anti-inflammatory/analgesic
8	Prozac	Fluoxetine HCl	Eli-Lilly	No	Yes	antidepressant
9	Total Zantac	Ranitidine HCl	Glaxo	No	Yes	histamine H ₂ receptor antagonist (antiulcer)
10	Triphasil	Levonorgestrel-ethinyl estradiol	Wyeth-Ayerst	No	No	birth control
11	Becloforte Inhaler	Beclomethasone dipropionate	Glaxo	No	No	anti-inflammatory corticosteroid (asthma)
12	Apo-Ranitidine	Ranitidine HCl	Apotex	No	Yes	histamine H ₂ receptor antagonist (antiulcer)

Source: IMS Canada and PMPRB

¹ Total refers to patent brand plus several generic copies.

Charles River and Associates (CRA) (1993) conducted a survey of the 206 top-selling pharmaceuticals sold in the U.S., and found that they accounted for over 40% of the total U.S. pharmaceutical sales. CRA also analyzed ten common therapeutic groups of pharmaceutical products in the U.S. for chlorine content (Table 20-2). The results of the CRA survey suggest that chlorine is present in the molecules of the active ingredient in about 20% of pharmaceuticals sold in the U.S. The results also suggest that chlorine is present in 6% of the compounds where the active ingredient is in the form of a hydrochloride salt, and that a much larger proportion (58%) of pharmaceuticals use chlorine or chlorinated chemicals in the manufacturing process.

**Table 20-2: Chlorine Content of Top-Selling Pharmaceuticals
in the United States**

Therapeutic Group	Percent of Sales in the Group with:				
	No. of Products Surveyed	Chlorine in Molecule	Hydro- chloride in Product	Chlorine in Manufacture	No Chlorine
Nutritionals	8	0	0	92.2	7.8
Blood Modifiers	7	0	0	46.1	53.9
Hormones	20	11.9	0	70.7	17.4
Cardiovasculars	43	28.6	2.4	46.6	22.4
Respiratory Drugs	16	24.5	4.7	49.6	21.2
Central Nervous System Drugs	39	31.7	16.0	44.0	8.3
Gastrointestinals	9	0	0	97.9	2.1
Anti-infectives	36	14.5	8.4	69.9	7.2
Biologicals	4	0	0	0	100.0
Topical Preparations	12	26.8	15.7	52.2	5.3
Antineoplastics	6	27.8	0	34.5	37.7
Miscellaneous	6	0	0	80.3	19.7
Total All Groups	206	20.3	6.1	58.1	15.5

Source: Charles River Associates, 1993

20.2 Alternatives to Chlorine-based Pharmaceuticals

The main alternatives to the use of chlorine-based pharmaceuticals include:

- directly substituting a non-chlorine based drug for a chlorine-based one in a particular application;
- developing a new non-chlorine based drug to replace the chlorine-based one; and
- adopting preventative health care options, such as diet, exercise and homeopathic medicine.

It is beyond the scope of this study to undertake a direct replacement cost analysis for the pharmaceutical industry. Therefore, the comparison below provides a qualitative discussion of the technical and economic characteristics of chlorine-based pharmaceuticals and non-chlorinated alternatives.

Chlorine is used in the molecular structure of the active ingredient of a drug, to influence physical and electrochemical properties of the molecule, such as polarity, molecular weight, and molecular density. Various chlorinated compounds are used to produce chlorinated molecules, but the most common forms are hydrochloric acid and chloroform. Some pharmaceuticals are sold as hydrochloride salts of an active ingredient, a common form of final dosage, characterizing four of the 12 top-selling Canadian medicines. Some of the pharmaceutical synthesis processes depend on chlorine, such as the use of hydrochloric acid for pH adjustment and chlorinated organics for extractions.

20.2.1 Substitution with Non-Chlorine-based Chemicals

For those pharmaceuticals which have chlorine in the active ingredient, it is likely that few non-chlorine based pharmaceutical substitutes exist. In situations where chlorine is used, primarily to facilitate manufacturing, substitution may be simpler. The applications where chlorine is used to facilitate production are the major use of chlorine in the pharmaceuticals industry.

Development of Non-chlorine-based Substitutes

Development of new products is costly and time-consuming. The rule of thumb used by the industry is that to develop a safe and effective medicine which can be introduced to the market, researchers begin by synthesizing or isolating on the order of 10,000 compounds. Of these, only about 20 show sufficient promise to undergo further pharmacological and toxicological study (PMAC, 1995).

The commercialization process in Canada involves three sets of clinical trials. If a drug succeeds through all three sets of trials, the company then files a New Drug Submission (NDS) with the Drugs Directorate of Health Canada. If the submission is successful, the company receives a Notice of Compliance (NOC) allowing the new medicine to be introduced to the marketplace. PMAC (1995) estimates that it took an average 1,142 days (over three years) for a NDS to be processed through the system. Health Canada estimated the approval time at even longer - 1,255 days (PMAC, 1995).

The lengthy drug approval process is costly. The Office of Technical Assessment of the U.S. Congress recently reported that the average time to develop a new commercial pharmaceutical product was 12 years in the U.S., with an estimated average cost for this process of US \$359 million. Industry Canada estimates that it costs about C\$250 million to develop a commercialized pharmaceutical product in Canada. The industry association agrees with this, estimating that it costs between \$250 to \$300 million to develop a commercialized product (PMAC, 1995).

These estimates of costs and timeframes are based on current product development processes which have chlorine available as an ingredient or facilitator, and may not be representative of the resources required to replace chlorine-based products with non-chlorine-based products.

It was beyond the scope of this study to attempt to estimate the costs of developing non-chlorine based drugs to substitute for chlorine-based ones. This is a complex issue that can only be properly addressed by examining specific medicines or classes of medicines, and considering the current state of research and development with respect to non-chlorine-based alternatives.

20.2.2 Alternative Health Care Options

Alternative, non-pharmaceutical-based health care options are largely preventive and typically include a combination of practices aimed at developing and maintaining a healthier lifestyle, such as physical exercise, diet, control of substance abuse (e.g., quitting smoking, reducing alcohol consumption), and ingestion of organic/natural substances (e.g., herbal teas).

While these life style changes would be effective in reducing some types of illness in the long run, there are a number of reasons why alternative health care options are unlikely to provide a total substitute for pharmaceutical-based health care, particularly in the short or medium run. Firstly, they involve a fundamental shift in the philosophy of health care and in terms of current behaviour. While this philosophy is gaining in acceptance, the proportion of the population accepting of these methods is small. Secondly, lifestyle changes take time to properly implement and tend to have a significant impact only in the medium and long run. Thirdly, alternative health care options are unlikely to be able to compensate for the specific acute functionality that drugs offer in their various applications. Options such as lifetime nutritional management, homeopathic treatment and genetic and technical engineering treatment, are likely to remain alternatives that can only address a relatively small number of health care conditions. Some studies are available that suggest pharmaceuticals are the most cost-effective technologies of those currently available, providing they are used properly. These studies suggest that a critical factor in maximizing health benefits, is not replacing pharmaceuticals, but rather ensuring that they are appropriately used (Science Council of Canada, 1991).

"Although methods of testing for side effects and toxicity continue to improve, adverse reactions to exposures through the clinical use of drugs remain a serious problem. The number of serious adverse effects is considerable, depending on a number of factors, including sensitivity, and multiple drug interactions, the latter of which is fairly common, particularly in a typical hospital environment, and in the older segment of the population. So while pharmaceuticals may provide previously unattainable prospects of alleviation

and cure, adverse effects will continue to be an unavoidable consequence of their pharmacological potency." (Festing, 1987)

20.3 Socio-Economic Profile of the Pharmaceutical Industry

Plants and Plant Locations: In 1989, there were 145 pharmaceutical companies in Canada. Currently, there are about 120 companies, reflecting a trend toward consolidation. This is driven by the large financial resources required to develop new drugs, and the cost-competitiveness of the industry. In the last few years, a number of patent periods expired, allowing generic drug suppliers to enter the market and provide less costly products. The industry experienced a round of layoffs in 1993 and is continuing to consolidate in an effort to reduce costs and pool resources. Mergers and acquisitions have enabled companies to develop a market presence in different countries and to provide a broader selection of products to the markets they serve.

According to the Pharmaceutical Manufacturers Association of Canada (PMAC), which represents 65 researched-based pharmaceuticals manufacturers in Canada, the multinational companies account for about 75% of Canadian pharmaceutical sales (PMAC, 1995). All are located in Ontario and Quebec, near the large urban centres. About 20 companies currently capture close to 80% of the Canadian pharmaceuticals market, with the remaining 20% of the market being divided among a number of small companies having only one or two product lines and relatively short production runs. No company has more than 7% share of the total market, since there are usually several competing products in each therapeutic segment (Industry Canada, 1995).

Manufacturers are divided into two basic groups: patent-holding ("innovative") firms and generic firms. Patent holding firms have about 63% of the volume of Canadian drug sales but 87% of the revenues (due to higher prices). They are usually branches of multinational companies which have been granted patent protection for their drugs for a period of up to 20 years.

As with the Canadian pesticides industry, the majority of pharmaceutical companies, such as those listed in Table 20-3, import the active ingredient and simply formulate the final drug product in the Canadian plants. However, there are several chemical synthesis companies who manufacture pharmaceutical active ingredients in Canada: Delmar Chemicals (La Salle, PQ), Raylo Chemicals (Edmonton, AB), Brantford Chemicals (Brantford, ON) and Torcan Chemical (Aurora, ON) are four significant examples. These companies make active ingredients for suppliers of generic drugs, such as those listed in Table 20-4, as well as suppliers of patented drugs.

Table 20-3: Major Multinational Patent Drug Companies

Company	Parent Country	Plant Location
Glaxo/Burroughs Wellcome Canada Inc.	U.K.	Etobicoke, ON Kirkland, PQ
Bristol-Myers Squibb	U.S.	Montreal, PQ
Merck Frosst Canada Inc.	U.S.	Kirkland, PQ
Syntex	U.S.	Toronto, ON
Cyanamid	U.S.	Montreal, PQ
Wyeth Ayerst	U.S.	Windsor, ON
American Home Products	U.S.	Guelph, ON
Rhone-Poulenc Rorer	France/U.S.	Perth, ON
Ciba-Geigy Canada Ltd.	Switzerland	Mississauga, ON
SmithKline Beecham Pharma Inc.	U.K.	Oakville, ON
Astra Pharma Inc.	Sweden	Mississauga, ON
Johnson & Johnson Inc. (Subs: Ortho-McNeil; Janssen)	U.S.	Montreal, PQ Guelph, ON Mississauga, ON
Upjohn Company of Canada	U.S.	Toronto, ON
Eli-Lilly Canada Inc.	U.S.	Scarborough, ON
Marion Merrell Dow Canada Inc. (bought out by Hoechst AG)	U.S.	Markham, ON Montreal, PQ

Source: PMAC, 1995

Table 20-4: Major Generic Drug Companies

Company	Plant Location
Apotex Inc.	Weston, ON
Novopharm Ltd.	Scarborough, ON Montreal, PQ
Newpharm	Richmond Hill, ON
Genpharm	Etobicoke, ON
Technilab	Montreal, PQ
Pharmascience	Montreal, PQ

Source: CDMA, 1995

Production Volumes: The Canadian pharmaceutical industry currently produces over 22,000 drug products for treatment of disease for humans and animals. The majority of these products are shipped from Canadian manufacturers. Retail drug stores account for 75% of wholesale sales. Other outlets include hospitals (15%) and government purchases (under 10%).

Imports and Exports: In 1990, shipments from Canadian manufacturers accounted for 77% of total Canadian pharmaceutical sales, with the remaining 23% being supplied by imports. The U.S., U.K., Switzerland and Germany are the major sources for imported pharmaceuticals. The Canadian pharmaceuticals industry has been increasingly exporting their products to other markets. Statistics Canada reports that exports increased 297% between 1988 and 1994 (Statistics Canada, International Trade Division, 1995).

Revenues: Statistics Canada estimates that the Canadian pharmaceutical producers generated about \$4.2 billion in domestic revenues in 1990. PMAC and CDMA estimate that production has grown to about \$5.8 billion in 1994. This would place the 1993 domestic revenues at somewhere over \$5.0 billion.

In 1993, the total Canadian retail market for pharmaceuticals is estimated at about \$11.8 billion, with brand-name products representing about 85% of these revenues (PMAC, 1995). Slightly over 50% of retail revenues, or \$6.3 billion, is for prescription medicines (Health Canada, 1994). Almost \$2 billion, or 16% of retail revenues are accounted for by non-prescription drugs (Non-prescription Drug Manufacturers Association of Canada, 1995). The remainder of retail drug sales are accounted for by veterinary drugs and biological products.

Employment: Total employment in the Canadian pharmaceuticals industry is estimated at about 20,000 people, with about 20% employed by generic manufacturers. Employment in PMAC member companies (65 of the 120 Canadian companies) in 1994 was 16,646, which is 14.6% higher than the employment level of 14,521 in 1987. The greatest growth area in new jobs in the pharmaceutical industry in recent years has been in the area of medical research and development (PMAC, 1995).

20.4 Contacts and References

20.4.1 Industry Contacts

- Canadian Drug Manufacturers Association
- IMS Canada
- Industry Canada
- Non-Prescription Drug Manufacturers Association
- Pharmaceutical Drug Manufacturers Association of Canada
- Walsh Canada

20.4.2 References

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Pharmaceutical Manufacturers Association of Canada (PMAC). The 1995-1996 Annual Review.

GLOSSARY

Glossary

Term	Definition
Adsorbable organic halides (AOX)	Halogenated organic compounds (usually organochlorides in pulp mill effluent streams) which are measured by adsorption on activated carbon..
Acetone	(CH ₃ COCH ₃) The most common ketone (oxygenated) solvent having a high volatility and strong solvency.
Acid gas	Combustion by-product which is acidic (or releases hydrogen ions). Hydrogen chloride is a common acid gas released in combustion of PVC.
Acrylonitrile-butadiene-styrene (ABS)	A mixture of styrene-acrylonitrile copolymer with acrylonitrile-butadiene rubber, which combines high strength and impact resistance properties.
Aliphatic hydrocarbons	Hydrocarbon molecules with a straight-chain or branched-chain structure, having the molecular formula C _n H _{2n+2} .
Alkaline cleaners	Aqueous detergent solutions having a high pH.
Alumina trihydrate	(Al ₂ O ₃ ·3H ₂ O) An inorganic powder used as an inexpensive filler and flame retardant.
Annualized capital cost	The amortization of the capital cost over a 20 year period at an interest rate of 9%.
Aqueous cleaning	The use of soaps or detergents solutions in water to clean organic compounds from surfaces or fabrics.
Aromatic hydrocarbons	Hydrocarbon molecules whose structure contains a 6-carbon "aromatic ring", so named because of the distinct odour imparted by the structure.
Asbestos cement pipe	Old form of pipe using asbestos filler bound with cement.
ATM	The acronym given to acetone-toluene-methanol solutions which were historically used for paint strippers before DCM.
Auxiliary blowing agent	A blowing agent added to a foam mixture to extend the natural foaming process to produce lower density foams.
Barrier properties	The relative degree of impermeability of a resin to gases and liquids.
Benzyl alcohol	(C ₆ H ₅ CH ₂ OH) A solvent for resins, dyes, waxes and other organic compounds. Used in paint stripper formulations.
Bleaching	A process in which pulp is brightened by removing lignins and other coloured impurities through the use of chemical oxidizing agents and extraction processes.
Blow moulding (extrusion)	A one stage process of blow moulding hollow plastic products where a molten hollow resin tube is extruded and then expanded with air pressure to form against two halves of a mould. Often used with PE and PVC bottles.
Blow moulding (injection)	A two-stage process of blow moulding hollow plastic products where a preform is injection moulded and then blow moulded separately. Often used for PET bottles.
Blowing agent	A gas used to expand a molten resin into a foam.
Boiling range	The temperature range in which a solvent mixture boils. Used as a indication of volatility and purity.
Brightness	A measurement of the whiteness (or absence of colour) in pulp on an ISO standard scale.
Brominated flame retardants	Organic flame retardant compounds which contain bromine atoms.
Butt-fusion	Joining of two plastic pipe sections by heating and fusing the materials.

Term	Definition
Cable	A construction of enclosed wires usually surrounded by protective jacketing.
Calendering	The process of forming plastic sheet and film which includes extrusion followed by rolling and stretching on several large cylinder rolls.
Canadian Environmental Protection Act (CEPA)	Federal legislation originally passed in 1988 regulating pollution prevention, toxic substances management, clean air and water, waste management.
Capital cost	The immediate investment cost for machinery, equipment and installation required to change to a non-chlorinated alternative.
Carbon dioxide	(CO ₂) The common gas produced as a by-product of the polyurethane -water reaction which acts as the principal blowing agent in polyurethane foam.
Casement windows	The most common form of window which swings open horizontally around a vertical axis.
Cast iron pipe	An old type of iron pipe produced by mold casting. It is no longer made.
Caustic soda	(NaOH) Common name for sodium hydroxide, the most important commercial caustic. An alkaline material which is usually available commercially in a 50% solution in water.
Chelating agents	A type of sequestering agent, in which the multi-armed molecular structure completely encloses a metallic ion, preventing precipitation or degradation reactions from occurring.
Chemi-thermomechanical pulp (CTMP)	The combination of chemical and mechanical processes to make pulp.
Chemical activators	A substance containing molecular groups which increases the reactivity of other substances, especially in lower temperature conditions.
Chemical caustic soda	Caustic soda produced by the chemical reaction of lime and soda ash.
Chlor-alkali	Descriptive term used to refer to the combined products of electrolysis: chlorine and caustic soda (alkaline).
Chloride process	The process of extracting and purifying titanium dioxide from rutile ore using chlorine to produce a titanium chloride intermediate.
Chloride salt	A compound formed by the reaction of a base with hydrochloric acid. Any compound containing a chloride ion.
Chlorinated flame retardants	Organic flame retardant compounds which contain chlorine atoms.
Chlorinated paraffins	Non-flammable chlorinated hydrocarbon liquids having a paraffinic structure ranging from about 9 to 22 carbons, used for metal working fluids and flame retardants.
Chlorinated solvents	Organic solvents containing chlorine as part of the molecular structure. The presence of chlorine usually makes these solvents non-flammable.
Chlorine (elemental)	(Cl ₂) The common form of chlorine, a non-flammable greenish-yellow gas, which is shipped as a liquid under pressure.
Chlorine dioxide	(ClO ₂) A powerful bleaching agent produced from sodium chlorate salt used as a substitute for elemental chlorine in pulp bleaching.
Chlorofluorocarbons (CFCs)	Volatile compounds containing chlorine and fluorine on a 1, 2 or 3 carbon structure.
Chlorolignins	A soluble, chlorinated form of lignin which can be dissolved in alkaline solutions.
Chloroprene	(H ₂ C:CHCCl:CH ₂) The monomer from which neoprene synthetic rubber is made.
Choline bitartrate	(C ₃ H ₁₄ NOC ₄ H ₃ O ₆) One of several small volume alternative salts of choline.

Term	Definition
Choline chloride	$[(CH_3)_3N(Cl)CH_2CH_2OH]$ The chloride salt of choline, derived from trimethylamine, ethylene oxide and hydrochloric acid and used for poultry and livestock dietary supplement.
Chronic toxicology studies	Long term trials studying the toxicological properties of a compound on various living organisms. (e.g., 2-year rat studies for reproductive effects)
Cold cleaning	The cleaning of oils and dirt from metal parts by immersion in, or wiping with, a cold solvent.
Colour concentrates	Plastic additives which have a high-content dispersions of colourants or dyes in carrier resins.
Compound	A blended material composed of resin(s) and additives.
Concrete	A solidified mixture of aggregate stone, sand and cement.
Concrete pressure pipe	Concrete pipe for water distribution use having high pressure tolerance.
Conduit	Pipe used to protect above ground electric wire.
Corrosion	The deterioration of a metal by an electrochemical surface oxidation process, resulting mostly in the formation of surface metal oxides.
Corrosion inhibitors	Chemicals added to aqueous systems to prevent or retard the corrosion process by neutralizing acidic environment.
Corrugated pipe	Pipe with a ribbed wall structure.
Cross-linkable polyethylene (XLPE)	A form of polyethylene in which the polyethylene chains are linked together in a reaction process to form a durable, non-crystalline thermoset compound. The linking reaction is typically catalyzed by the addition of moisture or peroxides to initiate the linking agent.
Defoamers	Chemical agents used to reduce the formation of foam in turbulent aqueous solutions by reducing surface tension and aiding decomposition.
Deinking	The process of removing ink from recycled printed papers.
Delignification	The removal of lignins, less resistant carbohydrates, resins and mineral matter through a cooking process.
Desulphurization	The selective removal of hydrogen sulphide from petroleum and gas streams by contact with caustic soda solution.
Dibasic esters	Refined dimethyl esters of adipic (C_6), glutaric (C_5) and succinic (C_4) acids which have been used successfully as paint stripper solvents.
Dichloromethane (DCM)	(CH_2Cl_2) A common chlorinated solvent used principally in paint stripper solutions. Also commonly called methylene chloride.
Digester	A vessel in which wood pulp is "cooked" to produce fibres. The average single batch digester in Canada has capacity of 80 T of pulp/day, while continuous digesters can process above 600 T pulp/day.
Direct replacement cost	The directly measurable annual capital and operating costs required to substitute with a non-chlorinated alternative.
Domestic revenue	The value of revenues from domestic production. Also calculated as domestic sales plus trade balance.
Domestic sales	The value of sales in the domestic market.
Drain, waste and vent (DWV)	Term used to describe the plumbing pipe market category.
Dry cleaning	Cleaning without water. The use of solvents (chlorinated or hydrocarbons) to clean fabrics.
Ductile iron (DI) pipe	A flexible, high-strength iron pipe produced by centrifugal casting.
Ducting	Pipe used to protect underground electric wire.

Term	Definition
Efficacy studies	Trials studying the effectiveness and identifying and measuring side effects of a compound on living organisms.
Elastomer	The class of synthetic polymers which have rubber-like (elastic) properties.
Electrolysis	The process of separating the components a salt by applying an electric current through a solution.
Electrolytic caustic soda	Caustic soda produced by the electrolysis process.
Electrophilicity	The tendency of a molecule or part of a molecule to be attracted to a concentration of electrons on another molecule. Related to polar.
Elemental chlorine free pulp (ECF)	Pulp produced using no elemental chlorine in the bleaching process. ECF pulp uses chlorine dioxide as the bleaching agent.
Elongation	The percentage increase in length that a material can be stretched before breaking.
Emulsifying agents	Substances which are added to stabilize emulsions (suspensions of two or more liquids which do not normally dissolve in each other) by modifying the surface tension of droplets.
Endothermic reaction	A reaction which absorbs energy, resulting in cooling of the surroundings.
Ethylene dichloride (EDC)	(C ₂ H ₄ Cl ₂) An intermediate chemical derived from ethylene and elemental chlorine that is used to produce vinyl chloride monomer. A PVC precursor.
Ethylene propylene diene monomer (EPDM)	An elastomer of synthetic rubber based on linear terpolymers (three monomers) of ethylene, propylene, and small amounts of a non-conjugated diene (a monomer having 2 double bonds more than 2 carbons apart).
Ethylene-vinyl acetate (EVA)	Specialty copolymer of ethylene and vinyl acetate which has increasing rubber-like properties with increasing vinyl acetate content.
Exothermic reaction	A reaction which releases energy, resulting in heating of the surroundings.
Extended cooking	The process of progressive addition of alkaline solution to pulp cooking in a digester. Also known as modified continuous cooking.
Extruder	A machine used to melt a plastic compound under heat and pressure (from an extruder screw) and produce linear products of various cross-sectional shapes.
Extrusion	A manufacturing process where molten material is forced through a shaped die and continuous lengths are produced. Pipe, siding, linear window profiles and wires are produced by this process.
Ferric chloride	(FeCl ₃) The higher oxidative state of iron chloride, produced from ferrous chloride and used mostly as a flocculant in sewage and industrial waste treatment.
Ferrous chloride	(FeCl ₂) The lower oxidative state of iron chloride, produced as a by-product of steel pickling with hydrochloric acid and used in dyes preparations, metallurgy and the production of ferric chloride.
Ferrous sulphate	(FeSO ₄) A by-product of steel pickling with sulphuric acid which is used in pigments, coatings, and flocculant in water and sewage treatment.
Filler	Inorganic mineral additives to polymer resin which provide low-cost inert mass and volume to extend a compound.
Flame retardant	Noun: An additive used to decrease the flammability of a compound. A flame retardant compound is not necessarily non-combustible. Adj.: The property of increased ignition resistance and reduced rate of burning.
Flammability	The degree to which a substance undergoes combustion.

Term	Definition
Flash point	The minimum temperature at which a spark will ignite vapours above a flammable liquid.
Flexural modulus	The relative ability of a rigid material to bend when a lateral force is applied.
Functional group	A portion of a molecule which has certain reactive properties and tendencies. Examples include -CH ₃ , -NH ₂ , -OH.
Galvanized steel pipe	Zinc-coated steel pipe produced by hot dipping into a molten zinc bath.
Galvanizing	An electrolytic process where a thin zinc coating is applied to the surface of a metal to inhibit corrosion of the substrate metal.
Gaskets	Rubber rings used to create an impermeable seal between two surfaces; commonly used between the bell and spigot ends of two pipe sections.
Halogens	The group of elements in Class VIIA of the periodic table, excepting hydrogen. Includes (in increasing atomic number) fluorine, chlorine, bromine, iodine, and astatine.
Heavy Aromatics	A liquid aromatic hydrocarbon solvent with molecules of 9-carbons or greater. Distilled from petroleum refinery aromatic streams.
High-density polyethylene (HDPE)	A crystalline form of polyethylene with a density above 0.940 g/ml.
Household chlorine bleach	A 5% solution of sodium hypochlorite.
Hydrocarbon solvent	Petroleum-based liquids composed of hydrocarbon molecules (carbon and hydrogen only - usually ranging from 6 to 9 carbons) which have high solvency.
Hydrochloric acid	(HCl) A strong acid produced by reacting hydrogen with chlorine available commercially in solutions of 31.5% and 37.5%.
Hydrochlorofluorocarbons (HCFCs)	Volatile compounds containing hydrogen, chlorine and fluorine on a structure having usually 1, 2 or 3 carbons. Defined as transitional substances in the Montreal Protocol.
Hydrofluorocarbons (HFCs)	Volatile compounds containing only hydrogen and fluorine on a structure having usually 1, 2 or 3 carbons, which are common choices for immediate an possible long-term replacement of CFCs and HCFCs.
Hydrogen peroxide	(H ₂ O ₂) Active oxidizing agent used in bleaching of textiles, wood pulp, and many other organic-based materials.
Hydrophilic	Having an affinity for water. Capable of uniting with or dissolving in water.
Impact modifiers	Elastomeric additives which increase the ability of a polymer resin compound to absorb the force of an impact.
Impact strength	The ability of a pipe to withstand a concentrated impact force.
Industrial degreasing	The cleaning of metal working oils from metal parts through vapour degreasing or cold cleaning.
Insulation	The material directly surrounding the metal wire conductor which has a resistance to conduction of an electrical charge.
Integrated pest management programs	Methods of pest control combining many biological, environmental, and chemical methods.
Iso-paraffinic	A branched chain hydrocarbon structure, usually having a low odour. The common structure of mineral oils and waxes.
Isocyanate	A chemical containing the isocyanate (-NCO) group. Often refers to diisocyanates, which are the raw materials for polyurethanes.
Jacketing	The outer layer(s) of a cable construction which provide physical and chemical protection for the wires.

Term	Definition
Kappa	A relative measurement of the effect of cooking and delignification of the pulp. This relates to the bleachability of the pulp.
Kraft (pulp, mills)	A pulping process using an alkaline environment, where the cooking liquor contains sodium hydroxide (major cooking chemical) and sodium sulphate. Also known as the "sulphate process". Kraft is German for "strong".
Labour intensity	The relative measure of the amount of labour input for a given unit of output. An index calculated by dividing the manufacturing employment by the domestic revenues is used in this study.
Laundry bleaching	The use of a bleaching agent in addition to detergents to oxidize and decompose stains in laundry fabric.
Lignin	A dark-coloured polymeric substance which binds individual wood fibres together in wood.
Lime	(CaO) The common name for calcium oxide.
Lime (slaked or hydrated)	(Ca(OH) ₂) The hydrated form of lime used to prepare chemical caustic.
Lineals	Another word for the linear extruded components of window profiles.
Linear low-density polyethylene (LLDPE)	A linear form of polyethylene with a density between 0.910 and 0.925 g/ml, with higher tensile strength, puncture resistance and tear properties.
Low-density polyethylene (LDPE)	A branched chain form of polyethylene with a density between 0.910 to 0.925 g/ml, commonly used for films.
Manufacturing employment	The number of people directly employed in manufacturing a product.
Mass merchandisers	Franchised retailers which carry high volumes of products in many stores.
Medium-density polyethylene (MDPE)	A form of polyethylene with a density between 0.926-0.940 g/ml.
Melt index	The relative flowability of a resin in the melt form.
Merchant compounders	Companies whose business is to supply compounds to manufacturers.
Metal working fluids	Solutions of low-viscosity oils usually having flame retardant properties used for lubricating and cooling of metal cutting tool surfaces.
Methylene chloride	The common name for dichloromethane.
Mineral spirits	The name given to the most common naphtha hydrocarbon solvent which has a boiling range of 310 to 390°F.
Moisture-cure XLPE	Cross-linked polyethylene produced using water as the initiator of the cross-linking reaction with a silane coupling agent. The process requires cables to cure in hot steam rooms for several hours.
Monomer	A reactive, low molecular weight compound with a simple structure, usually containing carbon, and capable of forming long chain polymers by combination with itself or other similar molecules.
Montreal Protocol	The international agreement, officially called "The Montreal Protocol on Substances that Deplete the Ozone Layer" that was signed in September 1987 by 24 nations, and ratified in 1991 by 68 nations.
n-Methyl pyrrolidone (NMP)	CH ₃ (NCH ₂ CH ₂ CH ₂ C)O A nitrogen-containing ring-structured solvent derived from formaldehyde and acetylene used on many resins.
Naphthas	A class of hydrocarbon solvents distilled from naphtha petroleum streams, which usually contain from 6 to 10 carbons and boil between 150 and 400°F.
Neoprene	A common name for polychloroprene elastomer. Original DuPont trademark for polychloroprene first developed in 1931.
Neutralizing	Adjusting the pH of a solution (waste stream) to the neutral range (6-8) by addition of an alkaline or acidic material.

Term	Definition
Nitrile butadiene rubber (NBR)	$[\text{CH}_2\text{CH}:\text{CHCH}_2\text{CH}_2\text{CH}(\text{CN})]_n$ A elastomer copolymer of acrylonitrile and butadiene.
Non-halogen cables	Cable constructions which use alternatives to PVC (PE, XLPE) and non-halogenated flame retardants.
Olefin	A hydrocarbon containing a double bond, which provides a reactive site.
Operating cost	The annual cost difference between the material costs (plus relevant additional costs) of the chlorinated and non-chlorinated alternative.
Organic solvents	The broad classification of all carbon-based solvents. Includes hydrocarbon, oxygenated, chlorinated and nitrogenated solvents.
Oriented polystyrene (OPS)	A flexible, durable type of crystalline polystyrene in which the polymer molecules have been oriented along an axis through heat and stretching, used for sheet packaging.
Overbased sulfonates (OBS)	A viscous compound combining a sulfonated inorganic base with a fatty acid or olefin used for flame retardant metal working fluids.
Oxidizing agent	A chemical agent which induces a chemical change (an increase in the oxidation state) of another substance.
Oxygen delignification	The removal of up to 50% of the lignin in pulp prior to bleaching by the reaction of pure oxygen with pulp lignin in a hot, alkaline environment.
Oxygenated solvents	Organic solvents containing oxygen in their molecular structure. Alcohols and ketones are the most common types, although aldehydes, glycols and ethers are also considered oxygenated solvents.
Ozonation	The generation and addition of ozone to municipal water for disinfection.
Ozone delignification	The removal of up to about 70% of the lignin in pulp prior to bleaching by the reaction of ozone mixed with oxygen in a hot, alkaline environment.
Ozone depleting substances	Volatile substances which react with ozone in the stratosphere, thereby depleting the ozone levels. These include most CFCs, CCl_4 , 1,1,1-trichloroethane, partially halogenated fluorocarbons and methyl bromide.
Paint stripper	A solution of solvents which have the ability to penetrate and soften a resin surface coating and disengage it from the substrate.
Pallet wrap	High strength film wrap for securing goods stacked on pallets (wooden platforms) for distribution.
Pentane	$(\text{C}_5\text{H}_{12})$ A volatile 5-carbon hydrocarbon solvent sometimes used as a resin blowing agent.
Perchloroethylene ("Perc")	See Tetrachloroethylene. The "per" prefix denotes complete substitution (or saturation) by chlorine atoms on the ethylene structure.
Perfluorocarbons	A group of fluorocarbons where fluorine atoms are completely substituted on the carbon structure.
Permeation	Diffusion of through a barrier driven by differences in concentration.
Peroxide-cure XLPE	Cross-linked polyethylene produced using peroxide as the initiator of the "curing" (cross-linking) reaction. An older, slower process requiring application of heat (steam jackets). Also known as continuous vulcanization.
Peroxy-type bleaches	Any bleaching agent containing the peroxy structure ("O-O-"), which provides a powerful oxidizing site.
Pesticides	A general term to describe all materials used for control of plant and animal pests. Includes herbicides, insecticides, and fungicides.
Plasticizers	Additives which are used to soften and make the compounds of inherently rigid resins more flexible. Flexible PVC is compounded with plasticizers such as adipates and phthalates.

Term	Definition
Plastisol	Liquid dispersion mixtures of fine particle-size polymers (often PVC) in plasticizers and organic solvents.
Polar	The property of a molecule where there is a strong concentration of electrons around one atom and a deficit at other atoms. Highly polar solvents are usually strong solvents due to these electronegative forces.
Polychloroprene	$(H_2C:CHCl:CH_2)_n$ A highly resilient type of elastomer resistant to oils, solvents, heat and weather, based on the polymerization of chloroprene.
Polyethylene (PE)	$(C_2H_4)_n$ The most common synthetic thermoplastic resin, derived from the polymerization of ethylene.
Polyethylene terephthalate (PET)	$(COC_6H_4COOCH_2CH_2O)_n$ A polyester resin derived from ethylene glycol and terephthalic acid used for oriented films, molding and fibres.
Polymerization	A chemical reaction which creates long chain molecules (polymers) from small reactive organic molecules (monomers).
Polyol	A chemical with more than one hydroxyl (-OH) group attached. The multiple groups are reactive sites which help form molecular networks.
Polyolefin	Blends of olefinic thermoplastics such as polyethylene and polypropylene.
Polypropylene	$(C_3H_6)_n$ A common synthetic thermoplastic resin derived from the polymerization of propylene.
Polyurethane slabstock foam	A flexible polyurethane foam made from the reaction of a diisocyanate, polyol and water, which is cut into slabs for use in bedding and furniture.
Polyvinyl chloride (PVC)	$(C_2H_3Cl)_n$ A common, low-cost synthetic thermoplastic resin derived from the polymerization of vinyl chloride monomer.
Polyvinylidene chloride (PVdC)	$(CH_2CCl_2)_n$ A polymer derived from the polymerization of vinylidene chloride monomer having superior barrier properties and high chemical resistance.
Primary treatment	Coarse screening and filtration to remove solids in water treatment.
Private label	An unbranded product supplied by manufacturers and sold without advertising support by retailers.
Pulping	A process in which wood is cooked under controlled conditions of temperature, pressure, time and chemicals to produce fibres (pulp).
Recausticization	The regeneration of caustic soda from the sodium carbonate present in the chemical residue of a pulp mill recovery furnace by the addition of lime.
Refrigerants	Working fluids used in the vapour compression cycle of refrigeration, air conditioning and heat pumping equipment.
Reinforced concrete pipe	Concrete pipe reinforced with lattice of steel rods to provide strength.
Relative humidity	The amount of water vapour in air divided by the maximum amount of water vapour that can be held by that air at that temperature. Expressed as a percentage.
Resin	The pure form of a polymer.
Salt cake	(Na_2SO_4) The common name of sodium sulphate.
Sanitary sewer	Gravity drained pipe carrying dirty water waste from kitchen and bathroom use.
Saponifiers	Aqueous alkaline solutions (usually sodium hydroxide) which react with esters of fatty acids to produce soaps.
Secondary treatment	Bio-oxidation process using activated sludge (micro-organisms) in a aeration tank to break down organic matter in wastewater.

Term	Definition
Semi-aqueous cleaning	The combination of aqueous cleaning solutions with an emulsification of solvents.
Sequestering agents	Chemicals which combine with a metallic ion to prevent usual precipitation reactions. Phosphates and ethylenediaminetetracetic acid (EDTA) are examples.
Short chain chlorinated paraffins	A class of chlorinated paraffins with molecules ranging from 9 to 13 carbons, used commonly for flame retardant metal working fluids.
Sizing chemicals	Materials such as starch, gelatin, oil or wax applied to yarns, fabrics, paper or other products to improve their strength, stiffness or smoothness.
Soda ash	(Na_2CO_3) The common name for sodium carbonate, used to prepare chemical caustic.
Sodium chlorate	(NaClO_3) A salt produced from electrolysis of concentrated sodium chloride in acid, which is used to generate chlorine dioxide at pulp mills.
Sodium hypochlorite	(NaClO) Bleaching agent used in aqueous solution for household and industrial cleaning. Commonly known as "bleach".
Sodium perborate	($\text{NaBO}_3 \cdot 4\text{H}_2\text{O}$) Bleaching agent used in textile bleaching, household bleaches and detergents.
Sodium percarbonate	(Na_2CO_4 or $\text{Na}_2\text{C}_2\text{O}_6$) A source of hydrogen peroxide. Decomposes in aqueous solution to hydrogen peroxide and sodium carbonate.
Soffit, fascia, rainware	Sheet material used for roof overhangs, eaves, and downspouts.
Solubility	The relative ability of a compound to dissolve in a liquid.
Stabilizers	A substance which makes a substance, solution, mixture more stable by retarding the decomposition reaction rate or preserving equilibrium.
Steel pickling	The use of an acid to remove corrosion from the surface of metal prior to finishing.
Storm sewer	Open source gravity drained pipe carrying rain runoff from open areas.
Subdistributors	Companies which source products from distributors to supply certain smaller regions or niches of the market.
Sulphate process	1. Another term for the kraft pulping process. 2. The process of extracting and purifying titanium dioxide from ilmenite ore using sulphuric acid to produce a titanium sulphate intermediate.
Sulphite (pulp, mills)	A pulping process using an acidic environment, where the cooking liquor contains sulphurous acid and bisulphite.
Sulphuric acid	(H_2SO_4) A powerful inorganic acid often used to extract metals from ores and clean metal surfaces.
Surface disinfecting	The use of a bleaching agent to kill germs on surfaces.
Surfactant	An abbreviation for "surface active agent". Any compound that reduces surface tension between two phases. Often applied to sodium salts of high molecular weight alkyl sulfates or sulfonates.
Tapping	Installation of a side connection to the wall of an operating pipe.
Tensile strength	The essential single indication of strength by the measurement of force required to break the material. For pipe, the ability to resist the forces caused by internal hydrostatic pressure and water hammer. For wire and cable, the ability to resist stretching.
Terpene	($\text{C}_{10}\text{H}_{16}$) An unsaturated organic compound derived from most the oleoresins of plants and commonly occurring in essential oils.
Terpineol	($\text{C}_{10}\text{H}_{17}\text{OH}$) A solvent used for resins, gums, waxes, oils and other products.

Term	Definition
Tertiary treatment	The application of chlorine or other oxidizing agent to wastewater effluent for final oxidation of residual organic matter.
Tetrachloroethylene	(C ₂ Cl ₄) The common chlorinated dry cleaning solvent, also used in vapour degreasing. Commonly known as perchloroethylene.
Thermal efficiency	The overall heat insulation property of windows.
Thermoplastic	The term applied to resins that can be softened and melted with heat and which regain their original structure upon cooling.
Thermoplastic elastomer	A family of polymeric materials which combine the processability of thermoplastics (plastic) with the functional performance of thermoset elastomers (rubber).
Thermoplastic olefins (TPOs)	One type of thermoplastic elastomer which combines blends of polyolefins with an olefinic elastomeric component. The most common types are blends of polypropylene with ethylene-propylene-diene rubber.
Thermoplastic urethanes (TPUs)	One type of thermoplastic elastomer which combines the tough thermoset polyurethane structure with thermoplastics.
Thermoset	Term applied to resins that set (bond) upon heating and cannot be remelted.
Titanium dioxide	(TiO ₂) A white inorganic mineral pigment used in paints, plastics, and paper.
Total chlorine free pulp (TCF)	Pulp produced using no chlorine in the bleaching process.
Toxic (CEPA)	The definition applied to substances on the Priority Substances List under section 11 of the CEPA if they are determined to be harmful to the environment or constitute a danger to human health.
Toxic Substances Management Policy	The June 1995 federal policy outlining the framework for management of toxic substances. The key objectives are i) the virtual elimination from the environment of persistent and bioaccumulative toxic (Track 1) substances; and ii) the life-cycle management of other (Track 2) substances to prevent or minimize their release to the environment.
Trade balance	The value of exports minus the value of imports.
Trichloroethylene (TCE)	(CHCl:CCl ₂) A common chlorinated solvent used for vapour degreasing.
Trona	A mineral deposit containing a high purity of sodium carbonate (soda ash).
Tuberculation	Formation of corrosion and scale deposits on metal surface blemishes.
UV radiation	The application of ultra-violet light to wastewater for disinfection.
UV stabilizers	Polymer resin additives which trap free radicals (reactive molecules) created by photo-oxidation and retard the photodegradation process.
Vapour degreasing	The process of cleaning oils and dirt from metal parts by immersing them in the vapour space of a boiling solvent in an enclosed space, where the solvent condenses on the metal surface and removes contaminants.
Vinyl chloride monomer (VCM)	(C ₂ H ₃ Cl) An intermediate chemical derived from ethylene dichloride that is used to produce polyvinyl chloride. A PVC precursor.
Volatility	The relative tendency of a chemical to vapourize. Generally, smaller molecules have a higher volatility.
Watermain	Pressurized water distribution pipe.
Wet cleaning	Cleaning with water. The use of aqueous solutions of soaps and detergents to clean fabrics. Alternative to dry cleaning.
Window profiles	Linear extruded components used in the fabrication of window frames.
Wire	A conductor surrounded by insulation and often some jacketing.