ECONOMIC INSTRUMENTS

for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes Basin

International Joint Commission
Commission mixte internationale

ECONOMIC INSTRUMENTS

for the virtual elimination of persistent toxic substances in the Great Lakes Basin

Printed in Canada
on Recycled Paper

December 1994

Hickling Report 4839-5
170 Bloor Street West #704
Toronto, Ontario M5S 1T9
Telephone: 416 928 2820
(10 February 1994)

International Joint Commission

Windsor

ISBN 1-895085-82-9

DISCLAIMER

This report to the Chairpersons of the Virtual Elimination Task Force and the International Joint Commission was carried out as part of the activities of the Task Force's Economic Subgroup. It was jointly funded by Environment Canada, MOEE, and U.S. E.P.A., with the Commission providing secretariat and project management support.

The specific conclusions and recommendations do not necessarily represent the views of the International Joint Commission, the Virtual Elimination Task Force, or the funding agencies.

Table of Contents

List of Figures iv
List of Tables iv
Preface v
Executive summary vii
Abbreviations x

1. **Introduction** 1
1.1 Persistent toxic substances in the Great Lakes Basin 1
1.2 Virtual elimination 1
1.3 A program of economic instruments 2
1.4 Approach of this report 3

2. **Sources of persistent toxic substances to the environment and control technologies** 5
2.1 Sources of persistent toxic substances 5
2.2 Alternative technologies and processes 7

3. **Overview of economic instruments** 9
3.1 Types of economic instrument 9
3.2 Criteria for assessment 12
3.3 Practical experience with economic instruments 13
3.4 Objections to economic instruments 14
3.5 Implementation 15
3.6 Approach of this study 16

4. **Persistent toxic substances from incineration** 18
4.1 Incinerators and emissions 18
4.2 Alternative technologies and processes 19
4.3 Policy instruments 19
4.4 Program design 21
4.5 Impact assessment 24

5. **Persistent toxic substances and polyvinyl chloride** 30
5.1 PVC production and use 30
5.2 Alternative technologies and processes 32
5.3 Policy instruments 32
5.4 Program design 32
5.5 Impact assessment 35

6. **Conclusions and recommendations** 39

7. **References** 41

Appendices:

A **Information and voluntary programs** 49
A.1 Canadian programs affecting persistent toxic substances in the Great Lakes basin 49
A.1.1 Environmental Choice Program 49
A.1.2 Canada's Green Plan 49
A.1.3 Ontario's Pollution Prevention Pledge Program 49
A.2 United States programs 50
A.2.1 Industrial Toxics Project (33/50 Program)

B **Overview of regulations** 51
B.1 A synopsis of regulations 51
B.2 Canadian regulations 52
B.2.1 Federal 52
B.2.2 Provincial 53
B.3 United States regulations 53
B.3.1 Federal 53
B.3.2 State 55

C **Sources of persistent toxic substances** 56
C.1 Mercury 56
C.2 Hexachlorobenzenes 66
C.3 Polychlorinated biphenyls 70
C.4 Dioxins and furans 80

D **Incineration in the Great Lakes basin - Action summary sheets** 91

E **Polyvinyl chloride in the Great Lakes basin - Action summary sheets** 109

F **Environmental equivalences of persistent toxic substances considered** 131

List of Figures

Figure 1 Mercury discards in the United States municipal solid waste stream (tonnes) 19
Figure 2 Incremental costs of achieving reductions in emissions from incinerators 26
Figure 3 Revenues from a tax on PTSs emissions from incinerators 26
Figure 4 Incremental costs of achieving reductions in PVC use 37
Figure 5 Revenues from a tax on PVC use 37

Figure C-1 The uses and fates of mercury 57
Figure C-2 The creation and fate of Hexachlorobenzenes (HCBs) 66
Figure C-3 The sources and fates of Polychlorinated biphenyls (PCBs) 70
Figure C-4 Sources and fates of dioxins and furans 80
Figure C-5 Sources and fates of PCPs 81

List of Tables

Table 1 Short list of actions to virtually eliminate PTSs in the Great Lakes Basin 8
Table 2 Effectiveness and costs of actions for reducing PTSs from incinerators 20
Table 3 Sequence of tax increments and progress towards virtual elimination 21
Table 4 Incinerator actions ordered by source and economic attractiveness 25
Table 5 PVC production in the Great Lakes Basin, 1992 31
Table 6 PVC demand and chlorine use in the Great Lakes Basin, 1992 31
Table 7 Sequence of tax increments and progress towards virtual elimination 33
Table 8 Economic statistics and estimates for PVC fabrication plants 35
Table 9 Economic statistics and estimates for PVC fabrication plants 37

Table C-1 Mercury consumption in the United States 56
Table C-2 Disposal and emissions of mercury in the Great Lakes Basin 58
Table C-3 Quantities, fates, market trends and technologies for major sources of mercury 59
Table C-4 Examples of voluntary programs to reduce mercury releases to the environment 64
Table C-5 Canadian regulations affecting mercury use or disposal 65
Table C-6 United States regulations affecting mercury releases to the environment 65
Table C-7 HCB emissions from contaminated pesticides 67
Table C-8 HCB effluent emissions in Ontario (1989-1990) 67
Table C-9 Quantities and fates, market trends and technologies for HCBs 68
Table C-10 Ontario PCB quantities in storage - October 1991 71
Table C-11 Ontario Hydro inventory of PCBs in-use and in storage 72
Table C-12 Summary of PCB quantities by source for Ontario and the United States 73
Table C-13 Sources of PCB emissions to air 74
Table C-14 Quantities, fates, market trends and technologies for major sources of PCBs 75
Table C-15 Example of voluntary programs to reduce mercury PCB releases to the environment — Ontario Hydro's plans 78
Table C-16 Canadian regulations affecting PCB use or disposal 78
Table C-17 Subjects covered in U.S. Regulations for PCBs 79
Table C-18 Total PCDD emissions to the air in Ontario for point, area and open sources and sector rank 82
Table C-19 Total PCDF emissions to the air in Ontario for point, area and open sources and sector rank 83
Table C-20 Effluent sources of dioxins and furans from the organic chemical manufacturing sector 84
Table C-21 Estimate of annual production of PCDD/F by incinerators in the United States 85
Table C-22 Fates, quantities, market trends and technologies for PCDD/Fs 86
Table C-23 Canadian regulations affecting dioxins and furans 89

Preface

This report presents the findings from a project undertaken for the Economic Subgroup of the Virtual Elimination Task Force of the International Joint Commission (IJC). This preface is intended to set the context within which this work fits.

The report builds on earlier work on economic instruments commissioned by the Economic Subgroup (VHB 1991), and assessments of environmental and scientific issues, and their causes. From that earlier work, the Subgroup decided to investigate in greater detail economic instruments for mercury and chlorinated organics.

Chlorinated organics are a diverse group of compounds making up a significant portion of the lists of priority persistent toxic substances prepared by numerous government agencies. On the one hand, it is difficult to assess these as a group because of the vast reaches in society they extend to, and widely varying toxicological, commercial, and chemical properties. On the other, they are connected by their common use of chlorine as a chemical building block, with its high electron affinity which makes it easy to react with electron-rich atoms, including carbon. These two "hands" have become the focus of a growing policy debate as some argue that dealing with individual compounds is too dangerous because there are so many, and their reactions with the environment are not well understood and others assert that dealing with them as a group leads to painting safe and useful compounds with the same brush as environmentally destructive ones, possibly leading to economic *and environmental* costs (Amato 1993).

The IJC is committed to the principle of "pollution prevention" and the necessity of looking at the whole life-cycle of products and their constituents to design effective policies for intervention. Based on its review of the chlorine policy debate, the Commission has recommended that "the Parties, 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 mans of reducing or eliminating other uses be examined" (IJC 1992).

Within this context, this project was initiated, and began with an analysis of sources and technologies for moving towards virtual elimination of mercury and four chlorinated organics: polychlorinated biphenyl (PCB), polychlorinated dibenzo-*p*-dioxin (PCDD), polychlorinated dibenzofuran (PCDF), and hexachlorobenzene (HCB).

Based on this context and the problem analysis, four options with different objectives were presented to the steering committee for consideration, and selection for further analysis:

- a comprehensive package of measures for a single contaminant
- selected measures for major sources
- demonstration of a range of instruments
- measures offering the quickest opportunities for success

After reviewing these options, the problem analysis, and the scope of the project, the Committee, in consultation with the project team, decided to focus on measures that address two specific case studies:

- input taxes (or permits) on chlorine used in polyvinyl chloride (PVC) production, and
- emission fees or discharge taxes levied on incinerators.

The PVC industry is the largest user of industrial chlorine, and PVC manufacturing and disposal has been connected to dioxins and furans, hexachlorobenzene and other chlorinated organics, and heavy metals. Incinerators are significant sources of mercury and chlorinated organics, including dioxins and furans. Both of these sources are growing in the Great Lakes Basin.

In conducting this study, we relied on the patient support of many people. In particular, this work benefited from comments provided by members of the Economic Sub-group of the Virtual Elimination Task Force, specifically: Peter Boyer (International Joint Commission), Jack Donnan (Ontario Ministry of the Environment and Energy), Bob Greene (United States Environmental Protection Agency), Judy Hull (Environment Canada), Tom Muir (Environment Canada), Dale Phenicie (Georgia Pacific Corporation), Ray Rivers (Environment Canada), Don Tate (Environment Canada) and Angela Zeiler (Environment Canada). The study team also thanks other members of the steering committee for their input, comments and suggestions throughout the course of the product: David Campbell

(National Wildlife Federation), Laura Cornwell (United States Environmental Protection Agency), Arthur Sheffield (Environment Canada), Bill Smith (Environment Canada), Geoffrey Thornburn (International Joint Commission) and Eva Voldner (Environment Canada). Finally, the study team especially thanks Peter Boyer (International Joint Commission) who served as the project manager for the study. Errors and omissions are the responsibility of the study team.

The project team also received helpful comments at various stages from Erik Haites of Barakat and Chamberlin, and Joel Smith of RCG Hagler-Bailly.

Members of the project team included David Heeney, Peter Stokoe, Murray Trott, and Usman Valiante (Hickling Corporation); John Palmisano; and Liz Nixon (ICF Resources Inc). During early stages of the project, research assistance was also provided by Jessica Campbell, Janet Friday, Evelyn Nepom, and Adam White.

Executive summary

Virtual elimination of persistent toxic substances (PTSs) is one of the cornerstones to achieving the Great Lakes Water Quality Agreement's (GLWQA) goal to "restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem" (Article II).

The goal of virtual elimination involves a large set of compounds, including heavy metals and toxic and persistent organic compounds. Of the heavy metals, mercury and alkylated lead are a particular concern. Of the organic compounds, many of the critical PTSs are chlorinated; the International Joint Commission's (IJC) Water Quality Board found that approximately half of the 362 chemicals confirmed to be present in the water, sediment or biota of the Great Lakes Basin Ecosystem are synthetic chlorinated organic substances, and many of these are expected to be persistent toxics.

An Economic Subgroup of the Virtual Elimination Task Force was established to assess the role that economic instruments or incentives can play in achieving virtual elimination.

This report responds to a request of the Subgroup to develop a program design for the use of economic instruments that together with the existing regulatory framework would implement the policy of virtual elimination.

Purpose of study

The report considers selected persistent toxic substances from the IJC's critical pollutants list: mercury, dioxins and furans (2,3,7,8 TCDD and 2,3,7,8 TCDF), hexachlorobenzene, and polychlorinated biphenyls (PCBs). These were selected to cover the spectrum of potential release pathways and production practices for PTSs. For example, some are in production, some are not; some are released from area sources, some from point sources; some are products, some are inadvertent by-products or contaminants.

For each contaminant considered, the major sources are identified based on a review of the literature and consultation with experts in government and industry. Market trends, regulatory initiatives and other programs that will affect future releases are reviewed, and major opportunities for changes in products or processes are identified.

To assess the potential for applications of economic instruments, three programs are considered:

- a program of economic instruments (applied to emissions of PTSs from municipal solid waste incinerators, and to inputs of chlorine used in the production of polyvinyl chloride (PVC))
- a program of regulatory instruments (prescribing a specific technology for the reduction of emissions from incinerators and from the production, use and disposal of PVC)
- a pollution prevention program (information, moral suasion and voluntary programs to reduce emissions from incinerators and from the production, use and disposal of PVC)

Based on cost effectiveness functions ("least cost curves"), the three programs are assessed for both flows of PTSs from incinerators and chlorine use in PVC manufacturing.

For both sources of PTSs the following are considered:

- sources
- alternative technologies and processes
- policy instruments that will complement the existing regulatory framework to achieve virtual elimination
- economic and financial impacts to those sectors or individuals that would be most affected by the implementation of the program

The criteria for assessing economic instruments among environmental policy instruments used in this study are:

- environmental effectiveness of the policy in achieving virtual elimination
- economic efficiency of the policy's contribution to achieving the optimal allocation of resources;
- equity of a policy instrument on the distribution of costs and benefits
- administrative feasibility and costs to monitor and enforce compliance with a policy instrument
- acceptability to stakeholders.

Main findings

The information collected on sources is sufficient to categorize sources of PTSs by emission type and quantity. However, the origins and fates of PTSs are not well documented, and what data exist cover only selected stages of the life-cycle and specific sources. Several types of regulations affect the PTSs considered, including bans on production of PCBs, environmental discharge criteria, and technology prescriptions. No regulations explicitly enable or prohibit the use of economic incentives for these PTSs.

The major points of mercury emissions into the environment are from incineration, smelting, fossil fuel use (particularly coal and oil), chlor-alkali production and paint volatilization. The major sources of mercury to incinerator feedstock include batteries, control instruments and electrical equipment, STP sludge and sludge collected in stacks. Incineration as a method of waste management appears to be increasing in the United States (new facilities are not permitted in Ontario). Mercury emissions from fossil fuel combustion are significant and growing, while releases from paint application and chlor-alkali production are declining.

The major sources of PCBs are sediments and transformer leakage. Thermal power generation is expected to grow modestly over the next decade. The quantity of PCBs in use will decline, but transformers using PCBs will be older and the net effect on leakage rates is unknown.

PCDDs and PCDFs come from a wide variety of sources, but major sources are waste incineration and pentachlorophenol (PCP). Pentachlorophenol use is declining.

The major sources of hexachlorobenzenes are incineration and chlorinated solvents and pesticides. Use of chlorinated solvents and pesticides is in decline.

Better monitoring of releases is an essential part of any program of economic instruments, but reasonable conclusions about major sources can be drawn from the available data.

The emphasis of much of the regulatory effort is on technology approvals; this emphasis creates no incentive for source reduction and is unlikely to result in virtual elimination of the PTSs considered. However, the regulations do not prohibit the use of economic instruments that could promote source reduction.
The sources of PTSs which are increasingly significant are:

- incinerators, particularly in the United States where their use is growing (Hg, PCDD/F, HCB)
- fossil fuel use, and particularly coal (Hg, PCBs)
- sediments and old landfills (Hg, PCBs, PCDD/F)
- leaks from PCB containing transformers and (in Ontario) storage

The review of emissions of persistent toxic substances from incinerators indicated that there are a range of actions that can lead to reductions and ultimately elimination of these emissions. The least expensive of these are reductions in mercury in consumer products, followed by retrofitting pollution control equipment, and ultimately substituting other waste management technologies for incineration. The latter have difficulty competing for existing market share because incinerators are very capital intensive, and the costs of changing to other waste management technologies are relatively high.

The analysis of input charges or marketable permits identified substitutes available for PVC. Some of these would appear to result in reduced costs, whereas in others the cost of the substitutes is higher. To the extent that innovation leads to the development of new substitutes less expensive than existing substitutes, the estimated cost of virtual elimination are overstated.

Consultation with stakeholders for both programs indicated that there was no consensus on either the need for achieving virtual elimination, nor on the preferred policy instrument to be used.

Recommendations and conclusions

Based on these analyses, six recommendations are advanced:

Recommendation 1

The Parties to the Great Lakes Water Quality Agreement continue and expand support for voluntary programs to reduce releases of persistent toxic substances.

Many actions can achieve significant reductions in releases of persistent toxic substances at no or low cost. These include reducing the mercury content of products, and source separation programs for mercury containing products. Using voluntary programs for these is likely to be broadly acceptable and relatively easily implemented. Voluntary programs for reduction of PVC use could lead to significant reductions also, but will not likely lead to virtual elimination.

Recommendation 2

The International Joint Commission continue to promote understanding of the rationale for action.

The rationale for action to virtually eliminate persistent toxic substances, including those associated with municipal waste incineration and polyvinyl chloride's life-cycle, are generally not known, understood or accepted by stakeholders outside government and environmental non-government organisations. If the objective is rapid action, then these stakeholders will need to be involved in the process, and will need to understand the rationale for changes in processes or products.

Recommendation 3

The International Joint Commission encourage the Parties to promote research and development, and continue to monitor progress in understanding the relationship between various policy alternatives and releases of persistent toxic substancess to the environment.

There are many uncertainties that complicate an assessment of all the policy instruments, both scientific and behavioural. For example, on the scientific side, the incineration process and the generation and destruction of PTSs is not fully understood. Monitoring of emissions is difficult and there are not widely accepted models relating persistent toxic substance emissions and operating parameters that can be easily monitored. There are conflicting scientific reports on the importance of waste characteristics (e.g. plastic content) on formation of various products of incomplete combustion, including dioxins and furans. Further, there is a general lack of understanding of environmental implications of substitute processes.

On the behavioural side, motivation for participation in voluntary programs is not well understood, nor are some of the institutional and other non-economic considerations that affect technology choices.

Recommendation 4

The International Joint Commission and the Parties continue research on the effects of economic instruments on achieving the goal of virtual elimination.

There is limited knowledge and understanding of the impacts and effectiveness of economic instruments to virtually eliminate persistent toxic substances. If the objective is rapid action, further research is required to improve our understanding of the relationship between different economic activities and the release of PTSs to the environment. Analyses of potential advantages and disadvantages of a range of policy instruments can improve understanding of these, and facilitate their adoption once commitment is reached on the policy objectives.

Recommendation 5

The International Joint Commission promote the formation of a forum for coordinating policies across jurisdictions.

The problems associated with persistent toxic substances cannot be seen as local problems amenable to local solutions. Although the International Joint Commission's activities can help meet the need such a forum addresses, the policy initiatives will likely be required at the continental and global level, not just those jurisdictions in the Great Lakes Basin.

Recommendation 6

The International Joint Commission encourage Parties to the Great Lakes Water Quality Agreement to adopt pilot programs to test economic instruments.

There are potential advantages to using properly designed economic instruments to achieve virtual elimination, but there is limited understanding of these by stakeholders, and limited practical experience. Pilot programs would facilitate understanding, and provide empirical data on the environmental and cost effectiveness of economic instruments, relative to alternative policy approaches.

A system of emissions taxes could be effective in encouraging adoption of improved pollution control equipment, and would ensure that incineration facilities are operated properly. This is important because operating conditions have a significant affect on emissions. To date there has been limited experience with economic instruments and much of the arguments surrounding effectiveness or lack thereof are based on ideology, not experience. Exclusive reliance on a command and control approach with a ban on incinerators as a final step could achieve virtual elimination, but would be inflexible, and hence subject to resistance and delay.

An input tax on chlorine use for PVC production is likely to reduce, and eventually eliminate, the fabrication of products containing PVC. A pilot program, based on an input tax on chlorine, would provide practical information and experience on the usefulness, design, and effect of using economic instruments to achieve the virtual elimination of PTSs. The results of the pilot program could facilitate the adoption of economic instruments for eliminating all uses of chlorine and emissions of PTSs. A command and control approach with a ban on chlorine use as a final step could achieve virtual elimination, but possibly at a higher cost to producers and society. A pilot program using an economic instrument permits a more thorough comparison of the relative effectiveness of economic instruments in reducing environmental impacts.

Abbreviations

a - the Système internationale d'unites (SI) symbol for year
AOX - Adsorbable Organic Halide
BACT - best available control technology
BAT - best available technology
CAA - Clean Air Act
CEPA - Canadian Environmental Protection Act
CFC - chlorofluorocarbon
CFR - Code of Federal Regulations
DCPA - dimethyl tetrachlorotere-2,3,5,6-tetrachloro-1,4-benzenedicarboxylate
DI - ductile iron
DSI/FF - dry scrubber injection/fabric filters
EJ - exajoules (10^{18})
EPA - Environmental Protection Agency
EQU - equivalent units
ESPs - electrostatic precipitators
FIFRA - Federal Insecticide, Fungicide and Rodenticide Act (1984)
gE - grams equivalent
GLCPA - Great Lakes Critical Programs Act (1990)
GLWQA - Great Lakes Water Quality Agreement
GNP - Gross National Product
H6CDD - hexachlorodibenzo-p-dioxin
H6CDF - heptachlorodibenzofuran
H6CDF - hexachlorodibenzofuran
H7CDD - heptachlorodibenzo-p-dioxin
HCB - hexachlorobenzene
Hg - mercury
IJC - International Joint Commission
IRR - Institute for Risk Research
ITP - Industrial Toxics Project
kt/a - kilotonnes/year
M - the SI symbol for mega, or 10^6
(e.g. M$ = million dollars)
MCL(s) - maximum contaminant level(s)
mg - milligrams
MISA - Municipal Industrial Strategy for Abatement
MOE - Ontario Ministry of the Environment (now MEE)
MPU - mobile processing units (Ontario Hydro)
MSW - municipal solid waste
MSWI - municipal solid waste incinerator
Na_2S - sodium sulphate
NAAQS - National Ambient Air Quality Standards
NESHAPs - National Emission Standards for Hazardous Air Pollutants
NO_x - nitrous oxides
NPDES - National Pollutant Discharge Elimination System
NSPS - New Source Performance Standards
OECD - Organization for Economic Cooperation and Development
OEPA - Ontario's Environmental Protection Act
OMEE - Ontario Ministry of the Environmental and Energy (formerly OMOE)
OMEE - Ontario Ministry of the Environment (prior to 1992)
ORTECH - formerly, Ontario Research Foundation
OTA - Office of Technology Assessment
P^4 - Ontario's Pollution Prevention Pledge Program
PCB - polychlorinated biphenyls
PCDD - polychlorinated dibenzodioxins
PCDF - polychlorinated dibenzofurans
PCNB - pentachloronitrobenzene
PCP - pentachlorophenol
PCPA - Pest Control Products Act
perc - perchloroethylene
pg/L - picograms/litre
PPA - Pollution Prevention Act (1990)
ppb - parts per billion
ppm - parts per million
ppq - parts per quadrillion
PTS(s) - persistent toxic substance(s)
PVC - polyvinyl chloride
RCRA - Resource Conservation and Recovery Act (1986)
RDF - residue disposal facility
SD/FF - spray dry/fabric filters
SI - Système internationale d'unites (metric system)
SIP - State Implementation Plans
STP - sewage treatment plant
SO_2 - sulphur dioxide
t - tonne (1,000 kilograms)
TCDD - tetrachloro-p-dibenzodioxin
TCDF - tetrachlorodibenzofuran
TCE - trichloroethylene
tE - tonnes equivalent (see Appendix F)
33/50 Program - Industrial Toxics Project (United States)
TRI - Toxics Release Inventory
TSCA - Toxics Substances Control Act
U.S. DOE - United States Department of Energy
U.S. EPA - United States Environmental Protection Agency
U.S. OTA - United States EPA's Office of Technology Assessment
VCM - vinyl chloride monomer
VE - virtual elimination
VETF - Virtual Elimination Task Force of the IJC
VOC - Volatile Organic Carbon

1. Introduction

1.1 Persistent toxic substances in the Great Lakes basin

The development of human activities and technological capabilities in the Great Lakes basin and elsewhere has increased the production and release, or enhanced the environmental availability, of many substances that are toxic and persist in the environment. Over the past forty years, there has been mounting evidence (IJC 1992) of the detrimental effects on ecosystem and human health of many of these persistent toxic substances (PTSs).

Levels of some PTSs emitted to the environment and present in birds and fish have decreased substantially since the high values reported in the 1970s. However, levels have plateaued since the early 1980s, indicating continued chemical input to the Great Lakes basin. The effects of these contaminants is only beginning to be understood, and significant biological and ecological effects are suggested (Environment Canada, Fisheries and Oceans, and Health and Welfare Canada 1991):

- there is good circumstantial evidence that contaminants were involved in the mass mortality of developing lake trout embryos in Lake Michigan during the early 1980s
- the geographic distribution of liver tumours in brown bullheads and white suckers, combined with laboratory studies, strongly suggests that these tumours are caused by environmental chemicals
- eleven wildlife species in the Great Lakes basin have experienced reproductive and other problems attributable to chemical contamination
- wildlife studies have shown that developmental and reproductive effects can occur in a wide range of species, including birds, reptiles, fish and mammals exposed to mixtures of contaminants in the Great Lakes basin.

On the basis of this evidence, the United States and Canada have adopted as policy, through the 1987 amendments to the Great Lakes Water Quality Agreement (GLWQA), that "the discharge of any or all persistent toxic substances be virtually eliminated" (United States and Canada 1987). The Agreement further specifies that "the philosophy adopted for control of inputs of persistent toxic substances shall be zero discharge" (United States and Canada 1987).

1.2 Virtual elimination

The International Joint Commission has been given responsibility by the United States and Canada (as the Parties to the GLWQA) to provide analysis and advice on Great Lakes water quality and on implementation of the Agreement. Based on the evidence that many of the persistent toxic substances entering the Great Lakes Basin Ecosystem are chlorinated organic compounds that are produced intentionally or unintentionally through the use of chlorine and its compounds in manufacturing processes, the Commission has recommended that "the Parties, in consultation with industry and mother 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" (IJC 1992).

Article II of the *Great Lakes Water Quality Agreement* (as amended 1987) states as policy of the United States and Canada that:

> "The discharge of toxic substance in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated."

As observed by the Virtual Elimination Task Force of the IJC (1991):

> "The policy goal of virtual elimination applies to the *presence* of persistent toxic substances in the Great Lakes Basin Ecosystem."

Virtual elimination is one of the cornerstones to achieving the Great Lakes Water Quality Agreement's goal to "restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin Ecosystem" (Article II). The Virtual Elimination Task Force of the International Joint Commission (IJC) has drawn conclusions about the approach to virtual elimination that inform the analyses in this report (IJC 1991):

- particular attention is required for substances that are **persistent**
- virtual elimination is an overall strategy that will require preventative approaches for some sources and remedial approaches for others

- virtual elimination must apply to all sources, including both point and non-point sources
- virtual elimination involves not just new sources, but also eliminating persistent toxic substances already present in the Great Lakes Basin Ecosystem
- the strategy is a challenge to continuously strive to eliminate the amount of persistent toxic substances entering the environment

The goal of virtual elimination of persistent toxic substances involves an extensive set of compounds, including heavy metals and toxic and persistent organic compounds. Of the heavy metals, mercury is a particular concern, along with alkylated lead. Of the organic compounds, many of the critical PTSs are chlorinated; the IJC's Water Quality Board found that approximately half of the 362 chemicals confirmed to be present in the water, sediment or biota of the Great Lakes Basin Ecosystem are synthetic chlorinated organic substances, and many of these are expected to be persistent toxics.

In 1985, the Water Quality Board identified eleven critical pollutants that cause detrimental effects on biota, human health or both and that are subject to regulation. The eleven critical pollutants are:

- Total polychlorinated biphenyls (PCB)
- DDT and metabolites
- Dieldrin
- Toxaphene
- 2,3,7,8 tetrachlorodibenzodioxin (2,3,7,8-TCDD)
- 2,3,7,8 tetrachlorodibenzofuran (2,3,7,8-TCDF)
- Mirex
- Mercury
- Alkylated lead
- Benzo(a)pyrene
- Hexachlorobenzene

The Virtual Elimination Task Force has concluded that these eleven critical pollutants are ideal candidates to determine why environmental levels remain elevated, and whether additional actions can be taken to virtually eliminate inputs (IJC 1991). Further, measures undertaken to virtually eliminate these PTSs are expected to be applicable to a larger set of substances of concern.

1.3 A program of economic instruments

In implementing any environmental protection policy, three crucial issues must be resolved (Power and Rauber, 1993):

1. "What level of environmental protection is desired in each particular location?"
2. "Who is going to pay the direct costs of achieving the targeted level of protection?"
3. "What policy tools will be used to achieve these levels and to impose the costs?"

In the present case, the first question is already answered by the policy adopted in the GLWQA: the desired level of environmental protection is virtual elimination of PTSs everywhere in the Great Lakes Basin Ecosystem.

The second question has not yet been answered explicitly for the policy of virtual elimination, but some guidance is offered by the Polluter Pays Principle recommended by the Organisation for Economic Cooperation and Development (OECD 1975)[1] to its member countries (which include the United States and Canada).

This study addresses the third question concerning policy tools. In particular, this study focuses on one *class* of policy tools, *economic instruments*, that might provide effective complementary means, in conjunction with regulatory and voluntary programs, toward virtual elimination of PTSs and sunsetting of chlorine and chlorine-containing compounds as an industrial feedstock. Among economic instruments, environmental taxes (or charges) and marketable allowance systems are considered as they might apply at two points in the generation and release of PTSs:

- the discharge of PTSs from incinerators
- the use of chlorine in the production of polyvinyl chloride (PVC).

The effects of different policy instruments are evaluated in terms of a range of currently feasible actions that they are likely to induce. The types of actions considered include those, such as product or process substitution

---

[1] Although it might also be considered to be fair, the Polluter Pays Principle is recommended by the OECD mainly on the grounds of economic efficiency. By imposing the costs of pollution abatement on polluters, the Principle provides a disincentive to pollution and polluting activities; it also tends to lead to the costs of pollution abatement (if not residual external costs) being passed along in the prices of goods and services, so that prices better reflect true costs, including environmental costs (as is conducive to economic efficiency). Another important consideration for the OECD in recommending the Polluter Pays Principle is to encourage countries to take the same approach, so that different approaches do not cause trade distortions: this is especially important in cases where two or more countries are major trading partners and are striving for a common environmental objective (as in the present case). If the distributional implications of the Polluter Pays Principle *by itself* are unacceptable in a particular case, it still may be possible to find a common approach for correcting these implications that does not defeat the purposes of the Principle.

and source separation of wastes, that are often cost-effective. In this way, the costs and impacts of programs for virtual elimination can be substantially reduced. One of the attractions of the use of economic instruments is that they can encourage development and application of the most cost-effective actions.

The assessment of economic impacts in this study encompasses direct impacts, but does not extend to macroeconomic impacts. To make confident predictions about macroeconomic impacts, it would be necessary to apply a macroeconomic model that accommodates the various possibilities of technological substitution and their implications. Precise descriptions of program options for virtual elimination should be established in consultation with policy-makers, so that the total impacts of the different options can be compared with such a model. In general, it would be expected that if an economic instrument program has less direct impact than a regulatory program, it would also have less total impact.

The absence of a full assessment of macroeconomic impacts is certainly crucial if such supporting analysis is considered essential to proceed with program implementation. Fortunately, economic instruments lend themselves to another approach: an economic instrument could be applied gradually, beginning at a low level (e.g. a low tax rate that is gradually increased). The impacts of this program could be monitored continuously. If it was felt that some impacts were becoming unacceptable as the program progressed, the program could be slowed until actions to mitigate the impacts were taken. Conversely, if no unacceptable impacts appeared, the program could be accelerated.

This study is a first step in an extensive process with many participants for instituting programs of economic instruments for virtual elimination. As described in the chapter on Next Steps, there are several stages in the creation of an environmental policy: 1) design or development, 2) implementation, 3) institutionalization, and 4) fine-tuning. The next step in design and development is to involve the regulatory agencies and personnel who would implement an economic instruments program. An Economic Subgroup of the Virtual Elimination Task Force was established to assess the role that economic instruments or incentives can play in achieving virtual elimination.

In consultation with the Economic Subgroup, an initial selection of persistent toxic substances for potential applications of economic instruments was made according to the following criteria:

- to provide the opportunity to exemplify the use of economic instruments that could be applied at various stages in the life–cycle
- to address processes and compounds which account for a significant portion of persistent toxic substances entering the Great Lakes Basin Ecosystem
- to make use of the best available data on sources and alternative processes or products to determine the projected impacts of economic instruments
- to exemplify the use of economic instruments to encourage source reduction.

Based on a consideration of these criteria the following compounds were selected for further analysis:

- mercury
- PCBs
- HCBs
- 2,3,7,8 PCDD and 2,3,7,8 PCDF.

Two specific *activities* contributing to these PTSs in the Great Lakes Basin Ecosystem were chosen to illustrate applications of economic instruments: municipal solid waste incineration (MCWI), and production and use of polyvinyl chloride (PVC). For each activity, the steps in the analysis are:

- to describe the nature and extent of the activity as a source of persistent toxic substances
- to identify alternative technologies and processes, applicable at stages throughout the life-cycle of products, that can reduce or eliminate the need for or production of persistent toxic substances
- to define, evaluate and recommend a range of effective economic instruments that will complement the existing regulatory framework or require further legislative initiatives to achieve virtual elimination
- to identify the economic and financial impacts to those sectors or individuals that would be most affected by the implementation of the program.

1.4 Approach of this report

1.4.1 Purpose

The purpose of the report is to design a program of economic instruments that together with the existing regulatory framework would implement the policy of virtual elimination. Three programs are considered, consistent with those outlined for this project by the

Steering Committee (Boyer 1993):

- a program of economic instruments (a tax on emissions of PTSs from MCWIs, and a tax on inputs of chlorine used in the production of PVC)
- a program of regulatory instruments (prescribing a specific technology for the reduction of emissions from incinerators and from the production, use and disposal of PVC)
- a pollution prevention program (information, moral suasion and voluntary programs to reduce emissions from incinerators and from the production, use and disposal of PVC)

Based on least-cost curves, the three programs are assessed for both flows of PTSs from incinerators and chlorine use in PVC manufacturing.

1.4.2 Scope of the analysis

The conclusions reached in this report are based on an analysis with the following components:

- Data on the sources and quantities of persistent toxic substances from incinerator and chlorine use in PVC production. Costs were obtained from the literature and from telephone interviews with industry and government representatives.
- An evaluation of the actions included in the analysis. For example, in the absence of institutional barriers, the effect of 3Rs programs is assumed to result in the adoption of all actions with an abatement cost of zero or less (e.g. source separation). The cost and effectiveness of a command and control program includes actions involving a traditional "bottom-of-stack" fix (e.g. new emissions control technology).
- An analysis of the policy programs based on the actions, sources and quantities identified in the Great Lakes basin. Estimates of the potential effectiveness of economic instruments, both at achieving abatement and for generating revenues are made. In the case of a tax, for example, those actions which reduce or eliminate emissions at lower cost than the tax can be expected to be adopted. Tax revenues are equivalent to the tax rate multiplied by the number of tonnes for which the costs of actions exceed the tax. At the limit, (or at the end of the program period when virtual elimination is required) the tax rate is higher than the unit rate of the most expensive action.
- The expected impacts of the three policy programs. A preliminary view of the acceptability of each program by stakeholders was gained from interviews with selected members of stakeholder groups.
- The implementation issues related to each policy program. The assessment of actions required multiple simplifying assumptions. These assumptions and their implications are discussed as part of the analysis of programs and evaluation of implementation aspects. They include such things as monitoring the effectiveness of each program, institutional constraints that discourage program adoption (e.g. split incentives), national or international jurisdictional barriers (rather than just regional action specific to the Great Lakes basin and others.

Details of the information used to estimate the costs of each action are provided in Appendix D and E. These actions and costs were used to develop least-cost abatement functions, and determine the actions and costs associated with the economic, regulatory and voluntary policy programs analyzed.

1.4.3 Types of actions

The following types of relevant alternative technologies and process changes to reduce and eliminate emissions of PTSs from the Great Lakes basin are assessed:

- source reduction — actions which reduce or eliminate the amount of a PTSs used in the production of products containing the PTSs (e.g. rechargeable batteries)
- product substitution — actions which propose the use of alternative products (e.g. mercury-free batteries) or materials (e.g. polyethylene piping)
- source separation — actions which focus on those waste types/feedstocks responsible for the largest proportion of environmental equivalency unit emissions from incinerators such as mercury in household batteries, electrical equipment and paint (McCorquodale *et al.* 1992a)
- source elimination — actions which eliminate sources of PTSs, including eliminating PTSs generated or used in the production process, pollution prevention actions such as recycling, reuse and best management practises, as well as changes in processing (e.g. incineration to landfill)
- pollution control — actions which apply are "bottom-of-stack" or "end-of-pipe" technologies which capture PTSs through: i) the installation of add on control technologies; ii) the improvement in the efficiencies of add on control technologies; or iii) the improvement in the operating conditions to improve incinerator combustion (e.g. incinerator pollution control technologies to reduce or eliminate PTSs in the flue gas).

2. Sources of persistent toxic substances to the environment and control technologies

This chapter reviews the sources and technologies for the five persistent toxic substances (PTSs) identified in Chapter 1: mercury, hexachlorobenzenes, polychlorinated biphenyls, dioxins and furans, and pentachlorophenols. The levels of these contaminants in the Great Lakes Basin Ecosystem are affected by the quantities released to the environment (loadings), which vary over time in response to market trends, technological change or substitution, and policy initiatives. Policy initiatives may include voluntary programs (like the 33/50 program in the United States or the P_4 program in Ontario), regulatory requirements (like the Canada *Environmental Protection Act*, or the United States *Clean Air Act*), or economic instruments such as deposit/refund systems, emissions trading programs or tax strategies.

A cursory overview of the major sources of PTSs and of the influences on them is presented below. Additional detail on sources, trends, policy initiatives, and technologies affecting these PTSs are appended.

2.1 Sources of persistent toxic substances

2.1.1 Mercury

The sources, uses and fates of mercury in the Great Lakes basin have recently been documented for the IJC (McCorquodale et al. 1992a). The major points of (uncontained) emissions to the environment are (in decreasing order of significance):

- paint volatilization
- air emissions and releases to land from smelting
- air emissions from fuel combustion, particularly oil and coal
- air emissions from incineration
- emissions to land from chlor-alkali plants
- air, water and land emissions from municipal and hazardous waste landfills
- land emissions from sewage treatment plants
- discharges to water from smaller sources, including catalyst, pharmaceutical, laboratory and fertilizer applications.

Emissions from the following sources have been and will continue to decline: paint volatilization; chlor-alkali; and control instruments and other electrical instruments. Demand for non-ferrous metals, and hence mercury emissions from smelting are predicted to remain relatively constant (Anders 1991). Fuel consumption and waste incineration are increasing, and based on this increase mercury emissions from these sources can be expected to increase. However, a major source of mercury to incinerators (and consequently from incinerators)— household batteries— is falling as mercury-free batteries capture a growing share of the battery market.

A number of policy initiatives may affect trends in mercury emissions. Mercury in batteries has been targeted by the Canadian EcoLogo environmental labelling program, and several municipalities have implemented programs to separate batteries from other waste. Mercury emissions are targeted by the U.S. 33/50 program, and regulations in both the United States and Canada prohibit certain uses of mercury and regulate mercury releases. Additional detail is found in Appendix B.

2.1.2 Polychlorinated biphenyls

In both the U.S. and Canada, the continued use of PCBs is allowed only in existing closed electrical systems. PCBs are primarily used as dielectric fluids in transformers and capacitors. There are three significant points of release of PCBs to the environment:

- contaminated sediments
- atmospheric emissions
- direct discharges

There is some evidence that the current concentrations of PCBs in the Great Lakes arise partially from resuspension of PCBs from contaminated sediments in tributaries feeding the Great Lakes and from sediments within the lakes themselves (Environment Canada, Department of Fisheries and Oceans and Health and Welfare Canada, 1991). A large number of sources emit PCBs to the air. The major source of PCBs to the air in both Ontario and the US is volatilization of PCBs from open sources such as leakages from electrical equipment and from municipal landfills. Electric power generation is the second largest source of airborne emissions of PCBs in Ontario and Eastern North America (ORTECH 1990). Direct discharges include a variety of sources such as erosion or leaching of contaminated soils, accidental spills or leaks, and PCBs in other discharges such as sewage treatment plant effluent. Quantitative estimates of direct discharges are incomplete, but erosion or leaching from contaminated soils is thought to be a major source of PCBs to the environment.

There are severe restrictions on PCBs: they may no longer be manufactured or sold, and therefore their use will either remain constant or decline. Increases in releases can be expected from fossil fuel use as it grows, and from PCB destruction facilities. However, average overall environmental loadings can be expected to be constant or to decline. (Loadings in a given time period may increase if there are large removals from use, or spills, for example, within the time period.)

Prohibitions on the manufacture, sale and transportation of PCBs except for the purposes of storage and disposal, and the efforts that have been induced by these regulations have increased the awareness of PCBs as a management problem. Many significant users or storers of PCBs, (e.g. Ontario Hydro) have therefore instituted some kind of individual management plan for the handling of PCBs and PCB-contaminated materials.

2.1.3 Dioxins and furans

The major sources of PCDD/F emissions to the atmosphere are the incineration of municipal and industrial wastes and sludges, residential fuelwood combustion and electric power generation. Emissions to land occur when host chemicals or products such as PCBs, PCPs, chlorinated pesticides are spilled or applied and when products containing PCDD/F (e.g. some papers) and residues from combustion, incineration and sludges from various processes are disposed of in landfills. Although difficult to quantify, leaching of PCDD/Fs has occurred from landfills and will continue to be a significant pathway to the environment.

Dioxins and furans also have been found in the effluents of the following industries:

- chlorine based pulp and paper manufacturing
- the manufacture of organic chemicals
- internal and external effluents from petroleum refining
- primary metals
- sewage treatment plants.

Another source of PCDD/F to water is the redissolving of PCDD/F from sediments. Though the solubilities of PCDD/Fs generally favour sedimentation, they maintain an equilibrium between the sediment and water phases. Many of the products that have traditionally been the largest sources of PCDD/F have been either reduced drastically in use or have been phased out totally (e.g. 2,4,5 and 2,4,6 trichlorophenol (still used), pentachlorophenol (reduced but still in use) and PCBs (in use but being phased out)). As the production and disposal of these chemical sources has decreased so have the associated quantities of PCDD/F.

In general, the rate of release of dioxins and furans depends on the demand for fossil and wood fuels, and thermally generated energy. The demand (and supply) of waste and sewage sludge incineration services directly affects levels of dioxin and furan release from those sources (these sources are unlikely to increase in the near future given the provincial regulatory prohibition on new incineration facilities).

Numerous policy initiatives have addressed dioxins and furans specifically, including public information campaigns by governments and non-government organizations. There have been several regulations aimed specifically at dioxins and furans.

2.1.4 Pentachlorophenol and PCDD/F

The major pollutant associated with the use of PCPs are dioxins and furans which are released upon application of PCP and in the incineration of materials coated with PCPs. PCPs contribute to the overall increase in PCDD/F loadings to the environment in two ways:

- by acting as transport media for PCDD/Fs as contaminants
- by acting as precursors to PCDD/Fs in sewage treatment plants, pulp mills and incinerators.

PCDD/F emissions occur at each life-cycle stage of PCP from manufacturing, through use and disposal of PCP treated wood in landfills or by incineration. PCP in treated wood contributes to the formation of additional PCDD/Fs when it is incinerated.

Potential emissions of organic compounds to air, land and water from wood preservation facilities may occur from (ORTECH 1990):

- chemical storage, transfer and preparation
- pressure treatment vessels when intermittently opened for wood change or removal
- handling and sorting the products as treated wood cools
- vented exhaust
- process spills and dripping from treated wood
- evaporation of preservative constituents during waste-water treatment (e.g incineration, evaporators etc.)

Air emissions of PCDD/F associated with PCP use are generally fugitive in nature. Consequently, emission factors are not available for PCP use.

There is a small number of producers of PCP in the Great Lakes basin. Individual producers are unwilling to divulge information related to their production levels and market shares, making it difficult to estimate trends in the demand for PCP treated wood. One major user in the Great Lakes Basin— Ontario Hydro— plans to reduce the percentage of PCP treated poles purchased this year by 25% (Ontario Hydro 1992).

Pentachlorophenol (PCP) use and disposal are regulated. For example, in Ontario, where PCP is used exclusively as a wood treatment, regulations require registration under the *Pest Control Products Act.* In the United States, a regulations restrict PCP concentrations in wastewaters destined for treatment in impoundments to 1 mg PCP/L.

2.1.5 Hexachlorobenzene

Hexachlorobenzene (HCB) is a synthetic organic compounds with no natural sources. Although it has been used as a pesticide, there are not current registrations in Canada or the United States. HCB is produced as a by-product of several industrial processes, including:

- chlorinated solvent manufacture (perchloroethelyene, trichloroethylene, carbon tetrachloride and chlorinated benzenes)
- contaminated pesticides
- chlorine gas production by electrolysis of sodium chloride using a mercury electrode
- combustion of fossil fuels and municipal and industrial waste

Emissions from solvent manufacturing are expected to decrease, due to declines in the demand for affected solvents as a result of (regulation driven) substitution, recycling and improved maintenance and operating procedures. In aggregate, releases associated with pesticides are declining; use of some of the pesticides contaminated with HCB exhibit is growing (e.g. pentachloronitrobenzene (PCNB)) and others exhibit declining use (dacthal, picloram). Chlorine production using a mercury electrode is in decline. HCB releases as a product of incomplete combustion in incineration can be expected to increase with the use of incineration for waste technology, though emissions at new plants can be expected to be lower than those at old ones (per tonne of waste processed).

There are no information or voluntary programs specifically directed at reducing emissions of HCBs in Canada or the United States.

2.2 Alternative technologies and processes

Eliminating the sources of persistent toxic substances discussed above will involve lifestyle changes, technological changes or both. The lifestyle changes emerge from the necessity of doing without some of the products or services that result in releases of PTSs. In most cases, it will not be necessary to "do without", because substitute products, technologies or services are available.

Substitute actions may be of several types, including reducing the use of the PTSs at the source, by either removing them from the process, or using processes that do not generate it. In other cases, releases may be reduced through control or containment, which transfers PTSs into a form or a medium where they pose less risk to the environment. In addition, reducing ambient levels may in principle result from decontamination of environmental sinks.

Technologies of each of these types are applicable to the persistent toxic substances considered above. A summary of the key technological actions is presented in Table 1. Major technologies, by source, are discussed in Appendices D and E.

The actions in the source reduction column reduce or eliminate the demand and use of PTS precursors. The control section identifies actions which can be undertaken to contain PTSs which would otherwise be released to the environment, so that they may be disposed of in a controlled manner, thereby reducing the likelihood of release into the Great Lakes Basin.

A number of actions are applicable to almost all of the PTSs addressed in this study. These include:

- substitution of coal and oil with cleaner burning fuels for combustion
- reducing demand for electricity
- installing control technology in stacks to remove PTSs in gaseous forms
- decreasing the use of incinerators for solid waste disposal
- improving source separation of products containing PTSs or which contain PTS precursors for (safer) disposal at a hazardous waste facility.

Other actions are applicable to certain portions of the list:

- reducing demand for or substituting mercury in batteries, electronic and control instruments
- reducing demand for, or substituting chlorinated organic precursors
- altering incineration and fossil fuel to encourage in-situ destruction of chlorinated organic PTSs
- adopting non-chlorine processes for pulp and paper bleaching and sewage treatment.

Table 1 Short list of actions to virtually eliminate PTSs in the Great Lakes basin

PTS	**Source reduction**	**Control and containment**	**Decontamination of environmental sinks**
Mercury	• substitute non-mercury batteries • substitute mercury technologies in control and electrical apparatus • substitute cleaner combustion fuels for oil and coal • reduce demand for electricity	• collect batteries, control and electronic apparatus for disposal in hazardous waste facility • install pollution control devices on incinerators, smelters and combustion technology • improve containment ability of landfills	• remove contaminated soils surrounding chlor-alkali plants • research and development
PCBs	• better housekeeping practices to control leaks from transformers and open sources • substitute coal and oil with natural gas for combustion • reduce demand for electricity • boiler modification	• flue gas cleaning • install afterburners • mix fuels for hotter combustion	• destroy backlog of PCBs • research and development
PCDD/F	• substitute non-chlorine bleaching technologies for pulp and paper • use non-chlorine sewage treatment process • reduce demand for plastic, PCP treated wood, chlorinated organic solvents, defoamers • stove design modification • substitute wood with other fuels	• remove chlorine and chlorinated precursors from incinerator feedstock • hotter combustion • decrease oxygen supply in incinerators • install air emission control technologies • increase portion of solid waste going to landfills (from incineration)	• research and development
HCB	• reduce (eventually to zero) demand for chlorinated solvents, pesticides	• install air emission control technologies	• research and development

SOURCES: McCorquodale et al. 1992a; Copowlski 1992; Paine 1992; IRR 1992; Environment Canada 1990; USOTA 1989; Denison and Ruston 1990; Fouhy 1992; Brna et al. 1990; Benefenati et al. 1991; Nottrodt et al. 1990; Marklund et al. 1990.

3. Overview of economic instruments

Based on the review of the previous chapters, the Economic Subgroup of the Virtual Elimination Task Force requested an analysis of the use and consequences of applying economic instruments to the virtual elimination of persistent toxic substances (PTSs) by means of two specific examples:

- the use of chlorine in the production of polyvinyl chloride (PVC)[2]
- the discharge of PTSs from incinerators.

The application of economic instruments to these two examples is intended to illustrate the potential application of economic instruments to virtual elimination generally.

This chapter briefly reviews the general topic of economic instruments for environmental protection, with particular attention to potential uses of such instruments in phasing out processes and activities that are deemed to be especially harmful to the environment. There is a vast and growing literature on the general topic of economic instruments for environmental protection. This chapter provides an overview of this literature reflecting the main issues for the present application. There are several references that can provide more extensive introductions to the topic from theoretical and applied perspectives, e.g. Baumol and Oates (1988), Environment Canada (1992), Macaulay, Bowes and Palmer (1992), OECD (1989, 1991) and Tietenberg (1985).

3.1 Types of economic instrument

There are several types of economic instruments that can be applied for environmental protection (OECD 1989):

- charges or taxes
- subsidies[3]
- deposit-refund systems
- marketable allowances or permits
- liability insurance or performance bonds
- (financial) enforcement incentives.

For the examples chosen by the Economic Subgroup of the potential application of economic instruments to virtual elimination, it was also decided to focus on the application of environmental charges (or taxes) and marketable allowances or permits.

3.1.1 Environmental charges or taxes

The idea of using charges or taxes for environmental protection was introduced by the British economist Arthur Pigou (1938). Pigou characterized environmental problems in economic terms as instances of *external costs.* An agent is said to impose an *external cost* on a second agent when an activity by the first agent causes a loss of welfare to the second agent *and* the loss of welfare is uncompensated. Pigou showed that if, as would usually be expected, the *marginal* (i.e. incremental) private benefit to the first agent is a decreasing function of the level of activity, and the marginal external cost to the second agent is an increasing function of the level of activity, a charge or tax per unit of the activity could be set that would provide an incentive to the first agent to reduce the level of activity to a level that would maximize the aggregate net benefits to the agents, which corresponds to the condition for economic efficiency or "Pareto optimum."

Where the external costs are so high as to justify the virtual elimination of anthropogenic emissions (as is the policy of the governments of the United States and Canada for persistent toxic substances under the Great Lakes Water Quality Agreement), this would suggest that a tax on such emissions should be set at a level high enough to deter all of these emissions; such a tax would be practically equivalent to an immediate ban on all of the emissions.

In practice, however, it is recognized that *immediate* bans (or the equivalent taxes) generally impose large adjustment costs; these adjustment costs can be reduced substantially by a program that phases out activities that generate the emissions over a set period of time. This phasing out could be encouraged by means of taxes (on activities or emissions) that are *increased over a period of time* so that emissions are progressively reduced until virtual elimination is achieved. Such taxes have the

---

[2] More precisely, the economic instrument was intended to be considered as applying to all uses of chlorine as an industrial feedstock, but, in order to simplify this illustrative analysis, only the consequences for PVC production and use were to be considered.

[3] Subsidies tend to be disfavoured by economists as instruments for environmental protection, because although in the short run such subsidies could encourage pollution abatement, in the long run they tend to increase total production in the industry, and thereby perhaps even increase pollution (Baumol and Oates 1988). Subsidies are also generally inconsistent with the Polluter Pays Principle (OECD 1975)

additional advantage that they provide time and escalating incentives for economic agents to develop *new* substitutes for the activities or processes that produce the emissions.
It is generally difficult to anticipate the development of new substitutes, so that the timetables for increasing the taxes could *initially* be based on the time required for agents to adopt *known* substitutes (which are already available for most activities that emit PTSs). As *new* substitutes are developed, the costs of phasing out activities or processes can be reduced (or even net benefits achieved), and timetables can be accelerated.

3.1.2 Marketable permits or allowances

The idea of using marketable permits or allowances for environmental protection was introduced by the Canadian economist John Dales (1968). In this system, agents who engage in activities that generate emissions have to obtain an allowance for each unit of activities or emissions from a total quantity of allowances established by the regulatory agency. Thus, the number of allowances set the maximum total level of activities or emissions.

Marketable allowances differ from permits under a pure "command and control" regulatory system (such as "Certificates of Approval" in Ontario) in that they are deemed to be transferable or marketable: agents are free to trade these allowances among themselves. Where one agent has lower costs of reducing the activity or emissions than another, both will benefit by the former agent selling allowances to the latter. The first agent must then reduce activities or emissions by the number of allowances sold; the second agent may increase activities or emissions by the same amount. The total level of activities or emissions will be no greater, but the total costs of achieving that level are reduced through the transaction. If there are enough agents to constitute a market in allowances, an equilibrium price of allowances will become established. This price will depend on the total number of allowances issued by the regulatory agency: the smaller the total number of allowances, the higher the equilibrium price. A review of several studies analysing the cost effectiveness properties of tradable allowance systems relative to regulatory systems indicated that potential pollution control costs could be reduced by more than 90 percent in some cases (Tietenberg 1985).

Marketable allowances could also be used in a program for virtual elimination. An initial quantity of allowances could be issued for an initial time period to allow activities or emissions at or below the current levels. In successive time periods, the total quantities of allowances could be reduced until virtual elimination is achieved. As in the case of taxes, the pace of reductions in the quantities of allowances could be determined according to the time required for agents to phase in substitute activities or processes. Like charges or taxes, marketable permits also provide incentives for agents to develop *new* substitutes. As these are developed the timetable for virtual elimination can be accelerated.

3.1.3 Similarities and differences between tax and allowance systems

Many economists advocate environmental taxes or marketable allowance systems as superior to regulatory ("command and control") systems, because, under the standard economic assumptions, they can be shown to maximize cost-effectiveness in pollution reduction, i.e. systems based on these economic instruments can maintain total activities or emissions within any given maximum level for the lowest total compliance cost[4]. These economic instruments also provide economic incentives to develop new activities or processes that further reduce the costs of compliance. To this extent, environmental taxes and marketable allowance systems are very similar in their effects.

Environmental taxes and marketable permit systems are also similar in the stringency of monitoring and accounting for activities or emissions that they require. Obviously, the accuracy of monitoring is important to assess the appropriate and fair tax on an agent. Accuracy of monitoring and accounting is especially important for trading programs, as explained by Hahn and Hester (1989) with regard to air emissions trading programs:

> Questions about the ability to monitor emissions have played an important role in the design of emissions trading policies. Monitoring emissions of air pollutants is a difficult task for regulators. Continuous monitoring often is infeasible due to technological and economic constraints. Regulators usually are reduced to estimating emissions based on assumptions about the typical parameters of a manufacturing process, about operating hours, and about the effectiveness of pollution control equipment. Absent trading, the difficulty of monitoring

---

[4] This result depends on the assumption that the administrative costs, or "transaction costs" generally, of each system are zero; it may be invalid if the transaction costs of economic instrument systems are greater than those of regulatory systems. In the case of marketable allowance systems, the result also depends on the assumption that there is a sufficient number of agents to approximate a perfectly competitive market.

> emissions creates uncertainty about the permit limits necessary to attain ambient air quality standards. When trading is introduced into the regulatory system, however, the difficulty of monitoring emissions creates ambiguities about the property rights to which firms are entitled and whether those property rights are "in use" or available for trading. One response to these difficulties has been an increase in the complexity of administrative requirements intended to resolve these ambiguities... however, these requirements increase transaction costs and reduce trading.

Environmental taxes are often termed "price-based instruments" in that they set the "prices" of activities or emissions. Marketable allowance systems are termed "quantity-based instruments" because they set the total level or quantity of activities or emissions. An important difference between price-based and quantity-based instruments emerges in any case where there are significant *uncertainties* about the effects of a "price" (tax) change on the level of activities or emissions. In such a case, the magnitude of the effect of a price-based instrument on the level of activity or emissions will be uncertain; the effect of a quantity-based instrument on the level of activity or emissions is always fixed, although the resulting equilibrium price of allowances will be uncertain.

At first sight, there appears to be a difference between taxes and marketable permits in that taxes yield revenues, while this is not obviously the case for marketable permits. The extent to which marketable permits can yield revenues depends on how they are initially allocated. Often where marketable allowance systems have been instituted (especially in the United States), allowances have initially been allocated to agents "free" on the basis of the total or some proportion of their current or past levels of activity or emissions; in this case, there would be no revenues. This practice of "grandfathering" was deemed to make the system more politically acceptable to the participants. An alternative, revenue-generating approach would be for the government agency that administered the system to auction all new allowances to the highest bidders. Under standard assumptions about competitive markets and bidding systems, such an auction should yield the same revenues as a tax (for a given final level of activity or emissions). Until prices become established, however, during the initial period of the auction and market creation, participants face a prospect of substantial uncertainties that can cause opposition to the program or inhibit trading.

If a lower level of revenues is sought than under a system where *all* allowances are initially auctioned, some allowances could initially be allocated "free" and the rest auctioned. A corresponding approach for taxes would be to allow some initial levels of activities or emissions "free," and only impose the tax on activities or emissions above these levels, or, equivalently, tax revenues could be partially or completely returned to agents in the form of lump-sum subsidies.

In theory, therefore, a quantity-based system can usually be designed to yield the same results as a price-based system, and vice versa. Then, the choice between the two kinds of instruments depends on practical considerations such as: actual conditions that may violate the standard economic assumptions, uncertainties, political acceptability, and administrative capacities and experience (especially within government agencies) for managing each system.

3.1.4 Allocation of revenues from economic instruments

The full effects of a program of economic instruments that generates government revenues depend on the allocation of these revenues. If these revenues allow a reduction in revenues from other taxes, especially individual and corporate income taxes, these tax reductions can increase economic activity (Lee and Misiolek, 1986, Terkla 1984). The *shift* of the tax burden *both* introduces a tax disincentive to the non-productive activity of waste generation *and* simultaneously *reduces* the tax disincentive to the productive activity of individual and corporate income generation so that productive activity increases. If the rates of these other taxes are not reduced, however, productive activity would not increase.

One of the productive activities to which revenues could be allocated is environmental remediation and restoration. Evaluations of the benefits of remediation and restoration are beyond the scope of the present study; preliminary evaluations have been developed in another recent report (Hickling et al. 1993). Here, we merely note that there is support from some individuals and bodies (e.g. the Environment and Taxation Committee of the Ontario Fair Tax Commission) for specifically earmarking revenues from economic instruments to environmental remediation and restoration. The effect of earmarking depends on whether it provides *additional* allocations for remediation and restoration, or it merely offsets reductions in allocations for remediation and restoration from other revenue sources. Clearly, the extent of remediation and restoration depends on the *total funding* that is allocated to these purposes, and not the revenue *sources* of this funding. Whether earmarking has the net effect of increasing funding for remediation and restoration depends on how it influences particular budgetary processes and authorities.

3.2 Criteria for assessment

The Organisation for Economic Cooperation and Development (OECD 1991) has recommended five general criteria for assessing economic instruments among environmental policy instruments generally. The OECD (1991) criteria are:

Environmental effectiveness

Environmental effectiveness is simply the effectiveness of the policy in achieving emissions reductions or other environmental objectives. In this case, the environmental objective is virtual elimination of persistent toxic substances; this may be achieved by sub-objectives, such as the elimination of chlorine and chlorine containing compounds as an industrial feedstock.

Economic efficiency

In the broadest sense, economic efficiency is the policy's contribution to achieving the "optimal allocation of resources" - "both in terms of the amount of pollution and expenditure on avoiding and accommodating pollution" (OECD 1991). For conventional pollutants, the "optimal" level of pollution is the level at which the marginal costs of abatement equal the marginal benefits of abating environmental damage, so that the total costs of damage *and* abatement are minimized. In the case of anthropogenic persistent toxic substances, however, there are strong reasons for adopting the "philosophy of zero discharge" as the "optimal level of pollution", especially when viewed in a long term perspective, and this is recognized in the policy of "virtual elimination".

This study assumes the policy of virtual elimination, and explicitly excludes consideration of environmental benefits, so that economic efficiency is regarded only in terms of *cost-effectiveness* in achieving the goal of virtual elimination. Cost-effectiveness is considered in terms of social costs, which include both private costs to directly-affected industries and consumers, and public-sector administrative costs (as well as public-sector compliance costs, where affected facilities, such as incinerators, are operated by the public sector). We do not generally consider *social cost* implications with respect to forward *and* backward linkages from directly affected sectors, which could occur in the absence of perfect competition. The analyses are generally confined to static partial equilibrium implications, which indicate the *differences* in social costs between the various policy instruments in achieving virtual elimination.

Private costs are considered quantitatively, and include direct costs of pollution abatement technologies and indirect costs for source reduction, substitution and other methods of pollution prevention. The differences in public-sector administrative costs among different policy instruments are considered *qualitatively*, and include administrative feasibility and costs (see "Administrative feasibility and costs" below).

Equity

Equity is concerned with the effect of a policy instrument on the distribution of costs and benefits. For example, consideration can be given to whether a policy affects different plants of an industry differently according to whether they are large or small, old or new, or whether or not they have previously invested in pollution abatement. More generally, consideration can be given to the implications of the policy for the distribution of income among different groups in society.

There are different kinds of equity implicit in economic instruments and other environmental policy instruments. Economic instruments tend to make the marginal costs of abatement equal among sources of pollution. In the case of input or emission charges, for example, every source pays the same unit charge. This is consistent with cost-effectiveness in pollution abatement, but might also be considered to be equitable. On the other hand, some might consider a policy to be more equitable if it requires the same average cost of abatement for all sources, or if *all* sources face the same standard, as would more likely be the case for a "command and control" instrument.

Another general difference between economic instruments and "command and control" with distributional implications is that economic instruments tend to drive firms with higher unit production costs out of the industry, while allowing those that remain to maintain their production levels. A regulatory program would likely lead to more even reductions across firms.

Decisions about what forms and degrees of equity are required of a policy must be made by policy-makers. Here, we merely indicate the *direct* implications of policies on employment and costs to industries and consumers. A more pertinent analysis of distributional implications requires knowing more about what specific distributional issues are important to policy-makers (Sugden and Williams, 1978; Bromley 1990).

We do not extensively consider broader macroeconomic impacts (indirect and induced impacts) nor, perforce, general equilibrium implications. Such analyses would go beyond the scope of the present study. Except in special circumstances, direct impacts are likely to be more concentrated than indirect or induced impacts, and thus of more concern with regard to distributional issues. In considering broader social costs and benefits, positive health and environmental implications should also be taken into account. Therefore, any macroeconomic analysis based on the information collected in this study would be incomplete. The discussions here are confined to suggesting where impacts are likely to be concentrated, and suggesting possible implications and options.

Administrative feasibility and costs

Administrative feasibility and costs depend on the availability and costs of means to monitor and enforce compliance with a policy instrument. Ideally, enforcement should be based on continuous monitoring of the discharges of concern, but in the case of low concentrations of persistent toxic substances, this may often be impractical or very costly.

Unfortunately, there is not yet much documented experience regarding the costs of economic instruments relative to other policy instruments, especially when applied to persistent toxic substances. Therefore, we generally consider administrative feasibility and costs only qualitatively.

Acceptability

Acceptability to stakeholders is related to, but distinct from, the preceding criteria. Policy instruments may be opposed by stakeholders based on effectiveness, efficiency, equity or other criteria. If there is substantial resistance (especially by target groups), this will detract from administrative feasibility and add to administrative costs. Therefore, it is very important to assess the views of stakeholders with regard to policy instruments, and provide for adequate information and consultation. This is especially important when consideration is being given to introducing a new and unfamiliar type of policy instrument, such as an economic instrument.

These five OECD criteria for choice of environmental policy instruments, are generally consistent with other criteria that have been proposed (e.g. by the Ontario Fair Tax Commission). In the federal constitutional systems of the United States and Canada, attention also needs to be given to the legal and jurisdictional issues concerning the applicability of each type of policy instrument.

These criteria are addressed in the sections on "impact assessment" in each of the case study chapters.

3.3 Practical experience with economic instruments

Despite advocacy of economic instruments by many economists, pollution abatement policy in most countries is administered primarily through regulatory "command and control" instruments (OECD 1989). Applications of economic instruments for environmental protection in western, industrialized countries are reviewed in OECD 1989. In general, the United States has tended to adopt marketable allowance systems rather than environmental charges or taxes (especially at the federal level); outside the United States, there is little experience with marketable allowance systems, but some experience with environmental charges and taxes. Here, we briefly survey practical experience with economic instruments in Canada, the United States, and with regard to phasing out activities or emissions.

3.3.1 Canada

Environmental taxes have been applied in Canada (at the provincial level of government) in a small number of cases (Environment Canada 1992). The most common "environmental" taxes in Canada are on tires and non-returnable alcoholic beverage containers. Ontario has both of these and a tax on fuel-inefficient vehicles. British Columbia has a charge on tires and on lead-acid batteries (Environment Canada 1992). British Columbia also has "waste management permit fees" for a wide range of wastes (British Columbia 1993).

3.3.2 United States

There is substantial experience with marketable allowance systems in the United States at the local, state and federal levels (Cropper and Oates, 1992). The United States is instituting a comprehensive emissions trading system for sulphur dioxide under the Clean Air Act (as amended in 1990), in order to reduce acid rain. At the state and local levels there is small but growing experience with environmental taxes and user fees.

One of the interesting innovations in marketable allowance systems in the United States, which may have applications in the Great Lakes basin, has been the extension of some systems to allow "trading" between point sources and non-point sources. Under these systems, proprietors of point sources who expect their emissions to exceed their allowances can contract with non-point sources (possibly through an intermediary) for the non-point sources to reduce emissions to offset the excess point source emissions, so that the total emissions reduction objective is met (Apogee Research 1992). The system can also take into account uncertainties about the effectiveness of non-point source controls by requiring a "trading ratio," whereby non-point source emission reductions must be a multiple of the excess emissions at the point source. For example, a trading program for phosphorus discharges into the Dillon Reservoir in Colorado requires a 2:1 trading ratio, i.e. point sources must obtain at least double the reductions from non-point sources than they would have had to make themselves (Cropper and Oates, 1992). With trading ratios greater than 1:1, trading between point sources and non-point sources allows lower levels of total discharges to be achieved at lower costs.

3.3.3 Economic instruments for phase-outs

Our literature review has revealed only two cases where economic instruments have been applied in phasing out releases of substances. Both cases are in the United States, and both applied marketable allowances to the production of the substances of concern.

The first case was a input allowance trading program administered by the U.S. Environmental Protection Agency for lead additives in gasoline (formally called "inter-refinery averaging"), whereby these additives were phased out during the period of 1983 to 1987 (Hahn and Hester, 1989). This case has generally been regarded by administrators and economists as a very successful trading program. The program helped to achieve the objective of phasing out lead additives in gasoline over a fairly short time period (four years) with much less opposition and delay from the industry than might otherwise have been expected.

The second case of the use of an economic instrument to support a phase-out is the current program of the U.S. Environmental Protection Agency to phase out the production (and import) of chlorofluorocarbons (CFCs) by 1996. This program also appears to be generally successful, apart from a concern that the restriction of production on import of CFCs, and consequent rise in prices, may have allowed producers and importers to reap excessive profits, which can in turn "have important impacts on the behaviour of firms over the long run" (Hahn and McGartland, 1989).

3.4 Objections to economic instruments

There are numerous objections to economic instruments, in general or in particular applications, on ethical and practical grounds.

3.4.1 Ethical objections

On ethical grounds, there is widespread concern that economic instruments (especially tradable allowances) can be seen as buying and selling rights to pollute the environment. Economists who advocate economic instruments tend to retort that this is superior to the current system (of non-tradable allowances) in which such rights are given away for free.

Kelman (1981) suggests that there may be social value in stigmatizing polluting behaviour. Such a stigma may be uncomfortable (and possibly unfair) to polluters, but it may help to rally and focus social concern to reduce or eliminate pollution in the longer term (Stokoe 1991). Kelman (1981) also draws attention to the "downvaluation effect" of attributing prices (via economic instruments) to environmental attributes that have hitherto been considered "priceless."

Frey (1992) extends these arguments and offers empirical evidence to suggest why economic instruments are much less used than regulatory instruments in environmental policy. Contrasting pricing and regulating, he notes that pricing is likely to "crowd out" environmental ethics in the sectors where pricing is applied, i.e. economic motivations rather than ethical motivations are likely to be validated. Furthermore, this "crowding out" may spill over into non-pricing environmental issues (sectors). The overall effect may be to increase pollution. Frey (1992) suggests that environmentalists and policymakers implicitly understand this, and thus tend to reject environmental pricing.

Economic instruments might be more acceptable in the context of programs to phase out or sunset substances if it is clearly understood that these programs are temporary measures leading to an eventual ban, and do not in any way imply valuations of the environment. Nevertheless, these concerns are still likely to lead to a preference for environmental taxes or charges over marketable allowance systems, because the former can be portrayed as penalties, while it is more difficult to distinguish a marketable allowance or permit from a "right to pollute."

3.4.2 Practical objections

There are also numerous practical concerns which inhibit the adoption of economic instruments in practice, including (Victor 1993):

- "command and control" is regarded as providing greater *certainty*, both to policy-makers of achieving intended results, and to those who are regulated of what is expected of them
- economists tend to consider efficiency or cost-effectiveness as a major policy objective, but others tend to accord much greater weight to distributional implications
- economists tend to consider a situation as fair if everyone faces the same price; others, of more juridical inclination (who tend to predominate in government and public service), tend to consider a situation as fair if everyone faces the same standard
- policy-makers are concerned about the administrative feasibility and costs (especially costs of monitoring performance) of economic instruments programs.

In the case of marketable allowance programs in particular, there are other concerns, including (Victor 1993):

- emissions trading may result in increased emissions or environmental damage in some locations.
- enough buyers and sellers, whose emissions have geographically similar impacts, are required for trading to work
- there are potential (but not insurmountable) problems in introducing or accommodating new sources into the program.

3.5 Implementation

This report is a first step contributing to an extensive process, involving many participants, of establishing a new environmental policy. Development of a new environmental policy that incorporates economic instruments is likely to be especially challenging, because understanding of economic instruments and capacities to administer them are still limited in both the public and private sectors.

There are several stages in the creation of an environmental policy; the adoption of economic instruments has implications at each stage. These stages are:

- design or development
- implementation
- institutionalization
- fine-tuning

Each stage has different characteristics requires different sets of experience, relies on different kinds of data, has different users, and relates in different ways to earlier and later stages.

3.5.1 Policy design

The first stage in an environmental policy is the design stage. In this stage, alternative regulatory approaches are assessed, some are discarded, and a single approach is selected. The design stage, therefore, seeks consensus on goals and administrative means, and anticipates specific private sector and public sector loci for the eventual implementation of the policy.

An example of this dynamic is environmental policy reform is the introduction of environmental auditing. Environmental auditing is a concept that could have been focused in the public sector; instead, because of decisions taken in both Canada and the U.S., the public sector has encouraged the evolution of environmental auditing to be private-sector oriented and relate to public sector compliance management interests. While early regulators tinkered with the notion that environmental auditing should closely relate to the public sector goals of getting better environmental outcomes for less money, regulators chose to keep a hands-off approach to environmental auditing and encourage its growth in the private sector from afar. In the design of related policies, mostly policy office staff became involved in assessing the government's role, sorting out alternative strategies to promote voluntary environmental auditing, and communicating policy alternatives and public sector decisions to either agency program or regional staff.

In the design stage of policy development, the rhetoric is high and broad, and analysis is often shaky, and those engaged in the debate are frequently organizationally far away from real world problems. As the design begins to take shape, those affected start to get engaged in the debate, and fine-tuning of design elements begins.

3.5.2 Policy implementation

In general, those responsible for the design of regulatory reforms are not the same as those responsible for the implementation of reforms. In addition, the mix of skills, interests, education, and experience of designers may be very different from the implementers. This fact is amply illustrated by the experience with the U.S. policy for the control of acid deposition. In general, those people inside and outside the government were not the same people in either industry or the public sector who were responsible for firm-level compliance management or for developing the implementing regulations at either U.S. EPA or state regulatory agencies. Clearly, there is a marked difference between reform designers and reform implementers. Recognizing this difference can help designers anticipate potential implementation problems and achieve greater success in the eventual implementation of reforms.

3.5.3 Institutionalization

For mandatory programs institutionalization is not critical. For voluntary programs, institutionalization is critical. Every organization has its own special myths; institutions are virtually defined by these myths, folkways, and mores. It is critical for reform designers to strive for eventual institutionalization of behaviour patterns which promote the intended goals of the policy they advocate. Some reforms such as the U.S. EPA's Bubble Policy never get institutionalized and are always outside of the standard way of doing business. Remaining outside of the regulatory mainstream is costly to the eventual adoption of the reform, deprives industry of potential cost savings, or forgoes substantial environmental clean-up. Institutionalization of the reform is a natural goal of all regulatory reformers.

3.5.4 Fine-tuning

We never can anticipate all the consequences of a regulatory reform. One group of people may react in a manner that was wholly unintended while another aspect of the reform may work exactly as expected. Fine-tuning the reform is impossible without designing and implementing an evaluation system. Such a system provides feedback to relevant stakeholder on failures and success. Without a feedback mechanism that includes the specification of anticipated outcomes and collects data on actual outcomes, serious evaluation of the reform is impossible and fine-tuning the regulatory program is merely at the whim of current regulatory politics, not fact. If designers do not focus on goals, measures for success, and data collection systems, fine-tuning is impossible.

The lead additives trading program was subject to several "mid-course corrections" and efforts at fine-tuning. This has also been the case with the trading program for production and import of CFCs. The need for "mid-course corrections" is a feature of many types of policies, but is especially acute for economic instruments. Fortunately, economic instrument programs are generally amenable to such corrections. Nevertheless, it should not be expected that programs will endure in the forms in which they are originally introduced. The likelihood that corrections will be needed should be anticipated by providing for flexibility in the design and implementation of these programs.

In work sponsored by the Joyce Foundation of the United States (forthcoming), it has been shown that failure to incorporate evaluation systems has lead to poor management of a variety of reforms (this is also true for commend and control policies, as well as economic instruments); the study group for the Joyce Foundation now endorses as a primary recommendation the importance of serious evaluation efforts as part of the design and implementation of any reform initiative.

As the stages of the reform come and go, the stages involve different people in different parts or different organizations. As a reform matures it becomes more of an administrative and routine activity and, therefore, relies more on systems than on people. Anticipating how the reform will evolve and what is required in each subsequent stage is the responsibility of designers who have the only opportunity to get funding and other resources for training, data tracking, outreach, and evaluation activities. Policy reformers need not design the perfect system the first time; clever reformers, however, anticipate mistakes by designing reform systems that self-correct as new, and perhaps, unanticipated situations develop.

3.6 Approach of this study

The approach of this study is to develop "least-cost abatement functions" (also known as "abatement supply curves") for each of the two case studies requested by the Economic Subgroup. These functions indicate the activities and costs required to achieve a given level of abatement at least cost. Additional work will be required to assess, quantitatively, the impacts of these programs, and to develop a specific implementation strategy that addresses the stages discussed above.

The least-cost abatement functions can be used to predict what activities would be undertaken and what costs incurred in response to a given tax or total allocation of marketable allowances. The functions can thus be used to predict the level of abatement for a given level of tax, or the equilibrium price for a given total allocation of allowances. The revenues that could be obtained from the tax or auction of allowances can also be predicted. In the event that a regulatory program is preferred over an economic instruments program, the least-cost abatement functions can indicate the activities that should be regulated to achieve a given level of abatement at least cost.

As taxes are increased or marketable allowances reduced to zero, the least cost abatement function indicates the costs[5] of achieving virtual elimination. If the same set of activities is mandated by regulation, the *costs* of achieving virtual elimination by regulation would be the same as for economic instruments; otherwise, they would be greater. Similarly, if the same set of activities is mandated by regulation, the *economic impacts* of achieving virtual elimination by regulation would be the same as for economic instruments; otherwise, they would be greater. The analysis here indicates only the *direct* economic impacts (costs) of achieving virtual elimination by means of economic instruments.

In considering the costs of substitutes for activities (e.g. landfilling for incineration) or products (e.g. steel pipe for PVC pipe), only direct costs are considered. If the substitutes are considered functionally inferior, then actual costs may be considered greater than accounted for here. Consequently, the price of the activity would have to be increased further to prompt adoption of the substitute. On the other hand, if *new or improved* substitutes are developed that are not considered in this analysis (perhaps in response to the incentives provided by economic instruments), then the actual costs of substitution would be less than accounted for here.

---

[5] Where costs are exclusive of program administrative costs, here and in the remainder of this paragraph.

4. Persistent toxic substances from incineration

It was noted earlier that incinerators are a major source of dioxins and furans, and also release other persistent toxic substances, including mercury. This chapter considers municipal waste incineration— the first case study. The chapter is divided into five sections:

- A description of the incineration process, and the determinants of emissions from incinerators
- A discussion of the technologies available for reducing or eliminating emissions from incinerators
- Policy instruments that could induce these technologies to be adopted. Voluntary, economic and regulatory instruments are introduced
- Five programs involving the policy instruments are described, including marketable permits, an emission tax, and a program combining voluntary, economic and regulatory instruments
- The programs are assessed against the criteria described in the previous chapter

4.1 Incinerators and emissions

Incinerators are a source of each of the persistent toxic substances selected for consideration (i.e. mercury, dioxins and furans, hexachlorobenzene and PCBs) in this study. Incinerators are operated to process hazardous, biomedical or municipal solid waste. This study considers emissions from municipal solid waste incinerators[6]. These account for almost 11 percent of air emissions of mercury in the Great Lakes basin (McCorquodale et al. 1992a) and until the closing of the Commissioners Street incinerator in Toronto, they were the primary source of dioxins and furan air emissions in Ontario (ORTECH 1990) as well as a significant source of HCBs (Voldner and Smith, 1992). Incinerators contribute about one percent of air emissions of PCBs in both Ontario and Eastern North America (ORTECH 1990)[7].

Incinerators reduce the volume of waste requiring landfilling, and may be designed to recover the energy content of the waste. However, certain components of the waste (such as metals and other inorganic compounds) are not destroyed by the heat, and may be released as an air emission, captured by air pollution control equipment, or be left in the slag. In addition, incinerators may actually **create** persistent toxic substances as products of incomplete combustion (PICs), including dioxins and furans, polychlorinated biphenyls and hexachlorobenzenes.

The heterogeneity of incinerator feed, the complex chemistry of the incineration process and the variety of incinerator types and operating practices make it difficult to estimate emissions precisely. Even within the same incinerator type, measured concentrations in flue gases varied for some compounds (e.g. PCDD) by four orders of magnitude (U.S. OTA 1989). Results from multiple tests of the same incinerator have sometimes indicated concentrations varying by a factor of three.

Although estimating today's emission levels is difficult, it is even more difficult to estimate future emissions. One determinant is the number and capacity of incinerators operating. Over the past few years the planned capacity in the United States has been substantial, but there have also been numerous cancellations.[8] In response to the difficulties associated with siting new landfills (particularly in heavily populated areas), some waste planners have turned to incineration, recognizing that incineration could play a much bigger role in waste management; by comparison with other countries— such as Denmark, Japan and Switzerland— the United States and Canada do not make heavy use of incineration to manage municipal waste. Incineration and landfill are not the only option for handling waste. Waste management strategies have been implemented in numerous jurisdictions which include significant programs to divert waste through the reduction, reuse and recycling of waste. At the same time there is often public opposition to incineration on the grounds of health and environmental impacts, and concern that incineration will undermine actual or potential recycling initiatives. Overall, EPA expects the fraction of waste incinerated to increase from 14.2 percent in 1988 to 22.8 and 25.5 percent in 1995 and 2000, respectively (Franklin Associates 1992).

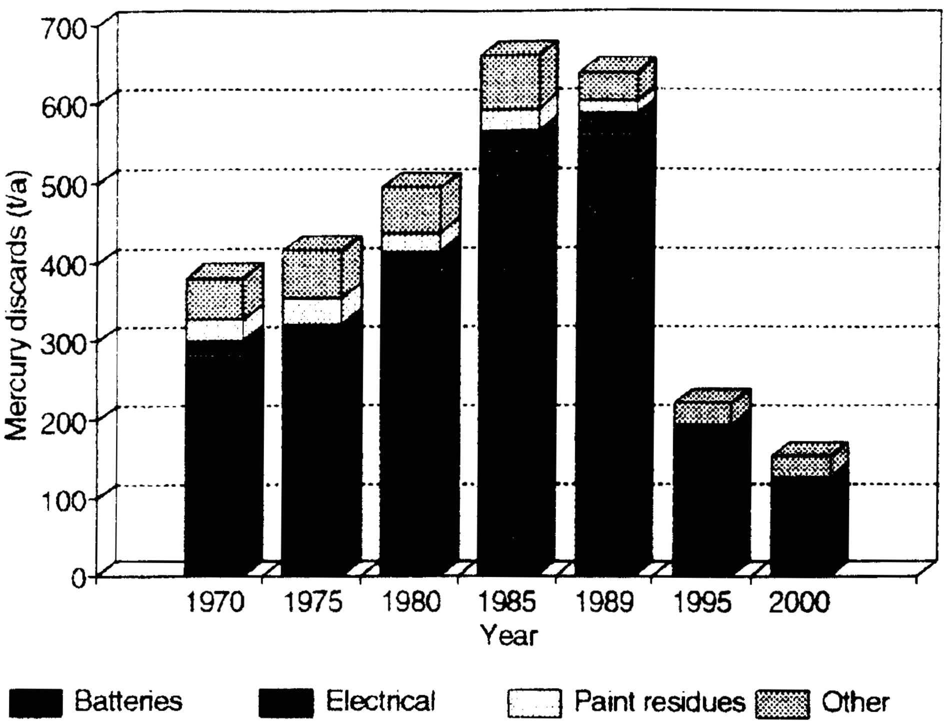
---

[6] In addition to air emissions of PTSs from incinerators, PTSs are also generally present in incinerator ash. It is assumed here that PTSs in the air emissions are the priority because they are immediately dispersed into the environment; however, the same policy instruments could be considered for PTSs in incinerator ash and wastewater streams.

[7] Given the quantities of PCBs believed to reside in different repositories, it is likely that the majority of PCBs entering the atmosphere are from stockpiles and landfills (MacKay 1991). PCBs are not very volatile (i.e. they do not evaporate readily at normal atmospheric temperatures), but they are extremely hydrophobic. Consequently, PCBs that are accidentally spilled into water have a large propensity to migrate to biota, to sediments or volatilize into the air (MacKay 1991).

[8] In Ontario, new municipal solid waste (MSW) incineration facilities are prohibited by regulation.

Figure 1 Mercury discards in the United States municipal solid waste stream (tonnes)



A second determinant of future emissions is future waste characteristics. Already under pressure from citizen groups and governments, industries that use mercury in their products, especially the battery and paint industries, have begun source reduction programs to reduce or eliminate their mercury use. Figure 1 presents projected mercury discards (U.S. EPA 1991).

A third determinant of future emissions is the control technology used. Almost half of old incinerators use electrostatic precipitators (ESPs) as their pollution control technology. ESPs may have no impact on mercury emissions, and may actually increase dioxin and furan emissions since the control technology reduces the efficiency of combustion (i.e. the temperature). In contrast, almost ninety percent of new facilities are expected to use dry scrubbers with fabric filters which may capture as much as 84 percent of mercury emissions and 98 percent of dioxin and furan emissions. As new facilities represent a growing share of the total incinerator stock, unit emissions (i.e. grams per tonne of waste incinerated) can be expected to decline.

4.2 Alternative technologies and processes

Several options are available to reduce persistent toxic substance (PTS) emissions from existing incinerators. The following types of relevant alternative technologies and process changes to reduce and eliminate emissions of PTSs from the Great Lakes basin are assessed:

- reducing the amount of waste generated, and particularly reducing those components of waste destined for incineration that contribute most to PTS discharges
- separating for special handling those components of waste destined for incineration that contribute most to PTS discharges
- adding or improving the pollution control equipment used in municipal waste incinerators
- diverting waste from incineration to other waste management technologies

Table 2 presents the effectiveness and costs of actions considered for reducing PTSs emissions from incinerators.

4.3 Policy instruments

Numerous policy instruments are available to influence the adoption of these actions, including options from each of the three main approaches:

- *Information and moral suasion programs*— several programs are already in place that will influence actions to be taken. Canada's Environ-

Table 2 Actions ordered by source and economic attractiveness[a,b]

Action type/action	Compound affected	Potential reduction (tE)	Average unit cost[d] ($/tE)	Action code
Source reduction				
Reduce the Hg content of paint	Hg[c]	9.2	$0	Paint1
Reduce the Hg content of batteries	Hg	17.8	$0	Battery1
Use batteries with low Hg levels	Hg	5.7	$0	Battery2
Landfill instead of incinerating waste	All[c]	230.6	$2 733 795	Landfill1
Product substitution				
Reduce mercury content of other products	Hg	14.4	$0	Other1
Source separation				
Remove paper, paper products and wood from incinerator feed	Cl Org[c]	NA	NA	Paper1
Remove polyvinyl chloride from incinerator feed	Cl Org	NA	NA	PVC1
Remove food, yard and other organic wastes from incinerator feed	Cl Org	NA	NA	Food1
Collect and recycle Hg containing paints	Hg	5.3	NA	Paint3
Collect landfill Hg containing paint	Hg	2.4	$7 066	Paint2
Collect and landfill other Hg containing product	Hg	2.7	$9 421	Electric1
Collect and recycle Hg containing batteries	Hg	33.5	$9 893	Battery4
Collect and landfill Hg containing batteries	Hg	33.5	$14 132	Battery3
Pollution control				
Use activated carbon adsorption	Hg	86.2	$103 642	CA
Use sodium sulphide injection	Hg	136.3	$103 642	Na2S
Use spray dry scrubbers and fabric filters	All	124.6	$764 932	SD/FF
Use dry sorbent injection with fabric filters	Hg	95.4	$999 149	DSI/FF

NOTES:
a - To facilitate cross compound comparisons, units and costs are in tE or tonnes equivalent, based on equivalency factors discussed in Appendix F.
b - More details on actions are in Appendix D, ordered by action code.
c - Cl Org refers to chlorinated organics (PCDD/F, HCB, PCB); Hg is mercury; All refers to both chlorinated organics and mercury.
d - Based on the average unit cost for all MSWI facilities in the GLB. Unit costs for individual facilities vary.

SOURCE: Appendix D.

mental Choice program allows companies who have reduced or eliminated mercury in their batteries to use the Eco-Logo. In the United States, pressure from citizen groups and the federal government has encouraged industries that use mercury in their products to adopt source reduction programs to reduce or eliminate their mercury use. In addition, some jurisdictions have voluntarily adopted battery separation programs from municipal solid waste, and others could be encouraged to do the same.

- *Regulatory approaches*— the traditional approach to "command and control" is the approval of technological works, and emission release standards. These have had the effect of encouraging new facilities to adopt improved pollution control equipment, and could be pushed further to require "best available technology" (BAT) for all new incineration facilities, and to require retrofitting of existing facilities. On the product sides, regulations could be used to require reduction or elimination of mercury, for example, in paints (as has been done, though not primarily over concerns about incineration; most mercury from paints is released during application).

- *Economic instruments*—economic instruments can be used to influence the demand and disposition of individual components that ultimately contribute to incinerator emissions, or to address emissions directly. For example, an input tax or tradeable permit scheme could be applied to mercury used in batteries or paints to eliminate over time mercury use in these applications. A deposit-refund scheme for batteries, for example could be used to influence the fate of used batteries. In the case of the chlorinated organics, these are largely produced within the incineration system, and are therefore less amenable to upstream measures. For these, a tax or limit on the total quantity (with tradeable permits) of emissions is possible.

4.4 Program design

4.4.1 An emissions tax

Characteristics of the program

To explore the potential of the instrument, the steering committee for the project requested that consideration be given to an emissions tax on incinerators that would apply to each of the persistent toxic substances considered. In response to the tax, incinerator operators would be expected to adopt— or encourage their clients to adopt— a selection of the actions identified on Table 2. Incinerator operators could influence generators through higher tip fees, by requiring that waste to be incinerated be source separated, or by supporting source separation programs.

To achieve virtual elimination, the tax would be raised over time until such time as the combination of actions adopted eliminated emissions of the substances of concern. At low levels for the tax, the cheap and easy actions would be adopted. As the tax is increased, it becomes increasingly onerous, particularly on those sources with high emissions, encouraging retrofitting pollution control technology, diversion of waste from incinerators to other waste management methods (such as recycling, composting, or landfills), or both. At a sufficiently high level, incinerators will no longer be used for municipal solid waste.

The intent of the program, and the timeframe for its implementation would be specified at the time the program is announced in order to give as much understanding as possible to decision-makers who will be affected by the program. This might include announcing estimates of how the tax will rise over time, recognizing that actual practice may deviate from this as response lags or exceeds expectations.

Given the estimated costs by action in Table 2, several incremental steps are suggested as indicated on Table 3.

Table 3 Sequence of tax increments and progress towards virtual elimination

Proposed year adopted	Unit tax on marginal emissions ($/gE)[a]	Reduction	Description
1995	$0.00	25%	Roughly one quarter of emissions could be eliminated at zero cost
1998	$1.00	85%	A tax of $1.00 per gE would make advanced pollution control attractive in almost all cases, even accounting for cost increments associated with retrofitting, and less than full amortization period for control equipment (see text)
2005	$30.00	95%	A tax at this level would result in operating costs (alone) in excess of landfilling costs for about two-thirds of the remaining waste being incinerated.
2010	≥$45.00	100%	In general, at this tax rate, landfilling is more attractive.

SOURCES: Table 4 and Figure 2.
NOTES: a dollar per gram of mercury equivalent (see Appendix F)

The administratively simplest system would involve applying these taxes to each unit of PTS equivalent emitted. Alternatively, the tax could be applied to units in excess of a specified threshold. This latter approach would reduce revenue generated, but would decrease the impact on generators who achieve or do better than the "target" level, with the target level changing over time. The threshold would most reasonably be tied to the input waste quantity.

Administrative considerations

Fundamental to the program is the need to effectively monitor emissions, a need which may be difficult to meet. Ideally, the tax would be based on accurate, continuous monitoring. However, the identified compounds are not routinely monitored on a continuous basis: continuous monitoring is usually restricted to CO, CO_2, acid gases, total hydrocarbons, opacity, oxygen and temperature. These parameters may be used as "indicators" of the persistent toxic substances of concern. For example, CO is sometimes used as an indicator of the extent of combustion; however, it is not clear that the correlation with emissions of products of incomplete combustion, such as dioxins and furans, is sufficiently high to justify setting a tax on the basis of CO concentration.

Other problems with monitoring include inherent variability in measurements (up to a factor of three or more in replicate runs at the same facility), and variation in flow measurements (by as much as 30 percent) (U.S. OTA 1989).

Assuming that these problems could be resolved, administrative requirements would be associated with the collection of the tax, and inspection to ensure that facility monitoring equipment is properly calibrated and operated.

Jurisdictional issues

A tax on emissions would most likely fall within the jurisdiction of the states and provinces, rather than the federal governments. There are already precedents for the application of emission taxes in both Canada and the United States.

4.4.2 A marketable allowances program

As discussed in Chapter 3, if the technical preconditions of an emissions tax program are met, a marketable allowances program should also be technically feasible. Instead of the tax rate increasing from an initial level, the number of allowances would be reduced over time from an initial number, until virtual elimination is achieved.

4.4.3 A voluntary program

Characteristics of the program

Voluntary initiatives can in some circumstances have dramatic impacts. For example, the United States Environmental Protection Agency's 33/50 program aims to reduce toxic releases by 33 and 50 percent for 1992 and 1995, respectively from participating companies.[9] In general, voluntary programs can be expected to encourage the taking of actions which result in net savings, have no net cost, or which have small total costs.[10] Table 2 presents several actions that meet these criteria, including actions to reduce or eliminate mercury in batteries, paints, and other products. These actions can yield significant reductions, but by themselves will not achieve virtual elimination.

A voluntary program has many desirable characteristics, aside from the obvious one that it involves voluntary action. Because the actions are voluntary, they are usually actions that involve little or no cost; in fact they are often associated with net savings. Further, to achieve the desired end at no cost, they often involve either better or different operating procedures which lead to pollution prevention, rather than pollution control.

Many of the actions identified as being taken voluntarily because they have no cost and possibly cost savings associated with them are being taken already, for example, battery manufacturers are producing mercury "free" batteries. Others, though of comparable or lower cost, may not be adopted due to a wide variety of factors, including:

- ignorance of opportunities and implications
- inertia driven by tradition, a concern with other aspects of operations, or uncertainty about the implications of a change
- perceived or actual differences in performance
- lack of access to credit to make the necessary investment
- difficulty in implementing alternatives (such as land-fill) due to public pressure and approval difficulties

---

[9] There is very high participation in the program from industries that release mercury or ship it off-site for disposal; participating industries account for almost 93 per cent of total industrial mercury releases (U.S. EPA 1992).

[10] In some cases, and for some firms or individuals, voluntary actions may be taken that have significant costs. Reasons for these are many, and include a sense of social responsibility on the part of the decision-maker, benefits beyond the immediate ones (e.g. market perception of initiator), or fear of regulation in the absence of action.

- a distribution of costs or benefits that does not provide an incentive for the person responsible to make the change to do so (for example, if garbage collection is free, generators have little incentive to reduce waste).

Thus an important part of the program will be an information and education program on the environmental implications of current practices, and the opportunities and benefits of a change in practices.

Administrative considerations

As indicated, information and education programs are important components of a voluntary program (and are likely required for a program of economic instruments or a command and control program as well). There will be public sector costs associated with these programs, but they are not expected to be onerous, and the required programs are well within the experience of governments in all jurisdictions of the Great Lakes basin.

Jurisdictional considerations

Given that there is no compulsion involved, and those taking the actions are usually indifferent to or benefit from the changes associated with voluntary programs, jurisdictional considerations are not usually a concern. In fact, voluntary programs create the best opportunity for cross-jurisdiction cooperation, with potential cost savings to program administrators.

4.4.4 Command and control

Characteristics of the program

Whichever policy approach is taken, it is likely that there will need to be some form of enabling legislation or other regulatory changes to permit the policy options to be introduced. However, the "command and control" option is associated with the conventional way of controlling or preventing pollution through approval or prescription of technologies.

There is already a movement towards requiring lower levels of emissions, the installation of advanced air pollution control equipment, or both. Other regulatory approaches have also been proposed or adopted: the U.S. EPA considered *requiring* battery separation from incinerator feed due to the difficulty of managing mercury (Denison and Ruston, 1990), and Ontario has imposed a regulation prohibiting new municipal waste incinerators. A regulatory program that would lead to virtual elimination of PTSs from incinerators would likely entail a prohibition on new incinerators, with grandfathering of existing incinerators until they exhaust their useful life. Under this scheme, the older facilities— which tend to be the ones with less advanced pollution control equipment and higher emissions levels— would be expected to shut down soonest.

Administrative considerations

Manufacturers of the major mercury containing products are already reducing the amount of mercury they use in their products, and regulation does not appear to be necessary.

There are a limited number of municipal waste incinerators in the Great Lakes basin, and it is quite practical to administer these few facilities.

The primary means of regulating incinerators is through the permitting process. However, the permitting process is applicable to new facilities. The financial costs of new incineration facilities and new landfill facilities are roughly comparable,[11] and thus the goal of virtual elimination ought to ensure that *new* incineration facilities are not constructed. New incinerators should be discouraged through a variety of policy instruments. Policy instruments to discourage new incinerators may include bans or economic instruments. These instruments could be designed to discourage the construction of new incineration facilities or encourage the development of new landfill capacity.

There are a number of actions identified that will affect existing facilities, and are not readily addressable through the permitting process.

Jurisdictional considerations

At the manufacturing level, the federal governments in both the United States and Canada have jurisdiction over controls on mercury content. For example, in the United States, under the *Federal Insecticide, Fungicide and Rodenticide Act* the U.S. EPA has cancelled all mercury compound registrations for mercury compounds used in exterior and interior paints and coatings.

State and provincial governments are responsible for permitting of incinerators, and for other aspects of waste management. This is the primary regulatory route for new incinerators.

---

[11] The financial costs of new incinerators and landfills are similar as a result of stricter standards applied to new landfill capacity, in comparison with existing landfill facilities, and the added costs of transporting waste to landfills.

In the United States, emissions from incinerators may be stipulated by the operating permit, or be controlled under various federal acts, the most significant of which is the *Clean Air Act.* The primary section of relevance is Section 111 which sets out New Source Performance Standards. In addition to specifying allowable emissions for new sources (based on Best Available Control Technology— BACT), states are expected to bring existing facilities up to the standard. Rules may be established under the Act for both existing and new facilities, with standards for existing facilities being given authority by individual states through their regulations.

Section 112 of the CAA enables the setting of National Emission Standards for Hazardous Air Pollutants (NESHAPs), and one has been set for mercury. NESHAPs relate to emissions that cause mortality or serious illness, and the level set for mercury would not likely affect municipal waste incinerators.

In Canada, emissions are primarily controlled by the provinces. The two main control mechanisms are ambient standards and Certificates of Approval (permits). Under proposed changes to the Ontario *Environmental Protection Act*, new source performance standards would be set on the basis of BACT. However, these changes are not being actively pursued, and their application to existing sources is unclear.

4.4.5 A combined program

The above options should not be seen as mutually exclusive. In practice, it is likely that any effective program will involve a combination of all the approaches. For example, in the short term, significant progress towards virtual elimination can be made with voluntary programs, and these can be introduced relatively quickly and easily. Over the medium term, an economic instrument— such as the emission tax— can push further towards virtual elimination. At the extreme, a prohibition (command and control) may be indicated. For example, Table 3 indicates that a 25 percent reduction can be achieved at zero incremental unit cost. Voluntary programs may be effective at ensuring these actions are taken. For the next most expensive actions, which have a net incremental unit cost greater than zero, an emission tax might induce their adoption. After the transition period has passed, it is probably more effective to institute a prohibition, rather than to maintain a tax system that has no participants.

4.5 Impact assessment

4.5.1 Elimination effectiveness

presents the specific actions considered, and their effectiveness and cost. There is considerable uncertainty associated with all the data that underlie these estimates, and they should be interpreted as indicative only.

The actions fall into three types:

- actions related to reducing the mercury content of goods ending up in the waste stream
- the retrofitting of improved emissions control technology onto existing incinerators
- an action related to diverting waste from incineration to landfill

Where capital has already been invested in pollution control equipment, the implicit result is that the emission reductions (or eliminations) associated with diversion to landfill are reduced, and the cost per gram of persistent toxic substance is higher.[12] For example, if all the municipal solid waste incinerators in the Great Lakes basin had SD/FF, and the mercury source reduction actions were taken, then the remaining emissions would be only about seven percent of the original amount, and the costs per tonne of PTS emission avoided would be more than 14 times higher than for an uncontrolled incinerator. Based on this concept, if incinerators are to be shut down, the greatest benefit is associated with shutting down incinerators that have the least effective control systems.

4.5.2 Cost effectiveness

The costs of achieving reductions are illustrated in Figure 2. The graph indicates that an emissions reduction of just over 25 percent can be achieved at no cost, by reducing the mercury content of batteries, paints and other products. For the remaining emissions, the costs of reduction vary, depending on the efficiency of the air pollution control system. The most expensive (per unit of PTS emission eliminated) are facilities with advanced pollution control equipment.

4.5.3 Anticipated revenues

The potential revenue from a tax on emissions of PTSs from incinerators is estimated. Potential revenues are

---

[12] The incinerator and landfill costs presented in this report relate to existing installations. The costs of shifting existing incinerators to landfill are high because capital charges associated with the incinerators no longer used will still be incurred.

Table 4 Incinerator actions ordered by source and economic attractiveness[a,b]

Source	Action type	Emissions 1992[e] (gE)	Incremental unit cost[c] ($/gE)	Reduction (%)	Cumulative reduction (%)
All sources[d]	Mercury reduction	45 667 746	$0.00	26.9%	26.9
Sources 26, 25, 3, 12	Pollution control	6 281 437	$0.04	3.7%	30.6
Sources 31, 28, 23, 32, 9, 21, 30, 27, 18, 29, 4	Pollution control	69 605 115	$0.05	41.0%	71.6
Sources 8, 34	Pollution control	12 562 874	$0.06	7.4%	79.0
Source 2	Pollution control	2 886 066	$0.09	1.7%	80.7
Source 11	Pollution control	8 148 892	$0.16	4.8%	85.5
Sources 6, 1, 5	Pollution control	1 867 454	$0.17	1.1%	86.6
Source 20	Pollution control	1 018 611	$0.20	0.6%	87.2
Sources 33, 17, 19	Pollution control	1 697 686	$0.27	1.0%	88.2
Sources 12, 26, 25, 5, 1, 4,6, 3	Landfill	2 037 222	$20.31	1.2%	89.4
Sources 8, 34, 13, 24, 10, 17, 20, 14, 15	Landfill	8 997 734	$28.72	5.3%	94.7
Sources 21, 9, 19, 11, 2, 28, 16, 32, 23, 31,	Landfill	7 639 586	$41.08	4.5%	99.2
Sources 18, 29, 27, 30, 22, 33	Landfill	1 358 149	$44.45	0.8%	100.0

NOTES:

a - To facilitate cross compound comparisons, units and costs are in gE or grammes equivalent, based on equivalency factors discussed in Appendix F. The incinerator and landfill costs presented in this report relate to existing installations. The costs of shifting from incineration to landfill are high because the capital charges of existing incinerators no longer used will still be incurred.

b - More details on individual actions are in Appendix D.

c - Unit costs for individual facilities.

d - Mercury source reduction and product substitution actions are costless. These actions were grouped together and the potential reduction applied to all sources.

e - Estimated total PTSs emissions are 169.8 million gE in 1992. Calculations are based on existing emission control efficiencies for mercury from incinerators in the GLB and on emission factors of dioxins and furans from incinerators.

SOURCES: Appendix D and Table 2. See report text for description of cost effectiveness methodology.

equivalent to the tax rate multiplied by the number of tonnes for which the costs of actions exceed the tax. The quantity of PTSs emissions from incinerators eliminated can be expected to fall as the tax on its use increases, following the curve in Figure 3.[13] The revenue generated will depend on the level of the tax, and the reduction actions available at a cost less than that tax.[14] At a tax level of zero, the revenue is zero; an infinitely large tax can also expect to have zero revenue, since no one would pay an infinitely large tax and would instead adopt actions to avoid the tax. The relationship between the level of the tax and the revenues generated is presented in Figure 3.

---

[13] The drop in PTS emissions is likely to be higher, for several reasons. First, the increased cost of incineration will cause some users of incinerators to seek alternative waste handling methods or to reduce their demand for incinerators. Secondly, products which contribute to PTS emissions and are not included in the analysis can also be expected to be diverted from incinerators as the tax rises.

[14] For example, a tax of $0.2/gE applies to about 22 million gE PTSs (170 million gE minus 148 million gE PTSs reduced from the adoption of actions to phase out PTS emissions from incinerators). Total tax revenue is estimated at about $4.4 million.

Figure 2 Incremental costs of achieving reductions in emissions from incinerators

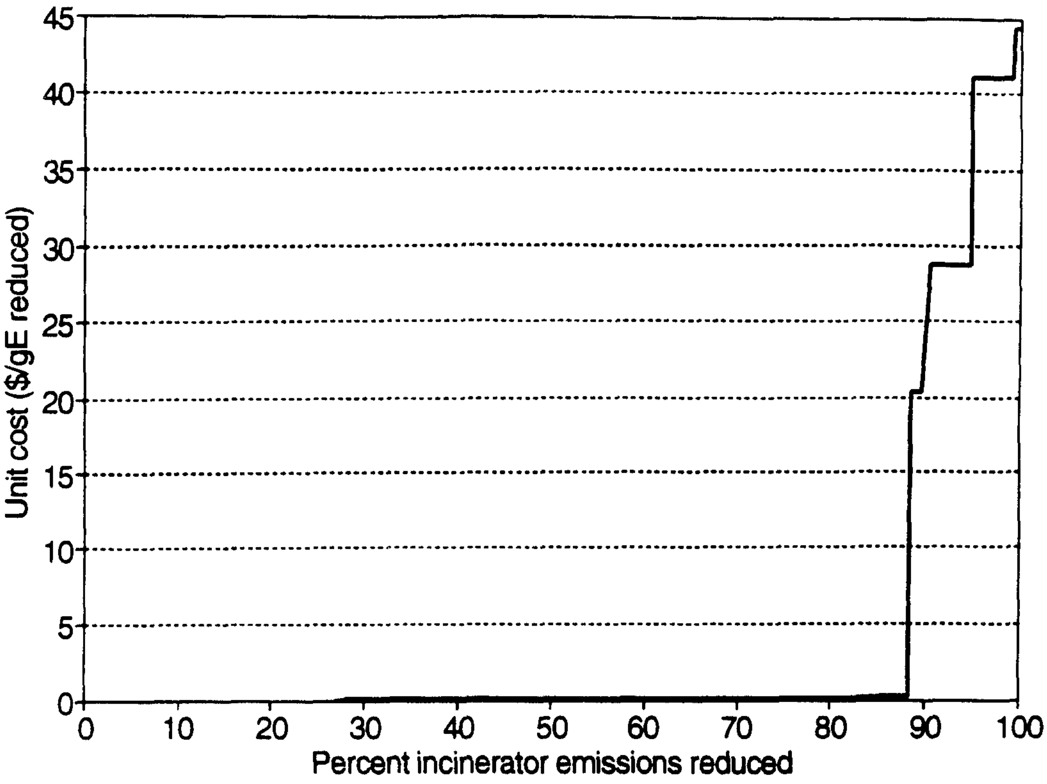
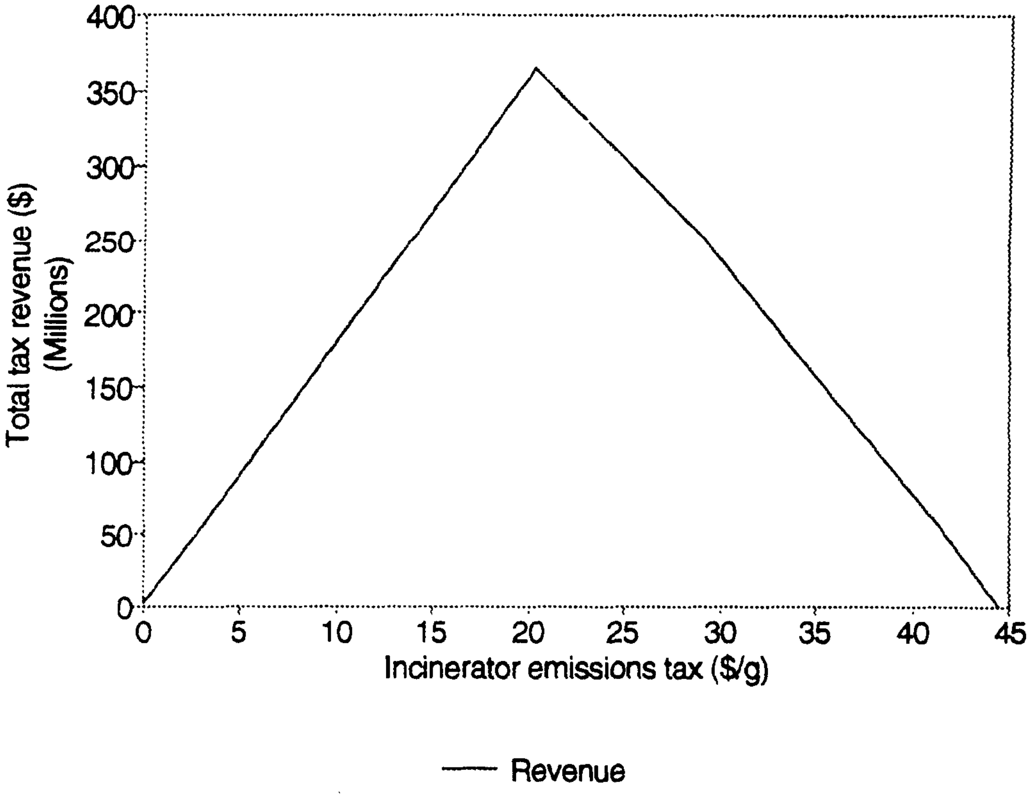


Figure 3 Revenues from a tax on PTSs emissions from incinerators



Revenues from a tax on PTSs emissions are expected to peak at about $20/gE, resulting in a reduction in the PTSs emissions from incinerators of about 90% (See Figure 3). The total revenue generated is about $350 million. A decline in tax revenue occurs from this peak as the level of the tax increases. There is a large shift in the level of the tax required to eliminate emissions at about a $0.25/gE tax. At this tax level almost 88% of PTSs from incinerators are expected to be eliminated. Total tax revenue would be about $5 million. The level of the tax would have to increase to about $20/gE to invoke further elimination of PTSs emissions. The large increase in the tax is required as a result of increasingly more expensive actions which must be adopted.

4.5.4 Distributional issues

For each MCWI, the order of actions by unit cost is the same: mercury reduction is the least expensive for all sources, pollution control is the next most expensive for all sources, and landfilling is the most expensive for all sources. Furthermore, it is always more cost-effective overall for *all* sources to adopt a given level of action before *any* sources undertake the next more costly action. The incremental unit costs of landfilling are generally at least two orders of magnitude greater than the incremental unit costs of pollution control.

There appear to be no particular patterns of the unit costs of reduction. In particular, there are no evident geographic patterns: the unit costs of sources in each jurisdiction are distributed more or less evenly through the range for all sources. There is substantially greater incineration of municipal solid waste in the United States than in Canada, however, and consequently *total* costs of reduction are greater in the United States than in Canada.

Unit costs of reduction are greater for incinerators with the lowest emissions, especially in the case of pollution control. Unit costs for the MCWIs with the greatest emissions are in the middle of the range.

There may be small changes in each jurisdiction in the numbers and incomes of people in waste management in the transition from incineration to other waste management practices, including landfilling. Furthermore, landfilling ideally requires use of land near the source of generation (near urban areas). The siting of landfills can have substantial and contentious distributional implications, as a consequence of the real and anticipated disamenities for nearby residents.

For the general population (other than those directly affected by working in waste management or residing near landfills or incinerators), the effects of each of the policy instruments on distribution of income depends on how the additional costs of municipal solid waste management and emissions charges are paid. If all households are required to pay an additional charge per unit of waste, this might have a regressive effect, because the amount of waste generated is generally greater in relation to income for poorer households than for wealthier households. Kemper and Quigley (1976) found in the United States that the income elasticity of user charges as a proportion of income is less regressive than the income elasticity of property taxes as a proportion of income. In the case of environmental charges, some of the revenues could be used to offset regressive effects through some form of compensation.

On the whole, however, economic instruments applied to incinerator emissions would likely encourage greater application of unit charge systems for municipal waste, combined with recycling programs. Numerous studies have shown that this can substantially reduce waste generation and waste management costs. Source separation and recycling programs could also be directed to materials that are most prone to generating PTSs when they are incinerated or landfilled.

For the most part, these considerations apply whether the policy instrument applied to incinerators is an economic instrument or "command and control." Under "command and control," a phased policy toward virtual elimination might first require all MCWIs to install pollution control, and then require each to convert to landfilling toward the end of the operational life of each incinerator, or within some other specified time. Depending on capital and operating costs and the policy schedule, however, it might be less costly for some incinerators (especially those close to the end of their operational lives) to close and convert to landfilling immediately, rather than incurring the capital cost of pollution control equipment.

Under an emissions tax program, an escalating emissions tax schedule would be announced as shown in Table 3. Emitters would have an initial three-year period for voluntary actions and preparation for the emissions tax. The tax would initially encourage advanced pollution control at existing incinerators, and eventually encourage substitution of landfilling for incineration. The emissions tax program would *also* provide increasing incentives for waste reduction and source separation of wastes most responsible for emissions of PTSs. The other advantage to the use of an emissions charge rather than "command and control" is that it might permit reductions to occur with less delay, as there would likely be less initial resistance to the program from sources for which unit costs are greatest: the sources for which unit costs are lowest would adopt pollution control soon, while those with higher unit costs could take more time.

4.5.5 Feasibility, limitations and mitigation options

The results indicate that the sequence of actions for *each* incinerator in order of incremental unit cost are the same:

- actions related to reducing the mercury content of goods ending up in the waste stream
- the retrofitting of improved emissions control technology
- an action related to diverting waste from incineration to landfill

If the private costs of mercury reduction are indeed close to zero, the only potential impediment to the implementation of a *voluntary program* with this purpose is the administrative feasibility and (public) cost of establishing a system and infrastructure for reduction. Experience in some jurisdictions indicates that the costs should not be great, especially considering the economies of scale that could be realized if a standard system was established throughout the Great Lakes basin or North America.

The main question about the feasibility of *economic instruments* for MCWI emissions concerns the technical feasibility (and cost) of continuous monitoring of emissions of PTSs or of reasonable proxies for these emissions. If proxies for emissions are required (e.g. carbon monoxide as a proxy for products of incomplete combustion), it is likely that these will be only approximate indicators of emissions. Consequently, the system may be considered less fair, and might not have the same beneficial incentive effects (e.g. it might not encourage pollution prevention actions that reduce emissions, if these actions do not affect the proxy for emissions).

If a satisfactory means of monitoring PTSs discharges can be found, either a discharge tax or a marketable allowance program can be considered. As discussed in Chapter 3, both kinds of economic instrument can be designed to achieve the same results. The main advantage of a marketable allowance program is that there is already substantial experience and acceptance of such programs in the United States: the necessary skills and administrative arrangements to operate such programs already exist and are rapidly becoming more widespread with the trading programs under the *Clean Air Act*. There is very little experience with environmental taxes (especially discharge taxes) in the jurisdictions in the Great Lakes basin.

The main disadvantage of a marketable allowance program for PTSs discharges from incinerators is the likely objection on ethical grounds against establishing perceived "rights to pollute," especially for PTSs. In this regard, a discharge tax may be more acceptable than marketable allowance program.

If revenue generation is an objective in establishing an economic instruments program, this could be served by either a tax or a marketable allowance program in which allowances are initially auctioned. Of course, it is likely that the greater the revenue that is sought, the greater will be the opposition to the program from those subject to it. In this regard, a marketable allowance program in which allowances are initially "grandfathered" is likely to meet with least opposition, but would generate no revenue. There is some anecdotal evidence that the generation of revenue from an environmental tax or marketable allowance program receives greater acceptance if the revenue is earmarked for environmental protection or restoration, or to compensate individuals or communities for the impacts of the program (Burtraw 1991).

There is some danger in having revenue generation as an objective in a program of economic instruments for virtual elimination, in that dependence on these revenues might develop and thereby diminish the will to advance toward virtual elimination, since advance toward this goal must eventually lead to the decline and loss of the revenues.

Given the incremental costs of incinerator actions (Table 4), the actions taken by incinerator operators under the suggested sequence of tax increments in Table 3 (or equivalent program in terms of marketable allowances) would be the same as those under a command and control program that required *all* incinerators to have improved pollution control by 1998, and to be decommissioned by 2010. *In this case*, there is no gain in economic efficiency by having an economic instruments program rather than this command and control program. Similarly, if there was no net revenue generation from the economic instruments program, the economic impacts of the programs would be the same.

Nevertheless, an economic instruments program might have several advantages over a "command and control" program:

- an economic instruments program might allow reductions to occur faster than a "command and control" program, since there might be less initial resistance to the program and delay from operators of sources with higher unit costs of reduction, since they could *initially* avoid the expense of having to make reductions by paying the tax (or buying more allowances)[15]
- an economic instruments program would provide incentives for the full range of effective actions, including pollution prevention actions, such as waste reduction and source separation, whereas a "command and control" program would not
- more generally, an economic instruments program would provide incentives for innovation in methods and technologies of pollution prevention and reduction; a "command and control" program would not.

There is another compelling advantage to the application of economic instruments in that they can help to address gaps in information on which actions and programs can be based. Currently, essential information about the processes, operating conditions, and components of the waste stream that lead to the production of PTSs (with the possible exception of mercury) is lacking, unreliable or unconfirmed. Economic instruments applied to emissions would provide waste management system operators strong incentives to obtain this information, because this is exactly the information that can help them to reduce and eliminate emissions in the most cost-effective manner. When this information is more comprehensive and reliable, it can help to indicate where other measures can most effectively be applied. If, for example, there are components of the waste stream that are especially responsible for emissions of PTSs, there will be strong incentives from economic instruments applied to emissions for waste management system operators to identify these components, and support their elimination from the waste stream.

---

[15] This situation is similar to that which was addressed by the use of a tradeable permit system for the phasing out of lead in gasoline in the United States, where the speed of implementation and phase-out was one of the main advantages of the use of the economic instrument.

5. Persistent toxic substances and polyvinyl chloride

As described above, policy measures for phasing out the use of polyvinyl chloride were selected because polyvinyl chloride (PVC) manufacturing is the largest (and growing) user of chlorine. The assessment of phasing out PVC use through the imposition of an input tax is illustrative of the likely impact of such a program to eliminate chlorine use in general.

This chapter consists of five sections:

- An overview of PVC production and use
- A discussion of the PVC substitution options
- Policy instruments that could induce these technologies to be adopted. Voluntary, economic and regulatory instruments are introduced
- Three programs involving the policy instruments are described, including an input tax
- The programs are assessed against the criteria described in the previous chapter

5.1 PVC production and use

Polyvinyl chloride manufacture is a large consumer of industrial chlorine in the Great Lakes basin (VETF 1993b).

PVC is produced from elemental chlorine and ethylene. These chemicals are combined to make the primary ingredient of vinyl chloride monomer (VCM). In Canada, production of ethylene dichloride comprised 41 percent of chlorine demand in 1990 (VETF 1993b). In the U.S., 27 percent of chlorine demand was for production of ethylene dichloride in 1990 (CamfordInformation Services 1991). The vinyl chloride monomers are combined to make polyvinyl chloride. By molecular weight, chlorine comprises about 58.1 percent of polyvinyl chloride, i.e. every tonne of PVC contains about 581 kg of chlorine.

Specific environmental concerns regarding PVC include (Norsk Hydro 1992):

- emissions from production of chlorine, vinyl chloride monomer and ethylenethe use of heavy metal stabilisers in PVC
- the migration of plasticisers
- the reaction of PVC to fire
- the degradation of PVC during production and use
- difficulties of recycling PVC

5.1.1. PVC production in the Great Lakes basin

Estimated production capacity[16] of PVC in the Great Lakes basin is shown in Table 5. Total PVC capacity is estimated at 507 kt/a (Camford Information Services 1991).

PVC production capacity in the Great Lakes basin represents approximately 9 percent of PVC production capacity in North America. However, PVC producers in the Great Lakes basin (particularly the northeastern United States) are characterized by relatively smaller and older plants than those in the rest of the continent. These plants tend also to produce dispersion and suspension PVC resins, used in the manufacture of flexible vinyl flooring, wall coverings and coated fabrics, while commodity grade resins, used in the production of rigid vinyl products such as siding and pipe, tend to be produced by newer and larger facilities located close to PVC feedstocks in the southern United States or offshore (Ho 1993). Because of these characteristics of plants located within the Great Lakes basin, there is likely considerable exporting and importing of PVC resins between the Great Lakes basin and the rest of North America.

5.1.2 PVC use in the Great Lakes basin

To evaluate the impacts of actions resulting from a phase out of chlorine as a PVC feedstock, it is necessary to determine at least the most significant products and applications from each major product category.[17]

Use of PVC by product type in the Great Lakes basin was estimated using PVC production figures for Canada and the United States, according to the distribution of products in the United States, and apportioned according to the population of the Great Lakes basin as a proportion of the total population of Canada and the United States.

Estimated use of PVC (and subsequent chlorine use) by product type in the Great Lakes basin is shown in Table 6. The use of PVC resin in the Great Lakes basin in 1992 totalled about 599.3 kt requiring about 348.2 kt of elemental chlorine. The major user of PVC in the Great

---

[16] Actual production may be less than production capacity.

[17] For the assessment of actions, the actual quantities produced and used are not important, since actions are assessed in terms of a proportional reduction in PVC production expressed as a percentage, rather than an absolute reduction in kilotonnes of PVC produced.

Table 5 PVC production in the Great Lakes Basin, 1992

Producer	**Location**	**Capacity (kt/a)**
Esso Chemical Canada	Sarnia, Ontario	130
Geon (formerly BF Goodrich) Canada	Niagara Falls, Ontario	184
Geon (formerly BF Goodrich)	Avon Lake, OH	79
Goodyear	Niagara, NY	57
Vygen	Ashtabula, OH	57
Total		**507**

NOTE: Production at Avon Lake plant was estimated as 10% of B.F. Goodrich United States production in 1992.

SOURCES: Camford Information Services 1991.

Table 6 PVC demand and chlorine use in the Great Lakes Basin, 1992

Major product category	**Product**	**PVC (kt)**	**(%)**	**Chlorine (kt)**
Building and Construction	Pressure - water pipe	82.6	13.8%	48.0
	Siding accessories	66.6	11.1%	38.7
	Sewer drain	57.6	9.6%	33.4
	Drain/waste/vent pipe	40.5	6.8%	23.5
	Conduit	34.7	5.8%	20.1
	Pipe fittings	14.8	2.5%	8.6
	Flooring (calendered)	13.8	2.3%	8.0
	Pressure - irrigation pipe	13.2	2.2%	7.7
	Building flooring (dispersion coated)	10.6	1.8%	6.2
	Composite window profiles	9.9	1.6%	5.7
	All-vinyl window profiles	8.6	1.4%	5.0
	Pond/pool liners	4.6	0.8%	2.7
	Other pipe and conduit	3.9	0.7%	2.3
	Pressure - other pipe	3.8	0.6%	2.2
	subtotal	*365.1*	*60.9%*	*212.1*
Packaging	Film	16.1	2.7%	9.4
	Bottles	12.8	2.1%	7.5
	Sheet	11.2	1.9%	6.5
	subtotal	*40.2*	*6.7%*	*23.3*
Electrical and electronics	Wire and cable	27.7	4.6%	16.1
	Appliances, business machines	5.4	0.9%	3.1
	Plugs, connectors, etc.	3.9	0.7%	2.3
	subtotal	*36.9*	*6.2%*	*21.5*
Consumer and Institutional	Hospital & health care	8.3	1.4%	4.8
	Medical tubing	5.2	0.9%	3.0
	Blood/solution bags	5.2	0.9%	3.0
	Footwear	4.3	0.7%	2.5
	Appliances	3.9	0.7%	2.3
	Garden hose	3.6	0.6%	2.1
	subtotal	*30.6*	*5.1%*	*17.8*
Furniture and furnishings	Upholstery	5.6	0.9%	3.3
	Wall covering	5.0	0.8%	2.9
	subtotal	*10.7*	*1.8%*	*6.2*
Vinyl latexes	Adhesives and sealants	4.6	0.8%	2.7
Compounders and resellers		23.8	4.0%	13.8
Exports		87.5	14.6%	50.9
Total production		**599.3**	**100%**	**348.2**

SOURCES: Modern Plastics 1993; Camford Information Services 1991.

Lakes basin is building and construction, which used approximately 365.1 kt (60.9 percent of PVC used in the Great Lakes basin), compared with about 40.2 kt (6.7 percent) used in packaging and 36.9 kt (6.2 percent) used in electrical applications in the Great Lakes basin.

Products using PVC may require a variety of different material characteristics, depending on the product's required reaction to:

- temperature (during assembly, finishing, shipping and in the final application)
- chemicals, solvents, acids, fuels (permeability and inertness)
- humidity, ultraviolet light and radiation

Other factors to be considered in the formulation of a resin to meet product specifications include:

- regulatory approvals (e.g. Health and Welfare Canada and the U.S. Food and Drug Administration require certain material standards in the use of PVC where it may contact food, pharmaceutical and cosmetic products)
- product assembly (includes considerations such as strength, flexibility and dimensional stability)
- finish (appearance, clarity, ability to retain pigments, and compatibility with applied finishes).

The material characteristic requirements of each product using PVC will require a specific formulation of PVC resin, fillers, stabilizers, plasticizers and pigments. A typical PVC compound may contain 6 to 10 different ingredients in addition to resin (Holsopple 1993). Geon Corporation (formerly a division of B.F. Goodrich) supplies more than 2,000 PVC compounds, each with different characteristics, to manufacturers of PVC-containing products (Dugan 1993).

5.2 Alternative technologies and processes

Alternative products for the different applications of PVC must be adopted to successfully phase out chlorine as a feedstock for PVC production. This study focused its major research effort on the benefits and costs of substitutes for the largest PVC product categories in the building and construction category. The uses include, pressure water pipes, siding and sewer drains/pipes, vinyl windows and electrical conduit and are major products using PVC. Primary data collection was undertaken to obtain benefit and cost information for these substitute products. Costs of substitutes for other products containing PVC were obtained from a study by Charles River Associates Incorporated (CRA 1993).

PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study. In the estimation of action cost per kilogram of PVC, it was assumed that 100% of the cost difference between the alternate and the PVC product was due to the cost of PVC and none was due to the cost of the additives. Details on action costs are appended.

5.3 Policy instruments

Numerous policy instruments are available to influence the adoption of these actions, including options from each of the three main approaches considered in this study:

- *Information and moral suasion programs*—education to both industries and consumers to provide for more informed decision making about the use of PVC. These programs could also provide information on environmental impacts associated with PVC.

- *Regulatory approaches*—with respect to PVC the traditional "command and control" regulatory regimes could be implemented at number of stages in the production of PVC. For example, a ban on the manufacture of PVC or on certain uses of PVC (e.g. packaging and other non-durable goods). Alternatively, a prohibition, or limits on incineration of PVC could be instituted. Regulatory approaches phasing out PVC will require the adoption of substitute products.

- *Economic instruments*—economic instruments can be applied to several stages of the lifecycle of PVC. For example, input taxes on chlorine or taxes on manufactured PVC itself. Deposits on PVC products to ensure control over disposal practices could also be adopted. Economic instruments. like regulatory approaches require the adoption of substitute products for PVC use.

5.4 Program design

5.4.1 An input tax

Characteristics of the program

This program involves applying an input tax on chlorine used in PVC production, with the tax rising over time to discourage PVC use. With each rise in the level of the tax, additional substitutes can be expected to become avail-

Table 7 Sequence of tax increments and progress towards virtual elimination

Proposed year adopted	Unit tax on PVC input[a]	Reduction	Description
1995	$0	25%	Numerous substitutes are already available at less cost than PVC
1998	$1	40%	Most watermain, sewer pipes and packaging would switch to substitutes at or below this tax level
2002	$3	60%	Most consumer and industrial products, furnishings and electronics would have switched out of PVC at this tax level
2005	$6	92%	All PVC uses except electrical conduit applications are unattractive at this tax level
2010	≥$10	~100%	It is likely that very few uses of PVC would remain at this tax level

NOTE: a - Input tax is in $/kg of PVC

SOURCE: Table 8 and Figure 4.

able, displacing PVC from additional uses. At very high prices, only those uses of PVC for which acceptable substitute materials are unavailable will continue to use PVC.

As discussed for the incinerator emissions tax, it is important at the outset of the program to announce the intent of the program, and the timeframe for implementation. This announcement will give decision-makers who will be affected by the program an understanding of what is to be achieved and when they will need to act. Given the estimated costs by action in Table 7, several incremental steps are suggested (see Table 7).

Administrative considerations

Much of the PVC use in the Great Lakes basin is of PVC produced outside the region. To reduce toxic emissions from PVC production, use and disposal in the Great Lakes basin, the program will be more effective and easier to administer if it is applied nationally in both Canada and United States. It would also be necessary to apply a tax or duty on imports of PVC, or otherwise restrict imports, into Canada and the United States to ensure that the program does not merely replace domestically produced PVC with imported PVC.[18]

There are several places in the manufacturing chain at which the chlorine tax could be applied. The point of intervention can be determined on the basis of the number of actors involved, and the effectiveness with which monitoring can occur. The most likely point of intervention is at the point of PVC production where chlorine is applied as a feedstock. This requires monitoring of the five PVC production facilities in the Great Lakes basin.[19]

The indicated taxes are substantial, especially when viewed relative to the typical selling prices of about $0.20 per kilogram PVC, suggesting the need for a careful monitoring system, involving monitoring of both PVC input materials, and off-site transfers.

Jurisdictional considerations

In the United States, such a tax could be introduced by either state governments or the federal governments. In Canada, the tax would fall within provincial jurisdiction.

---

[18] This is analogous to the marketable allowances program for CFCs in the United States (mentioned in Chapter 3), which applies to both domestically-produced CFCs *and* imports.

[19] Given the objective of virtual elimination, it is expected that these plants would cease producing PVC. In fact, given that the plants in the Basin tend to be older and smaller facilities, they might well be expected to be among the first to cease operations as the industry responds to the contraction associated with the program in both countries.

5.4.2 A voluntary program

Characteristics of the program

Information incentives may include advertising, education, moral suasion, and the signalling of change by adopting non-statutory standards (Cassils 1992). The information provided may seek to introduce broad ecological concepts (to change the way people view the world and their work and consumption habits) or may focus rather narrowly on specific programs or campaigns, to encourage recycling or energy conservation, for example.

Information programs to induce actions to reduce the use of PVC might include:

- affirmative disclosure (labelling products for their PVC content)
- targeted advertising (to consumers, or consumer groups, illustrating the environmental or economic benefits of alternative products)
- general education programs (for the general public or school or community groups)
- audit programs (to review the use of PVC-containing products with a view to reducing their use or replacing them with alternative materials)
- moral suasion (public comments by government officials, persuasion of decision-makers, and admonitions to encourage industry and consumers to recognize the environmental or economic benefits of reducing their use of PVC)

Administrative considerations

The administrative requirements associated with the program include development and implementation of information and education programs, and consultation with stakeholders. These are also requirements for a program of economic instruments (like the input tax) or a command and control program.

Jurisdictional considerations

As with the municipal solid waste incinerator voluntary program, there is no compulsion involved for those taking the actions. As such, jurisdictional considerations are not likely to be an issue. Again, there is an opportunity for multi-jurisdiction cooperation and collaboration, with potential cost savings to individual program administrators.

5.4.3 Command and control

Characteristics of the program

"Command and control" policy measures may include:

- bans
- emission controls
- prescribed technology standards

Historically, policy measures to control releases of persistent toxic substances to the environment involved emission controls and prescribed technology standards for production processes and pollution control. Comprehensive bans on the use and release of persistent toxic substances have traditionally been extremely difficult to implement. An example of a significant exception to this tradition is the Ontario provincial regulation designed to phase out the use of chlorofluorocarbons (CFCs) as aerosol propellants and blowing agents.

A command and control program to induce actions to virtually eliminate the use of polyvinyl chloride, in the product categories discussed earlier, would likely differ from the traditional command and control approach. Like the CFC regulations, the appropriate form for a command and control approach to reducing the use of PVC in the Great Lakes basin would be a ban to phase out the use of PVC in specified applications over time.

For example, a gradual ban on the use of PVC might address vinyl doors and windows, water main pressure pipes and sewer pipes in the first phase (inducing those actions costing less than zero), and then siding and accessories, electrical conduits, vinyl tile and flooring and irrigation pipes in a subsequent phase, etc. It would likely be preferable to include use categories in each phase in order of increasing cost to society. Like the CFC regulations, where exceptions and exemptions were granted to uses of CFCs deemed to have a high social value (like aerosol propellants for pharmaceuticals), it would likely be desirable to postpone banning applications of PVC with high social value until acceptable alternatives are developed.

Administrative considerations

The actual phase out through regulatory prohibitions would be ordered not according to economic attractiveness, but according to environmental damage associated with the product, tempered where there are not available substitutes or where the product is considered socially desirable.

Jurisdictional considerations

Regulations to prohibit the manufacture or sale of PVC containing products could be implemented by either state/provincial or federal governments in both jurisdictions, and there are precedents for banning the use of certain materials in products (e.g. CFCs).

5.5 Impact assessment

5.5.1 Elimination effectiveness

The selected actions for reducing PVC use are presented in Table 7. All of the actions shown in Table 7 require the substitution of PVC products implying a 100% reduction in PVC for these uses. The actions include all uses of PVC identified in Table 6 and account for about 100.0% of total PVC use in the Great Lakes basin. The largest use of PVC on a percentage basis is for vinyl flooring, siding and windows, about 15% of total PVC manufactured. The use of PVC for water main pressure pipes is also significant, accounting for about 14% of total PVC manufactured.

5.5.2 Cost effectiveness

Table 7 also lists the actions by their economic attractiveness for reducing PVC use from the least costly to the most expensive. Ranking is based on the incremental unit cost of each action. Window profiles are the most economically attractive resulting in a cost savings of about $38/kg of PVC reduced (kg-PVC). In addition, eight other actions for sewer pipe and water main pressure pipes had negative costs. The most costly actions were those for electrical conduits, costing between almost $6/kg-PVC reduced and about $10/kg-PVC reduced, respectively.

The abatement cost curve is estimated by plotting and sorting the incremental costs of actions against the cumulative percent reduction in PVC use. For example (Table 7), SEWER1 (sanitary sewer pipes) is more attractive than action WATMAIN3 (water main pressure pipes) for redu-cing PVC use since its incremental unit cost is less (SEW-ER1 costs $-0.21/kg-PVC versus WATMAIN3 $0.48/kg-PVC). Figure 4 presents the data in Table 8 graphically.

Table 8 Actions ordered by source and economic attractiveness

Action code[a]	**Description**	**PVC use 1992[c] (kt)**	**Reduction in PVC use (%)**	**Incremental unit cost[b] ($/kg reduced)**	**Cumulative reduction (%)**
VINYL3	Building and construction - windows	21.6	3.6%	($38.00)	3.6%
SEWER2	Sewer pipes - storm	45.2	7.5%	($1.09)	11.2%
WATMAIN9	Water main pressure pipes - 20 inch	10.7	1.8%	($1.00)	12.9%
WATMAIN8	Water main pressure pipes - 18 inch	10.7	1.8%	($0.88)	14.7%
WATMAIN5	Water main pressure pipes - 12 inch	10.7	1.8%	($0.60)	16.5%
WATMAIN7	Water main pressure pipes - 16 inch	10.7	1.8%	($0.55)	18.3%
WATMAIN6	Water main pressure pipes - 14 inch	10.7	1.8%	($0.39)	20.1%
WATMAIN4	Water main pressure pipes - 10 inch	10.7	1.8%	($0.29)	21.9%
SEWER1	Sewer pipes - sanitary	22.2	3.7%	($0.21)	25.6%
ELECT1[d]	Electrical and electronics - wire and cable	32.4	5.4%	$0.29	31.0%
PACK1[d]	Packaging - film	18.9	3.2%	$0.34	34.2%
PACK3[d]	Packaging - sheet	13.1	2.2%	$0.34	36.4%
PACK2[d]	Packaging - bottles	15.0	2.5%	$0.43	38.9%
WATMAIN3	Water main pressure pipes - 8 inch	10.7	1.8%	$0.48	40.7%
WATMAIN2	Water main pressure pipes - 6 inch	10.7	1.8%	$1.15	42.4%
IRRIG1[d]	Irrigation pipes - underground	15.5	2.6%	$1.51	45.0%
FURNISH1[d]	Furniture and furnishings - upholstery	6.6	1.1%	$1.65	46.1%
CONSIND1[d]	Consumer and industrial - healthcare	9.7	1.6%	$1.65	47.7%
CONSIND5[d]	Consumer and industrial - appliances	4.6	0.8%	$1.65	48.5%
FURNISH2[d]	Furniture and furnishings - wallcovering	5.9	1.0%	$1.65	49.5%
ELECT2[d]	Electrical and electronics - appliances, business	6.3	1.0%	$1.65	50.5%
COMPOUND1[d]	Compounders and resellers	27.8	4.6%	$1.65	55.2%
ELECT3[d]	Electrical and electronics - plugs, etc.	4.6	0.8%	$1.65	55.9%

Cont'd next page

Table 8, *cont'd* Actions ordered by source and economic attractiveness

Action code[a]	**Description**	**PVC use 1992[e] (kt)**	**Reduction in PVC use (%)**	**Incremental unit cost[b] ($/kg reduced)**	**Cumulative reduction (%)**
CONSIND4[d]	Consumer and industrial - footwear	5.0	0.8%	$1.65	56.8%
CONSIND2[d]	Consumer and industrial - medical tubing	6.1	1.0%	$1.65	57.8%
CONSIND6[d]	Consumer and industrial - garden hose	4.3	0.7%	$1.65	58.5%
CONSIND3[d]	Consumer and industrial - solution bags	6.1	1.0%	$1.65	59.5%
POP1[d]	Pressure - other pipe	4.4	0.7%	$3.11	60.3%
WATMAIN1	Water main pressure pipes - 4 inch	10.7	1.8%	$3.26	62.1%
CONDUIT9	Electrical conduits	0.3	0.0%[c]	$3.31	62.1%
DWV1[d]	Drain/waste/vent pipes	47.4	7.9%	$3.57	70.0%
VINYL2[d]	Building and construction - tile flooring	28.5	4.8%	$3.90	74.8%
VINYL1	Building and construction - siding and accessories	78.0	13.0%	$4.13	87.8%
CONDUIT5	Electrical conduits - 1.50 inch	1.8	0.3%	$4.50	88.1%
ADHESIVE1[d]	Vinyl latexes - adhesives and sealants	5.4	0.9%	$4.84	89.0%
CONDUIT6	Electrical conduits - 2.00 inch	7.7	1.3%	$5.84	90.3%
CONDUIT3	Electrical conduits - 1.00 inch	9.9	1.7%	$5.97	92.0%
CONDUIT2	Electrical conduits - 0.75 inch	18.8	3.1%	$6.33	95.1%
CONDUIT7	Electrical conduits - 2.50 inch	8.3	1.4%	$6.75	96.5%
CONDUIT4	Electrical conduits - 1.25 inch	8.2	1.4%	$6.95	97.9%
CONDUIT8	Electrical conduits - 3.00 inch	2.2	0.4%	$7.51	98.2%
CONDUIT1	Electrical conduits - 0.50 inch	10.7	1.8%	$9.51	100.0%

NOTES: a - Action code refers to the coding of Action Information Sheets appended.
b - Costs are for reduction in PVC use (1992C$).
c - Less than 0.5%.
d - Incremental unit cost calculated based on CRA 1993.
e - Total PVC production is 599.3 kt in 1992 (see Table 5).

SOURCES: Appendix E and CRA, 1993. See report text for description of cost effectiveness methodology.

5.5.3 Anticipated revenues

The potential tax revenues from a tax on chlorine use for PVC production is estimated. Potential tax revenues are equivalent to the tax rate multiplied by the number of kilograms for which the costs of actions exceed the tax.[20]

At the limit (or at the end of the program period when virtual elimination is required), the tax rate is higher than the unit rate of the most expensive action.

The quantity of PVC demanded can be expected to fall as the tax on its use increases, following the curve in Figure 4.[21] The revenue generated will depends on the level of the tax, and the reduction actions available at a cost less than that tax. At zero tax, the revenue is zero; if the tax is large enough to encourage substitution of other materials for PVC in all applications, then the PVC production would be obviated, and the revenue would again be zero. Between no tax and the prohibitive tax, revenues could rise and fall with the tax level. The relationship between the level of the tax and the revenues generated for use in the Great Lakes basin is presented in Figure 5.[22]

Revenues from a tax on PVC are expected to peak at about $3.3/kg. The total revenue generated is about $750 million. The cumulative reduction in the use of PVC at this point is 62.1 percent (see Table 8). A decline in tax revenue occurs from this peak as the level of the tax increases. A second peak in the level of tax revenue arises at

---

[20] For example, a tax of $6/kg applies to about 48 million kg PVC (599 million kg minus 551 million kg-PVC reduced from the adoption of substitute for lower cost PVC uses replaced at lower tax levels applied to PVC). Total tax revenue is estimated at about $300 million.

[21] The drop in PVC use is likely to be higher, for several reasons. First, the increased cost of PVC will cause some users to reduce their demand for PVC containing products, even if they do not switch to a substitute material.

[22] The curve represents the possible stream of tax revenue based on the actions identified in Table 7.

Figure 4 Incremental costs of achieving reductions in PVC use

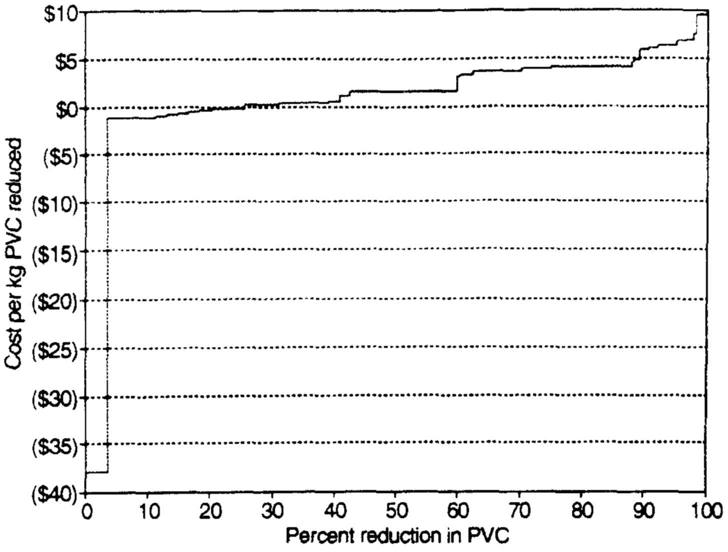


Figure 5 Revenues from a tax on PVC use

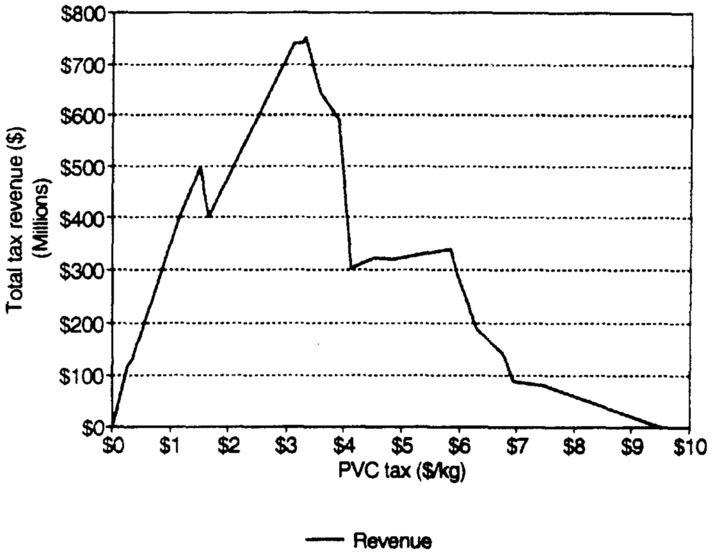


Table 9 Economic statistics and estimates for PVC fabrication plants

	United States	Canada
Number of PVC fabrication plants	2 530	215
Investment in PVC fabrication plants ($million)	$10 074	$856
Investment in all chlorine-dependent processing plants ($million)	$68 350	$5 336
Direct employment in chlorine-dependent processing plants	366 700	28 400

NOTE: Dollar values expressed in Canadian 1992$.

SOURCE: Charles River Associates 1993.

a tax level of about $6/kg when a total of about 92% of all PVC use is eliminated. This second peak is the result of the small quantity of PVC removed from production as the tax increase from $3.3/kg to $6/kg. At a level of about $10/kg the tax is expected to eliminate 100% of total PVC use.

5.5.4 Distributional issues

The PVC actions consist of substitution of PVC by other materials mainly in construction and engineering uses. For water main pressure pipes, there are small or negative incremental unit costs of PVC reduction. Changes in these costs would be reflected in the costs incurred in water-supply and could be reflected in water utility rates. Any small change in these rates would be widely distributed among industries and households served by water utilities. Similar considerations apply for sewer pipes.

Except for the substitution of aluminum clad wood for vinyl windows, the other uses of PVC all have positive costs. These costs would be widely distributed among industries and households.

The numbers of plants and estimated investment in North America[23] in 1993 for PVC fabrication plants and investment and direct employment in chlorine-dependent processing plants is summarized in Table 9.

A reduction in PVC use would bring about a corresponding reduction in employment and investment in PVC fabrication. In addition, there would be losses in employment in chlorine and vinyl chloride production to the degree that each of these contributed to the lost PVC production. Offsetting these losses in employment, however, there would be gains in employment in the production of substitute materials and products (e.g. greater employment in the production of ductile iron, steel, concrete and polyethylene pipes, and aluminum siding and window frames).

5.5.5 Feasibility, limitations and mitigation options

It would be technically straightforward to monitor the input of chlorine into PVC production. It would likely be more difficult, however, to monitor and control imports of PVC products, because of the wide variety of these products. This problem would likely be exacerbated by the rise in the domestic price of PVC as domestic production was restricted

- the higher the price, the greater incentive for importers to evade import controls and duties.

Either an input tax or a marketable allowance program could be applied to inputs of chlorine into PVC production. If, under a marketable allowance program, allowances were "grandfathered," PVC producers would reap excess profits or "rents" as the number of allowances was restricted and the price of PVC increased (in the same way as in the CFC marketable allowance program in the United States). These rents could be "captured" by auctioning allowances, or applying an input tax instead of a marketable allowance system.

With regard to mitigation of the impacts of an input tax on chlorine in PVC production, it has been noted that the impacts of higher costs to users for PVC or substitutes will be widely dispersed. These costs can be mitigated by encouraging research and development on PVC substitutes in its various applications.

The most concentrated economic impacts would fall on PVC fabrication plants and chlorine and vinyl chloride producers and their respective employees. Eventual elimination of PVC fabrication would be required by all types of programs for sunsetting PVC manufacture, so the ultimate impacts of all would be the same.

The most direct form of mitigating these dislocations would be to assist producers and manufacturers technically and financially in switching to other products (such as other plastics). This form of mitigation would also complement the effects of the economic instrument in reducing PVC production by encouraging producers and manufacturers to switch. The proceeds of the input tax or allowance auction could be ear-marked partly for such assistance.

In some cases, however, it may not be technically feasible or economically efficient for a plant to convert from PVC production to another product. In these cases, it might be more efficient to assist the plant or production line in closing, and its employees in adjusting and finding other work.

Where the producer or manufacturer is a major employer in a community, some mitigation of the economic impacts on the community as a whole may be warranted. Research and experience indicate that it is usually easier to achieve an outcome that is generally considered fair by compensation in kind (related to the loss) rather than simple monetary compensation (Burtraw 1991). In this case, compensation in kind could include investment to create other comparable employment in the community, or additional training opportunities for other forms of employment.

---

[23] Statistics for all of North America are given, because it is assumed that for practicality any policy would have to apply to the whole continent (and to imports).

6. Conclusions and recommendations

Recommendation 1

The Parties to the Great Lakes Water Quality Agreement continue and expand support for voluntary programs to reduce releases of persistent toxic substances.

Many actions can achieve significant reductions in releases of persistent toxic substances at no or low cost. These include reducing the mercury content of products, and source separation programs for mercury containing products. Using voluntary programs for these is likely to be broadly acceptable and relatively easily implemented. Voluntary programs for reduction of PVC use could lead to significant reductions also, but will not likely lead to virtual elimination.

Recommendation 2

The International Joint Commission continue to promote understanding of the rationale for action.

The rationale for action to virtually eliminate persistent toxic substances, including those associated with municipal waste incineration and polyvinyl chloride's life-cycle, are generally not known, understood or accepted by stakeholders outside government and environmental non-government organisations. If the objective is rapid action, then these stakeholders will need to be involved in the process, and will need to understand the rationale for changes in processes or products.

Recommendation 3

The International Joint Commission encourage the Parties to promote research and development, and continue to monitor progress in understanding the relationship between various policy alternatives and releases of persistent toxic substancess to the environment.

There are many uncertainties that complicate an assessment of all the policy instruments, both scientific and behavioural. For example, on the scientific side, the incineration process and the generation and destruction of PTSs is not fully understood. Monitoring of emissions is difficult and there are not widely accepted models relating persistent toxic substance emissions and operating parameters that can be easily monitored. There are conflicting scientific reports on the importance of waste characteristics (e.g. plastic content) on formation of various products of incomplete combustion, including dioxins and furans. Further, there is a general lack of understanding of environmental implications of substitute processes.

On the behavioural side, motivation for participation in voluntary programs is not well understood, nor are some of the institutional and other non-economic considerations that affect technology choices.

Recommendation 4

The International Joint Commission and the Parties continue research on the effects of economic instruments on achieving the goal of virtual elimination.

There is limited knowledge and understanding of the impacts and effectiveness of economic instruments to virtually eliminate persistent toxic substances. If the objective is rapid action, further research is required to improve our understanding of the relationship between different economic activities and the release of PTSs to the environment. Analyses of potential advantages and disadvantages of a range of policy instruments can improve understanding of these, and facilitate their adoption once commitment is reached on the policy objectives.

Recommendation 5

The International Joint Commission promote the formation of a forum for coordinating policies across jurisdictions.

The problems associated with persistent toxic substances cannot be seen as local problems amenable to local solutions. Although the International Joint Commission's activities can help meet the need such a forum addresses, the policy initiatives will likely be required at the continental and global level, not just those jurisdictions in the Great Lakes Basin.

Recommendation 6

The International Joint Commission encourage Parties to the Great Lakes Water Quality Agreement to adopt pilot programs to test economic instruments.

There are potential advantages to using properly designed economic instruments to achieve virtual elimination, but there is limited understanding of these by stakeholders, and limited practical experience. Pilot programs would facilitate understanding, and provide empirical data on the environmental and cost effectiveness of economic instruments, relative to alternative policy approaches.

A system of emissions taxes could be effective in encouraging adoption of improved pollution control equipment, and would ensure that incineration facilities are operated properly. This is important because operating conditions have a significant affect on emissions. To date there has been limited experience with economic instruments and much of the arguments surrounding effectiveness or lack thereof are based on ideology, not experience. Exclusive reliance on a command and control approach with a ban on incinerators as a final step could achieve virtual elimination, but would be inflexible, and hence subject to resistance and delay.

An input tax on chlorine use for PVC production is likely to reduce, and eventually eliminate, the fabrication of products containing PVC. A pilot program, based on an input tax on chlorine, would provide practical information and experience on the usefulness, design, and effect of using economic instruments to achieve the virtual elimination of PTSs. The results of the pilot program could facilitate the adoption of economic instruments for eliminating all uses of chlorine and emissions of PTSs. A command and control approach with a ban on chlorine use as a final step could achieve virtual elimination, but possibly at a higher cost to producers and society. A pilot program using an economic instrument permits a more thorough comparison of the relative effectiveness of economic instruments in reducing environmental impacts.

7. References

Ackerman, Bruce A., and Richard B. Stewart. 1988. "Reforming Environmental Law: The Democratic Case for Market Incentives." *Columbia Journal of Environmental Law*, vol. 13, pp. 171-199.

Air and Waste Management Association. June, 1991. "Air Toxics Emissions from Municipal, Hazardous and Medical Waste Incinerators and the Effect of Control Equipment."

Amato, I. 1993. The crusade against chlorine. *Science*. 261: 152-154.

Anders, G. 1991. The history and economic role of Ontario's mineral sector. *Geology of Ontario*: Ontario Geological Survey 4:1. Ministry of Northern Development and Mines, Toronto.

Anonymous. 1992. New municipal solid waste data show increase in recycling and incineration. *Journal of the Air and Waste Management Association* 42(10):1280

Apogee Research, Inc. 1992. *Incentive analysis for Clean Water Act Reauthorization: point source / nonpoint source trading for nutrient discharge reductions.* Washington: U.S. Environmental Protection Agency (Office of Water and Office of Policy, Planning and Evaluation).

Apotheker, Steve. April, 1991a. "The Cost Effectiveness of Yard Debris Recovery." *Resource Recycling.*

Apotheker, Steve. September, 1991b. "Mixed Waste Processing: Head-to-Head With Curbside Recycling Collection." *Resource Recycling.*

Arthur D. Little Inc. 1981. *Exposure and risk assessment for mercury.* Prepared for the United States Environmental Protection Agency.

Barton, R.G., W.D. Clark, W.S. Lanier and W.R. Seeker. 1990. Dioxin emissions from waste incinerators. *Chemosphere.* 20:1825-1832.

Barton, Douglas A., James J. McKeown and Robert Branck 1990. A screening study of the treatability of dioxins and furans in bleach plant filtrates and mill wastewaters. *Chemosphere.* 20:1747-1754.

Baumol, W. and W. Oates. 1988 (2nd edition). *The theory of environmental policy.* Cambridge: Cambridge University Press.

Benefenati, E., G. Mariani, R. Fanelli and A. Farneti. 1991. Synthesis and destruction of PCDD and PCDF inside a municipal solid waste incinerator. *Chemosphere.* 23:715-722.

Berenyi, Eileen and Robert Gould. 1991. "1991 Resource Recovery Yearbook." Governmental Advisory Associates, Inc.

Bloxam 1992. Appendix C, page 11

Bobet, E., M.F. Berrard and T. Dann. 1990. The measurement of PCDD and OCDF in ambient air in southwestern Ontario. *Chemosphere.* 20:1439-1446.

Bohm, Peter and Clifford F. Russell. 1985. "Comparative Analysis of Alternative Policy Instruments." Pp. 395-460 in Allen Kneese and James Sweeney eds., *Handbook of Natural Resource and Energy Economics*, vol. 1 (Amsterdam: North-Holland).

Botts, Lee and Glenn Paulson. 1991. *An analysis of the legislative and regulatory factors in a virtual elimination strategy for persistent toxic substances in the Great Lakes Basin Ecosystem.* Pritzker Institute of Environmental Engineering, Chicago.

Boyer, Peter. 1993. Outline and budget to complete economic instruments project. Facsimile from Peter Boyer, International Joint Commissions to David Heeney, Hickling Corporation, January 27, 1993.

Bregar, B. 1993. Increasing wood prices give vinyl windows an opening. *Plastics News.*

British Columbia. Ministry of Environment, Lands and Parks. 1993. *Fact Sheet. Waste management permit fees: an update.*

Brna, T.G. and J.D. Kilgroe. 1990. Control of PCDD/PCDF emissions from municipal waste combustion systems. *Chemosphere.* 20:1875-1882.

Bromley, D. 1990. The ideology of efficiency: searching for a theory of policy analysis. *Journal of environmental economics and management* 19: 86-107.

Brown, R.S., K. Pettit, K.J. Mundy, P.W. Jones and W. Noble. 1990. Incineration: the British experience. *Chemosphere.* 20:1785-1792.

Burtraw, D. 1991. Compensating losers when cost-effective environmental policies are adopted. *Resources* 104 (Summer 1991): 1-5.

Camford Information Services. 1991. *Product profiles - chlorine and polyvinyl chloride.* Don Mills, Ontario.

Canadian Paints and Coatings Association. Date unknown. *Mercury in paint: its use as a preservative.* Reprint available from the Association.

Canadian Council of Resource and Environment Ministers (CCREM) 1992. *Canadian water quality guidelines.* Prepared by the Task Force on water quality guidelines of the CCREM. Ottawa, Ontario.

Canadian Council of Resource and Environment Ministers (CCREM). 1986. *The PCB Story.*

Cantox Inc. 1986. Environmental Health Evaluation for Hexachlorobenzene. Prepared for the Ontario Ministry of the Environment.

Carpenter et al. 1986. Table C-9

Cassils, Anthony. 1992. *Opportunities and economic instruments.* Toronto: The Ontario Round Table on the Environment and Economy.

CEPA 1990. *Priority substances list assessment report no. 1 : polychlorinated dibenzodioxins and polychlorinated dibenzofurans.* Ottawa.

Chandler, J. G., and M. J. Veschler. 1991. *Summary of ideas discussed at the April 11-12, 1991 roundtable on the achievement of zero discharge through legislation and regulation.* Memorandum to IJC Commissioners, Washington, DC.

Charles River Associates Incorporated (CRA). 1993. *Assessment of the economic benefits of chlor-alkali chemicals to the United States and Canadian economies.* Prepared for The Chlorine Institute.

Chemical Marketing Reporter, 1992. "Trichloroethylene; Producers, demand, uses, etc.: Chemical Profile" Vol. 241, No. 5, Pp. 42.

Chemical Week, December 4, 1991, E.M. Kirschner, "Perchloroethylene gets taken to the cleaners," page 16.

Christian Science Monitor, April 25, 1991, "Incineration Expected to Increase in the 90's

Chung, A. and D. Halliburton. 1990. Measures to control chlorinated dioxin and furan formation and releases at Canadian bleached chemical pulp mills. *Chemosphere.* 20:1739-1746.

Clark, Colin W. 1976. *Mathematical Bioeconomics.* 2nd Edition. New York, John Wiley and Sons.

Cleghorn, H.P., R.B. Caton, N.W. Groskepf and L.W. Pilger. 1990. Production of dibenzofuran fumes during splicing of PCB contaminated electrical cables. *Chemosphere.* 20:1517-1524.

Cohen, Susan. April 1993. "Recycling Nickel-Cadmium Batteries." *Resource Recycling.*

Copowlski, Ray (Environment Canada). Personal communication August 12, 1992.

Cropper, M.L. and W.E. Oates. 1992. Environmental economics: a survey. *Journal of economic literature* 30: 675-740.

Czuczwa, Jean M. and Ronald A. Hites. 1984. Environmental Fates of Combustion-Generated Polychlorinated Dioxins and Furans. Environmental Science and Technology. 18:444-450.

Czuczwa, Jean M. and Ronald A. Hites. 1986. Airborne Dioxins and Dibenzofurans: Sources and Fates. *Environmental Science and Technology* 20: 195-200.

Dales, J.H. 1968. *Pollution, property and prices: an essay in policy-making and economics.* Toronto: University of Toronto Press.

Dales, John H. 1974. *Pollution, Property, and Prices.* U.S.A., University of Toronto Press.

Deangelo, Mario (Nedco, Division of Westburne Electrical Distributors). 1993. Personal communication 23 April and facsimile 27 April 1993.

Deister, U. and R. Pommer. 1991. Distribution of PCDD/F in the Vicinity of the Hazardous Waste Incinerator at Schwabach. *Chemosphere.* 23:1643-1651.

DeMarco, J., R. Miller and D.J. Hartman. March 1988. Discovery and Elimination of Dioxins from a Carbon Reactivation Process. *American Water Works Association Journal* 80:66-72.

Denison D.A., Ruston J. 1990. *Recycling and Incineration : Evaluating the choices.* Environmental Defense Fund. Washington D.C.

Donnelly, J.R. April 1991. "Overview of Air Pollution Controls for Municipal Waste Combustors."

DuBois, Annette. February 1992. "Household Batteries: Drop-off and Curbside Collection." *Resource Recycling.*

Duess, L., Canadian Building Products Ltd. 1993. Personal communication with A. White, 23 April 1993.

Dugan, M., Geon Corporation. 1993. Personal communication with A. White, 27 April 1993.

Earl, Paul. 1990. Technology for Reducing Organo-Chlorines in Pulp Mill Effluents. Report of the Technological Committee to the Great Lakes Science Advisory Board. Toronto.

Electric Utility Week, September 7, 1992, "Clean Water Report Labels Utilities Top Mercury Emitters, Urges Controls," p.5

Environment Canada. 1983a. *Socio-economic impact analysis of Chlorobiphenyl Regulations No. 2 (Product) and Chlorobiphenyl Regulations No. 3 (Release).* Environmental Strategies Directorate.

Environment Canada. 1983b. *A national strategy for accelerated phase-out of chlorobiphenyls: stage 1.* Commercial Chemicals Branch.

Environment Canada. 1986. *PCBs: Question and Answer Guide Concerning Polychlorinated Biphenyls.* Minister of supply and Services Canada.

Environment Canada. 1988. *Handbook on PCBs in Electrical Equipment, third edition.* Minister of Supply and Services Canada.

Environment Canada. 1990. *National Inventory of PCBs In Use and PCB Wastes in Storage in Canada - June 1990.* Prepared for the Canadian council of Ministers of the Environment.

Environment Canada, Department of Fisheries and Oceans, and Health and Welfare Canada. 1991. *Toxic chemicals in the Great Lakes and associated effects.* Minister of Supply and Services Canada

Environment Canada. 1992. *Economic instruments for environmental protection: discussion paper.* Ottawa: Minister of Supply and Services.

Environmental Choice 1992. Environmental Choice Program, 107 Sparks Street, Second Floor, Ottawa, Ontario K1A 0H3. Environment Canada.

Eutrotech Inc. 1991. *Used batteries and the environment: a study on the feasibility of their recover.* Prepared fro the Technology Development Branch, Environmental Protection, Conservation and Protection, Environment Canada.

Feitelson, E. 1992. An alternative role for economic instruments: sustainable fiance for environmental management. *Environmental Management* 16(3): 299-307.

Foran, Jeffery A. and Ann Jarrell. 1989. *An analysis of the statutory framework for the ban or phase-out of hazardous chemicals.* Report submitted to The International Joint Commission Virtual Elimination Task Force. Washington.

Foran, Jeffery A. 1991. *The control of discharges of toxic pollutants into the Great Lakes and their tributaries: development of benchmarks.* Report to the International Joint Commission.

Fouhy, Ken. June 1992. Legislation Scrubs Fluegas Emissions. *Chemical Engineering.* 31-35.

Fouquet, A., F. Messier, D. Colgan and A. Grondin. 1990. Investigation for presence of chlorinated dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDFs) in bleaching processes from pulp and paper industries. *Chemosphere.* 20:1707-1714.

Franklin Associates. 1992. Characterization of municipal solid waste in the United States: 1992 update. Washington: U.S. EPA.

Frey, B. 1992. Pricing and regulating affect environmental ethics. *Environmental and Resource Economics* 2(4): 399-414.

Garden, S. and T. Tseng. 1990. Baseline levels of adsorbable organic halogen in treated wastewaters from bleached kraft pulp mills in Ontario. *Chemosphere.* 20:1695-1700.

Gihr, R., W. Klopffer, G. Rippen and H. Partscht. 1991. Investigations on potential sources of polychlorinated dibenzo-*p*-dioxins and dibenzofurans in sewage sludges. Chemosphere. 23:1653-1659.

Glass, G.E., J.A. Sorensen, K.W. Schmidt and G.R. Rapp. 1990. New Source Identification of Mercury Contamination in the Great Lakes. *Environmental Science and Technology.* 24: 1049-1069.

Goldfarb, T.D., M. Maertz, F.J. Roethel, C.R. Iden and R.A. Rieger. 1990. PCDDs and PCDFs in incinerator ash from several types of facilities in the northeastern United States. *Chemosphere.* 20:1833-1838.

Goldfarb, T.D. and S.J. Harrad. 1991. Consideration of the environmental impact of the volatilization of PCDDs and PCDFs. *Chemosphere.* 23:1669-1674.

Granier, L. and M. Chevreuil. 1991. Automobile traffic: a source of PCBs to the atmosphere. *Chemosphere.* 23:785-788.

Greenwire, September 9, 1991, "Incinerators: Burners on Defensive in Five States."

Hahn, Robert W. 1989a. *A primer on environmental policy design.* Harwood Academic Publishers Limited, New York.

Hahn, Robert W. 1989b. Economic prescriptions for environmental problems: how the patient followed the doctor's orders. *Journal of Economic Perspectives* 3(2): 95-114.

Hahn, Robert W. 1989c. Economic prescriptions for environmental problems: not exactly what the doctor ordered. In: J.F. Shogren, ed. *The political economy of government regulation.* Topics in regulatory economics and policy series. Boston/Dorecht/ London: Kluwer.

Hahn, R.W. and A.M. McGartland. 1989. The political economy of instrument choice: an examination of the U.S. role in implementing the Montreal Protocol. *Northwestern University Law Review* 83: 592-611.

Hahn, R.W. and G.L. Hester. 1989. Marketable permits: lessons for theory and practice. *Ecology Law Quarterly* 16: 361-404.

Harless R.L., Lewis R.G. 1982. *Chlorinated Dioxins and related compounds-impact on the environment.* Pergamon Press. New York.

Harris, W.E. April 1991. Dioxins - an overview. *TAPPI Journal.* 267-9.

Hawkins, Keith. 1984. *Environment and enforcement: regulation and the social definition of pollution.* Oxford, Clarendon Press.

Hazilla, Michael, and Raymond J. Kopp. 1990. "Social Cost of Environmental Quality Regulations: A General Equilibrium Analysis." *Journal of Political Economy,* vol. 98, no. 4 (August), pp. 853-873."

Heathcote, Isobel W. 1991. *Policy and regulatory opportunities for the implementation of virtual elimination in the Great Lakes Basin.* A report submitted to: The International Joint Commission Virtual Elimination Task Force. Toronto.

Hickling Corporation, Econometric Research Limited, LURA Group and Michael Michalski & Associates. 1993. *Development potential and other benefits of restoration, enhancement and protection of Great Lakes Basin watersheds.* Burlington: Environment Canada (Inland Waters Directorate, Ontario Region).

Ho, A.K.W. and R.E. Clement. 1990. Chlorinated dioxins/furans in sewage and sludge of municipal water pollution control plants. *Chemosphere.* 20:1549-1552.

Ho. R. (Occidental Chemical Corporation). 1993. Personal communication with A. White, 29 April 1993.

Holsopple, P. S. (Head, Vinyl Plastics Division, Society of Plastics Engineers). 1993. Personal communication with A. White, 27 April 1993.

Hunter, 1987. Appendix B, page 5

Hunter, 1992. Table C-9 (Chlorinated Pesticides)

Hurd, David. May, 1992. "Getting a Charge Out of the Waste Stream: The Status of Consumer Battery Recovery." *Resource Recycling.*

Illinois Department of Energy and Natural Resources. March 1989. "Landscape Waste Compost: Distribution and Marketing Strategies for Centralized Municipal Composting Operations." Springfield, IL.

Institute for Risk Research (IRR). 1992. *Assessing the environmental effects of disposal alternatives for household batteries.* Prepared for the Canadian Battery Manufacturer's Association.

International Joint Commission (IJC). 1988. *Mass Balancing of Toxic Chemicals in the Great Lakes: The Role of Atmospheric Deposition.* Windsor, Ontario.

International Joint Commission. 1992. *Sixth Biennial Report on Great Lakes Water Quality* IJC: Ottawa

International Joint Commission (IJC). 1993a. *A Strategy for Virtual Elimination of Persistent Toxic Substances.* Windsor, Ontario. Volume 1

International Joint Commission (IJC). 1993b. *A Strategy for Virtual Elimination of Persistent Toxic Substances.* Windsor, Ontario. Volume 2

International Joint Commission (IJC), 1991. *Persistent Toxic Substances: Virrtually Eliminating Inputs to the Great Lakes.* Interim report prepared by the Virtual Elimination Task Force. ISBN 1-895085-27-6. 42 pp.

Jobb, B., M. Uze, R. Hunsinger, K. Roberts, H. Tosine, R. Clement, B. Bobbie, G. LeBel and D. Williams. 1990. A survey of drinking water supplies in the Province of Ontario for dioxins and furans. *Chemosphere.* 20:1553-1558.

Joeres, E. and M. Davids, eds. 1983. *Buying a Better Environment: Cost Effective Regulation through Permit Trading.* Madison, University of Wisconsin Press.

Kahr, G., J. Pauliney and E. Fercher. 1990. Destruction of dioxins and furans adsorbed on fly ash in a rotary kiln furnace. *Chemosphere.* 20:1855-1858.

Kelman, Steven. 1981. *What Price Incentives?* Boston, Massachusetts, Auburn House Publishing Company.

Kemper, Peter and John M. Quigley. 1976. *The economics of refuse collection.* Cambridge: Ballinger.

Kilgroe, J.D. and T.G. Brna. 1990. Control of PCDD/PCDF emissions from refuse-derived fuel combustors. *Chemosphere.* 20:1809-1816.

Kitunen, V.H. and M.S. Saklinoja-Salonen. 1990. Soil contamination at abandoned sawmill areas. *Chemosphere.* 20:1671-1678.

Kitunen, V.H. and M.S. Sakinoja-Salonen. 1990. PCDDs/PCDFs in unbleached pulp. *Chemosphere.* 20:1663-1670.

LeBel, G.L., D.T. Williams and F.M. Benoit. 1991. Determination of chlorinated dibenzodioxins and dibenzofurans in selected paper products. *Chemosphere.* 23:737-746.

Lee, D.R. and W.S. Misiolek 1986. Substituting pollution taxation for general taxation: some implications for efficiency in pollution taxation. *Journal of Environmental Economics and Management* 13(4): 338-47.

LeFleur, L., B. Brunck, T. McDonough, K. Ramage, W. Gillespie and E. Malcolm. 1990. Studies on the mechanism of PCDD/PCDF formation during the bleaching of pulp. *Chemosphere* 20:1731-1738.

Lenoir, D., A. Kaune, O. Hutzinger, G. Mutzenich, and K. Horch. 1991. *Influence of operating parameters and fuel type on PCDD/F emissions from a fluidized bed incinerator.* Chemopshere (23), Nos. 8-10.

Life Systems, Inc. 1989 draft. *Toxicological Profile for Hexachlorobenzene.* Prepared for the Agency for Toxic Substances and Disease Registry, U.S. Public Health Service.

Lindner, G., A.C. Jenkins, J. McCormack and R.C. Adrian. 1990. Dioxins and furans in emissions from medical waste incinerators. *Chemosphere* 20:1793-1800.

Lister, Dave (Scepter/Canron Inc.). Personal communication 23 and 27 April 1993.

Macauley, M.K., M.D. Bowes and K.L. Palmer. 1992. *Using economic incentives to regulate toxic substances.* Washington: Resources for the Future.

Mackay, D., Paterson, S., Eisenreich, S. J. and Simmons, M.S. (eds.). 1983. *Physical Behaviour of PCBs in the Great Lakes.* Ann Arbor: Ann Arbor Science Publishers.

Mackay. 1991. Multimedia Environmental Models. Lewis Publishers.

Mackay, Donald (Department of Chemical Engineering, University of Toronto). Personal communication 17 March 1993.

MacLeod, K. 1979. *Sources of emissions of polychlorinated biphenyls into the ambient atmosphere and indoor air.* EPA-604-78-022.

Manscher, O.H., N.Z. Heidam, J. Vikelsoe, P. Nielsen, P. Blinksbjerg, H. Madsen, L. Pallesen and T.O. Tiernan. 1990. The Danish incinerator dioxin study, Part 1. *Chemosphere* 20:1779-1784.

Marklund, S., I. Fangmark, C. Rappe, N. Berge and B. Stromberg. 1990. Use of a synthetic refuse in a pilot combustion system for optimizing dioxin emission. Part 1. *Chemosphere.* 20:1859-1866.

McBain, David (Chemicals Evaluation Division, Environment Canada). Personal communication 23 March 1993.

McBeath, I. 1983. *Decommissioning of mercury cell chlor-alkali plants in Canada.* Report EPS 3-EP-83-5. Environmental Protection Service, Environment Canada, Ottawa.

McCabe, M. 1989. Pesticide law enforcement: a blueprint for state action. *National Environmental Enforcement Journal.* June: 3-6.

McCorquodale, J.A., J.K. Bewta, N. Biswas, M. Siddique, A. McCorquodale and A. Spicer. 1992a. *The contribution of technology prevent the generation of persistent toxic substances - mercury* (draft report). Prepared for the International Joint Commission.

McCorquodale, J.A. 1992b. Personal communication. October 1992.

McKee, P., A. Burt, D. McCarvin, D. Hollinger, R. Clement, D. Sutherland and W. Neaves. 1990. Levels of dioxins, furans and other organic contaminants in harbour sediments near a wood preserving plant using pentachlorophenol and creosote. *Chemosphere.* 20:1679-1686.

Michigan Waste Industries Association. "Sanitary Landfill Costing in Michigan." Special House Democratic Task Force on Solid Waste Disposal."

Modern Plastics. 1993. *Resin sales by process and market.* January 1993.

Moxley, Jacqueline. 1989. *Survey of pesticide use in Ontario, 1988: estimates of pesticides used on crops, fruits and vegetables.* Prepared for Economics and Policy Coordination Branch, Ontario Ministry of Agriculture and Food, Toronto.

Moyeda, D.K., W.R. Seeker, G.C. England and D. G. Linz. 1990. The formation and control of PCDD/PCDFs from RDF-fired combustion systems. *Chemosphere* 20:1817-1824.

Murdoch, B.S. 1990. Mercury: An atmospheric hitchhiker. *Health and environment digest* 4(4):1-4

Murphy, T.J., Formanski, L.J., Brownawell, B. and Meyer, J.A., 1985. Polychlorinated Biphenyl Emissions to the Atmosphere in the Great Lakes Region. Municipal Landfills and Incinerators. *Environmental Science and Technology* 21(2): 155-162

Nabholz, Vince (Office of Pollution Prevention and Toxics, USEPA). Personal communication 16 March 1993.

Naf, C., D. Broman, R. Ishaq and Y. Zebuhr. 1990. PCDDs and PCDFs in water, sludge and air samples from various levels in a waste water treatment plant with respect to composition changes and total flux. *Chemosphere* 20:1503-1510.

National Energy Board. 1991. *Canadian energy supply and demand 1990-2010.* Supply and Services Canada, Ottawa.

NCASI. 1990. USEPA/Paper Industry Cooperative Dioxin Study: the 104 Mill Study. Technical Bulletin No. 590. New York.

Neilson, Bob (Rehau Industries). Personal communication 23 April 1993.

Norsk Hydro. 1992. *PVC and the environment.* Norsk Hydro Petrochemical division. Norway

Nottrodt, A., U. Duwel and K. Ballschmiter. 1990. The influence of increased excess air on the formation of PCDD/PCDF in a municipal waste incineration plant. *Chemosphere* 20:1847-1854.

Nriagu, J.O., Pacyna, J.M. 1988. Quantitative assessment of world-wide contamination of air, water and soils by trace metals. *Nature* 333:134-139

Oates, Wallace E., Paul R. Portney, and Albert M. McGartland. 1989. "The *Net* Benefits of Incentive-Based Regulation: A Case Study of Environmental Standard Setting." *American Economic Review,* vol. 79, no. 5, pp.1233-1242.

OECD. 1975. *The Polluter Pays Principle.* Paris: Organisation for Economic Cooperation and Development.

OECD. 1989. *Economic instruments for environmental protection.* Paris: OECD.

OECD. 1991. *Environmental policy: how to apply economic instruments.* Paris: OECD.

Oehme, M., S. Larssen and E.M. Brevik. 1991. Emission factors of PCDD and PCDF for road vehicles obtained by tunnel experiment. *Chemosphere* 23:1699-1708.

Ontario Hydro. 1992. *Ontario Hydro 1991 Performance.* Ontario Hydro. Toronto.

Ontario Ministry of Agriculture and Food (OMAF), Ontario Ministry of Environment (OMEE), Ontario Ministry of Health (OMH), 1986. *Guidelines for sewage sludge utilization on agricultural lands.* Toronto.

Ontario Ministry of the Environment (OMEE) and Michigan Department of Natural Resources (MNR). 1986. CESARS: Chemical Evaluation Search and Retrieval System - Hexachlorobenzene search.

Ontario Ministry of the Environment. 1989. *Municipal-Industrial Strategy for Abatement: Preliminary Report on the First Six Months of Monitoring in the Petroleum Refining Sector.* Toronto: Queen's Printer.

Ontario Ministry of the Environment. 1990. *Municipal-Industrial Strategy for Abatement: Second Report on the Monitoring Data for the Petroleum Refining Sector.* Toronto: Queen's Printer.

Ontario Ministry of the Environment. 1991. *Municipal-Industrial Strategy for Abatement: Preliminary Report on the First Six Months of Process Effluent Monitoring in the MISA Pulp and Paper Sector.* Toronto: Queen's Printer.

Ontario Ministry of the Environment. 1992. *Ontario Inventory of PCB Storage Sites - October 1991.* Queen's Printer for Ontario.

Ontario Ministry of the Environment. 1992b. *Municipal-Industrial Strategy for Abatement (MISA) Six-Month Monitoring Data Report Organic Chemical Manufacturing Sector.* Toronto: Queen's Printer.

Ontario Ministry of the Environment. 1992c. *Best available technology for the Ontario pulp and paper industry.* Prepared for the Water Resources Branch, OMOE by Neil McCubbin, Howard Edde, Ed Barnes, Jens Folke, Eva Bergman and Dennis Owen. Toronto.

Ontario Ministry of the Environment. 1992d. *The pollution prevention pledge program: Abstract.* Toronto: MOE.

Opschoor, J.B. and H.B. Vos. 1989. *Economic instruments for environmental protection.* Paris: OECD.

Opschoor, J.B. and D. Pearce, eds. 1991. *Persistent pollutants: economics and policy.* Dordrecht, Kluwer Academic Publishers.

Ortech International (ORTECH). 1990 draft. *MOE toxic chemical emission inventory for Ontario and North America.*

Ozvacic, V., G. Wong, G. Marson, R. Clement, D. Rokosh, S. Suter, G. Horsnell, J.C. Hipfner, S. Burns, H. Corinthios, M. Young and B. Birmingham. 1990. Biomedical waste incinerator testing program. *Chemosphere* 20: 1801-1808.

Paine, Peter (Environment Canada). Personal communication August 11, 1992.

Pearson, R.G., D.L. McLaughlin and W.D. McIlveen. 1990. Concentrations of PCDD and PCDF in Ontario soils from the vicinity of refuse and sewage sludge incinerators and remote rural and urban locations. *Chemosphere* 20: 1543-1548.

Phyper, John-David and Brett Ibbotson. 1991. *The handbook of environmental compliance in Ontario: understanding the legislation responsibility and penalties step-by-step compliance.* McGraw-Hill Ryerson Limited, Scarborough.

Pigou, A.C. 1938 (4th edition). *The economics of welfare.* London: MacMillan and Company.

Power, T.M. and P. Rauber. 1993. The price of everything. *Sierra* (November/December 1993): 87-96.

Rappe, C., L. Kjeller and S. Kulp. 1991. Levels, Profile and Pattern of PCDDs and PCDFs in Samples Related to the Production and Use of Chlorine. *Chemosphere* 23:1629-1636.

Rees, G., Assistant Director, Water Resources Branch, Ontario Ministry of the Environment. 1992. Personal communication with A. S. White, 2 September 1992.

Reid, N.W., D.B. Orr, M.N. Shackleton, M.A. Lusis, C. Tashiro and R. Clement. 1990. Monitoring dioxins and dibenzofurans in precipitation in Ontario. *Chemosphere* 20: 1467-1472.

Reutlinger, Nancy and Dan de Grassi. April 1991. "Household Battery Recycling: Numerous Obstacles, Few Solutions." *Resource Recycling.*

Rosenberg C., L. Nylund, T. Aalto, H. Kontsas, H. Norppa, P. Jappinen and H. Vainio. 1991. Volatile Organohalogen compounds from the bleaching of pulp - occurrence and genotoxic potential in the work environment. *Chemosphere* 23: 1617-1628.

Russell, Clifford S., Winston Harrington, and William J. Vaughan. 1986. *Enforcing Pollution Control Laws* (Washington, DC: Resources for the Future).

Russell, Clifford S. 1988. "Economic Incentives in the Management of Hazardous Wastes." *Columbia Journal of Environmental Law*, vol. 13, pp. 257-274.

Rymen, T.A., B. Griepink and S. Fachetti. 1990. Contribution of the Community Bureau of References (CBR) of the Commission of European Communities (CEC) to quality improvement and certification of reference materials for PCDD and PCDF analysis. *Chemosphere* 20:1291-1298.

Schelling, Thomas C. 1983. *Incentives for environmental protection.* Cambridge, Massachusetts, The MIT Press.

Senes Consultants Ltd. 1992. *A global warming inventory for the province of Ontario.* Prepared for the OMOE. Toronto.

Sergeant, D.B. 1990. Quality assurance in analysis of environmental matrices for PCDDs and PCDFs. *Chemosphere* 20:1263-1268.

Shaub, Walter B. and Wing Tsang. 1983. Dioxin Formation in Incinerators. *Environmental Science and Technology* 17: 721-30.

Sheffield, A. 1983. *National inventory of sources and emissions of mercury.* Prepared for the Air Pollution Control Directorate of Environment Canada.

Sherman, R.K., R.E. Clement and C. Tashiro. 1990. The distribution of polychlorinated dibenzo-*p*-dioxins and dibenzofurans in Jackfish Bay, Lake Superior, in relation to a kraft pulp mill effluent. *Chemosphere* 20:1641-1648.

Shiu, Wan Ying, William Doucette, F.A.P.C. Gobas, A. Andren and D. Mackay. 1988. Physical-Chemical Properties of Chlorinated Dibenzo-p-dioxins. *Environmental Science and Technology* 22:651-658.

Smith, R.M., P.W. O'Keefe, K. Aldous and S. Conner. 1990. Continuing atmospheric studies of chlorinated dibenzo-furans and dioxins in New York State. *Chemosphere* 1990:1455-1462.

Socha, Adam (Hazardous Contaminants Branch, Ontario MEE). Personal communication 16 March 1993.

Someshwar, A.V., A.K. Jain, R.C. Whittemore, L.E. LaFleur and W.J. Gillespie. 1990. The effects of sludge burning on the PCDD/PCDF content of ashes from pulp and paper mill hog fuel boilers. *Chemosphere* 20:1715-1722.

Steer, P., C. Tashiro, R. Clement, M. Lusis and E. Reiner. 1990. Ambient air sampling of polychlorinated dibenzo-*p*-dioxins and dibenzofurans in Ontario: preliminary results. *Chemosphere* 20:1431-1438.

Stokoe, P. 1991. *Integrating economics and EIA: institutional design and analytical tools.* Hull: Canadian Environmental Assessment Research Council.

Sugden, R. and A. Williams. 1978. *The principles of practical cost-benefit analysis.* Oxford: Oxford University Press.

Tashiro, C., R.E. Clement, B.J. Stocks, L. Radke, W.R. Cofer and P. Ward. 1990. Preliminary report: dioxins and furans in prescribed burns. *Chemosphere* 20:1533-1536.

Taylor, Alison, and Richard Kashmanian. December 1988. "Study and Assessment of Eight Yard Waste Composting Programs Across the United States." U.S. EPA, Office of Policy, Planning, and Evaluation. Washington, D.C.

Tejima, H., K. Nakazato and M. Nishigaki. 1990. PCDDs, PCDFs emiss-ion control by dry scrubbing system. *Chemosphere* 20:1899-1906.

Terkla, D. 1984. The efficiency value of effluent tax revenues. *Journal of Environmental Economics and Management* 11(2): 107-123.

Thompson, T.S., R.E. Clement, N. Thornton and J. Luyt. 1990. Formation and emission of PCDDs/PCDFs in the petroleum refining industry. *Chemosphere* 20:1525-1532.

Thorndyke, S.J., 1988. Airborne trace organic emission program at the Ontario Lambton Thermal Generating Station. Ontario Research Foundation (now ORTECH International) for Ontario Hydro.

Tietenberg, T.H. 1985. *Emissions Trading: and exercise in reforming pollution policy.* Washington, D.C., Resources for the Future, Inc.

U.S. EPA. 1987. *Health Advisories for 25 Organics.* Office of Drinking Water, U.S. EPA. NTIS.

U.S. EPA. 1988. *Toxic release Inventory.* U.S. EPA, Washington D.C.

U.S. EPA. 1989. *A management review of the Superfund program.* United States Environmental Protection Agency, Springfield, Virginia.

U.S. EPA 1990d. *Code of federal regulations - 40 Part 761.* U.S. EPA 40 cfr cH. 1 (7-1-90 Edition) Washington, DC.

U.S. EPA. 1990c. *Toxic air pollutant emission factors a compilation for selected air toxic compounds and sources, 2ed.* Prepared for the U.S. EPA by Radian Corporation. Research Triangle Park, NC.

U.S. EPA. 1990b. *Characterization of the Municipal Solid Waste Stream in the U.S. 1990 Update.* Solid Waste and Emergency Response.

U.S. EPA. 1990a. *Toxicity Characteristic Regulatory Impact Analysis.* Economic Analysis Staff, Office of Solid Waste, U.S. EPA. Washington, D.C.

U.S. EPA. 1991. *Municipal Waste Combustion: Background Information for Materials Separation.* Report No. EPA-450/3-90-021.

U.S. EPA. 1992. *EPA's 33/50 program: Reducing risks through voluntary action.* Second progress report. Report TS-792A, Office of Pollution Prevention and Toxics, Washington D.C.

U.S. General Accounting Office (U.S. GAO). 1991. *Water pollution: Observations on EPA's efforts to clean up the Great Lakes.* (GAO/T-RCED-92-1) October 4, 1991 p. 10.

U.S. Office of Technology Assessment (U.S. OTA). 1989. *Facing America's trash : What next for municipal solid waste.* OTA-O-424. Washington D.C.

U.S. Department of Energy. 1992. *Annual Energy Outlook 1992,* United States Department of Energy, Washington, D.C.

U.S. Public Health Service 1989. Table C-9

United States and Canada. 1987. *Revised Great Lakes Water Quality Agreement of 1978 as amended by Protocol signed November 18, 1987. Office consolidation.* Washington and Ottawa: International Joint Commission.

Vanness, G.F., T.O. Tiernan, M.S. Hanes, C.J. Reynolds, J.H. Garrett, D.J. Wagel and J.G. Solch. 1990. Determination of dibenzo-*p*-dioxin (DBD) and dibenzofuran (DBF) in paper pulp mill defoamer additives and in paper pulp samples. *Chemosphere* 20:1611-1618.

VHB Research and Consulting Inc. 1991. *Virtual Elimination of PCBs, Mercury and Persistent Toxics from the Pulp and Paper Industry in the Great Lakes Basin: A Role for Economic Instruments?* Toronto: VHB Research and Consulting Inc.

VHB Research and Consulting Inc. 1992. *Updated tables for Chapter 5 of Volume 1 of the OWMC Environmental Assessment 1990 and 1991.*Prepared for the OWMC. Toronto.

Victor, Peter. 1993. Presentation at a seminar in honour of J.H. Dales, on 18 March, 1993 at the Institute for Environmental Studies, University of Toronto.

Vinyl Siding Institute. 1993a. *What home-owners want to know about vinyl siding.* Vinyl Siding Institute, The Society of the Plastics Industry, Inc., New York.

Vinyl Siding Institute. 1993b. *Vinyl siding: right for you, right for the environment.* Vinyl Siding Institute, The Society of the Plastics Industry, Inc., New York.

Voldner, E. C. and L. Smith. 1992. *Production, Usage and Atmospheric Emissions of 14 Priority Toxic Chemicals.* Report prepared for Proceedings of the workshop on Great Lakes Atmospheric Deposition. Toronto.

Waddell, D., B. Chittim, R. Clement, C. Tashiro, S. Davies, A. Szakolcai, P. Steer and T. Dann. 1990. Database of PCDD/PCDF levels in ambient air and in samples related to the pulp and paper industry. *Chemosphere* 20:1463-1466.

Watts, B. K. 1992. Letter to T. Barton, City of Guelph. Duracell Canada. (19 May)

White, David and Kristina Nebel. September, 1990. *Summary of Information Related to Mercury Emission Rates and Control Technologies Applied to Municipal Waste Combustors.* Radian Corporation.

White, David and Kristina Nebel. *Municipal Waste Combustors: A Survey of Mercury Emissions and Applicable Control Technologies.* Radian Corporation.

Whittemore, R.C., L.E. LaFleur and W.J. Gillespie. 1990. A study of the variability of 2,3,7,8-TCDD and 2,3,7,8-TCDF in bleached kraft mill pulps, sludges, and treated waste waters. *Chemosphere* 20:1633-1640.

Zemek, A. and A. Kocan. 1991. 2,3,7,8 Tetrachlorodibenzo-*p*-dioxin in soil samples from a trichlorophenol-producing plant. *Chemosphere* 23:1769-1776.

Zimmerman, A., President, Noranda Forests Inc. 1991. Personal communication with A. S. White, October 1991.

Appendix A Information and voluntary programs

A.1 Canadian programs affecting persistent toxic substances in the Great Lakes basin

A.1.1 Environmental Choice Program

The Environmental Choice program was created to "help consumers find products that ease the burden on the environment" (Environmental Choice 1992). Criteria for a given product or service are developed by a 16-member Environmental Choice Board, made up of Ministerial appointees from government, industry, and environmental non-governmental organizations, as well as scientific and technical experts. After a public review, criteria are incorporated into guidelines for awarding the Environmental Choice label to specific products or services. Final guidelines are published in the Canada Gazette under the authority of Canadian Environmental Protection Act (CEPA).

A.1.2 Canada's Green Plan

The *Green Plan* is a broadly-based program of policies designed to achieve a range of environmental objectives, and is a vehicle for funding programs of research, development and remediation to achieve these objectives. Couched in the terms of sustainable development, the Government of Canada has outlined these general foci of the *Green Plan*:

- clean air, water and land-sustainable use of renewable resources
- protection of special spaces and species preserving the integrity of the north
- global environmental security
- environmentally-responsible decision-making at all levels of society and
- minimizing the impacts of environmental emergencies
- has dedicated three-billion dollars to be spent between 1990 and 1995

Endorsing the goal of virtual elimination of persistent toxic substances, the *Green Plan* promises to:

- regulate the discharge of individual chemicals where the toxicological evidence already exists
- accelerate toxicology research
- promote full life-cycle management of chemicals to reduce discharges beyond regulated amounts.

Regulatory initiatives proposed under the National Regulatory Action Plan to-date include:

- regulations for the control of emissions of dioxins and furans from pulp and paper mills (already promulgated) to be in full force by 1994
- by 1994, control option reports for major sources of persistent toxic substances (PTSs), including smelters, petroleum refineries, chemical production facilities and power generation stations
- by 1994, control option reports for toxic Priority Substances in emissions from metal finishing and textiles industries, metal mines and mills and chemical productions and steel plants.

A.1.3 Ontario's Pollution Prevention Pledge Program (P^4)

On 5 November 1992, Ontario Environment Minister Ruth Grier announced the Pollution Prevention Pledge Program (P^4). The program has two objectives: to encourage companies to continue voluntary emission reduction activities that benefit the environment; and to challenge other companies to join in (OMEE 1992).

The program has four progressive levels:

- registration/planning level— in which companies indicate their intention to develop a pollution prevention plan, or make a commitment to reduce their pollutant releases and production of wastes
- reduction commitment level— during which companies of facilities make public commitments to reduce or eliminate the release or disposal of specific chemicals by certain dates and begin to achieve reductions
- reduction achievement level— during which companies make significant progress in reducing release or disposal of pollutants and wastes
- pollution prevention achievement level— during which a company achieves the reduction targets set by the use of pollution prevention.

Associated with each level is recognition by the Ministry of the Environment in its pollution prevention registry (level 1) or with a certificate (levels 2–4).

It is hoped that the program will result in average reductions for participating facilities and companies of 50% by 1995 and 90% by 2,000 for selected chemicals, which include all of the selected PTSs.

A.2 United States programs

A.2.1 Industrial Toxics Project (33/50 Program)

As part of its comprehensive national pollution prevention strategy, the U.S. EPA has developed the Industrial Toxics Project (ITP) or 33/50 Program which aims to reduce releases of 18 high risk chemicals. The 33/50 Program attempts to encourage industrial companies to voluntarily reduce aggregate environmental (multimedia) releases of 18 specific chemicals: benzene, cadmium, carbon tetrachloride, chloroform, chromium, cyanide, dichloromethane, dioxin, lead, mercury, methyl ethyl ketone, methyl isobutyl ketone, 1,1,1-trichloroethane, nickel, perchloroethylene, toluene, trichloroethylene and xylene. These chemicals have been determined to present both significant risks to human health and the environment as well as opportunities for reducing such risks through pollution prevention tactics. The U.S. EPA has set a nation-wide goal of reducing the total releases of these pollutants to the environment by 33 percent by the end of 1992 and at least 50 percent by the end of 1995. "EPA will measure success according to whether its goals have been achieved on an aggregate, multi-media basis, rather than for each chemical, industry sector, or company" (U.S. EPA 1991). The program is a voluntary program, which is not meant to replace or interfere with other environmental laws.

The program was instituted by the U.S. EPA in 1991 through direct contact with over 600 identified companies. The U.S. EPA encouraged those companies to voluntarily participate in the program by developing their own release reduction goals, which could be more or less ambitious than the national goals of 33 percent and 50 percent. As of September 1992, approximately 1,000 individual plants had made commitments under the program.

Reductions in chemical releases must be measurable in order to be credited under the 33/50 Program. The 1988 Toxic Release Inventory (TRI) data is to be used as the baseline for measuring reductions in releases of the 18 chemicals. (However, companies are permitted to use 1987 TRI data as the baseline if they can demonstrate that real reductions occurred in this year.) The TRI was established under Section 313 of the Emergency Planning and Community Right-to-Know Act, which requires certain manufacturers to report on an annual basis the amount of over 300 toxic chemicals that are released to the air, land or water or that are transferred off-site. While this data base is the best available for tracking multi-media releases of chemicals into the environment, it has several limitations, including: 1) it includes only *estimates* of emissions; 2) it does not cover *all* toxic pollutants; and 3) it does not cover *all* sources of toxic releases, especially those that are below reporting thresholds.

In order to encourage company participation in the 33/50 Program, the U.S. EPA established several incentives. One incentive is the positive publicity companies will gain for becoming involved in the program. In addition, the U.S. EPA has stated that the voluntary reductions made under the 33/50 Program will not become enforceable permit conditions, unless the reductions are otherwise required. This will leave the opportunity open for companies to take credit for the reductions under State and Federal emissions trading programs. For example the Federal VOCs emissions trading program, and the toxics trading program established under the Clean Air Act amendments of 1990. States can also implement trading programs, so long as the limits set do not exceed limits previously set under Federal law.

The U.S. EPA has also stated that reductions in certain Hazardous Air Pollutants made under the "Early Reduction" program (see Section 112(i)(5) of the Clean Air Act, which provides a six-year extension from compliance with new technology-based standards for companies which commit to reduce emissions by 90 to 95 percent) will be creditable under the 33/50 Program and vice versa. The U.S. EPA has stated a desire to "...work with companies to ensure that any initiative taken to reduce emissions ahead of statutory schedules receives appropriate credit toward complying with any subsequent regulatory requirements (U.S. EPA 1991)." The U.S. EPA has also stated that it will work with companies to address any regulatory or permit barriers which might inhibit participation in the program.

However, one disincentive for sources committing to participate in the program is that the timing and extent of reduction commitments may not be consistent with future mandatory control requirements for reducing the same pollutants. This could cause sources to reevaluate emission control plans at a later date.

Appendix B Overview of regulations

Economic instruments intended to achieve (or move towards) the virtual elimination of persistent toxic substances (PTSs) will need to coordinate with regulatory initiatives and requirements. The reasons for this include:

- economic instruments will be reinforced by **using** regulatory instruments. The objectives, requirements and operations of the program are likely to be specified in regulations. This is the case with existing economic instruments, including, for example, emission trading provisions under the Clean Air Act.
- economic instruments must be a part of a larger policy initiative that will rely upon appropriate policy tools, including voluntary programs (such as 33/50 and P^4) and regulations (such as bans on production of DDT and PCBs).

Consequently, it is desirable to identify:

- regulations that specifically enable or prohibit using economic instruments to achieve environmental improvement
- monitoring requirements for releases of persistent toxic substances to the Great Lakes basin. (In order to assess the efficacy of economic instruments at a particular point of intervention or life-stage, emissions/production at that point must be able to be measured and monitored)
- the form that regulatory initiatives take which encompasses:
  - "total loadings" of persistent toxic substances (rather than effluent concentrations or media-quality standards)
  - inter-media transfers of persistent toxic substances, for example the transfer of water-based PTSs to the atmosphere, or to sediment
  - provisions related to life-stages other than discharge or point-of-impact, i.e. from genesis to final destination and includes banning or phasing-out production or use
  - technology prescriptions (which may limit incentives for source reduction).

In addition, other regulations not specifically addressing persistent toxic substances may affect toxic emissions, e.g. Clean Air Act (U.S.) controls on SO_2, "bans" on incineration, other emissions controls on fossil fuel generation, and metal smelting.

Because PTSs are produced, intentionally or otherwise, at different points in the life-cycle of products, it is desirable to virtually eliminate persistent toxic substances and their precursors efficiently and to design a program of economic instruments that considers each point of release. With few exceptions (notably, mercury in paint in the United States), the current regulatory framework does not address points of possible intervention other than disposal, discharge and hazardous goods transportation.

Of these persistent toxic substances, PCBs and HCB are both products and by-products of manufacturing processes, while dioxins and furans are strictly by-products of production processes. (Since by-products are produced incidentally in the production process of other chemicals, and PCBs and HCB are no longer manufactured in the Great Lakes basin, PCBs and HCB are considered not to have by-products. However, products caused by the break-down of PCBs and HCB are not considered explicitly here.) Mercury is a product in some cases and a by-product or waste product in other cases. In addition, mercury and chlorine are inputs to many production processes.

B.1 A synopsis of regulations

The current regulatory framework, relevant to virtual elimination of persistent toxic substances in the Great Lakes basin, may be characterized as follows:

Except for bans on the production and specified uses of certain persistent toxic substances, such as DDT, PCB, HCB[1] and mercury-containing substances[2], life-stages other than discharge are not specifically regulated for persistent toxic substances.

Heathcote (1991) notes that:

> In virtually all cases, (probably now excluding [the Canadian Environmental Protection Act] CEPA), the regulatory framework does not permit us to question the use of a particular substance or to require substitution of other,

---

[1] HCB use was restricted in 1971 (Environment Canada, Department of Fisheries and Oceans and Health and Welfare Canada. 1991).

[2] Uses of mercury containing substances, in particular pesticides, fungicides and preservatives, regulated under the Pest Controls Products Act, must be registered with the Plant Protection Division, Agriculture Canada

> less polluting materials. Controls may be imposed on discharges from a facility, usually under site-specific control documents that require considerable resources to generate and track. But upfront controls— bans— may be much more difficult to impose...

In the United States, Superfund money may be used for remediation, but there are no regulations equipped to deal specifically with remediation. An important additional component of Superfund legislation is the assessment of liability with respect to the costs of remediation.

The primary means for controlling discharges has been through approval of works (e.g. certificate of approval), including recent initiatives to require the use of BAT (best available technology). These approaches can best be characterized as end-of-pipe and end-of-stack fixes. They may act as a disincentive for pollution prevention, or dealing with earlier stages in the life-cycle, because it may be more difficult to attain approvals for innovative approaches.

The majority of regulations pertaining to PTSs relate to discharge into the environment, and are media-quality-based standards, i.e. concentrations in air and water, rather than total loadings.

Regulations that prescribe allowable ambient concentrations are, in principle, compatible with virtual elimination (e.g. when the allowable ambient concentration is zero), and are fully compatible with the use of economic instruments.[3] In practice, ambient based concentrations are difficult to monitor and it is difficult to ensure compliance is achieved, particularly in the presence of inter-media transfers and long-range transport.

Regulations that specify discharge limits leave some discretion for source reduction. For example, if an incinerator operator must reduce mercury emissions to n mg/m^3, this may be done through the installation of pollution control equipment, or it may be done by regulating the feed to the incinerator. However, where this discretion exists, monitoring will be required to ensure compliance. Approval of works was sometimes seen as a way around this, since if appropriate technologies were in place, then releases could be assumed to be adequately controlled[4].

Regulations pertaining to PTSs relate almost exclusively to site-specific, point sources, e.g. Ontario's Municipal Industrial Strategy for Abatement[5]. Notable exceptions are lead in gasoline, and pesticides control regulations.

"Provincial and federal [Canadian] legislation respecting water impairment from non-point sources may be sufficiently general to limit pollution. However, there is no legislation specifically directed to pollution from non-point sources" (Hunter 1987).

B.2 Canadian regulations

B.2.1 Federal

The legislative basis for pollution control, relevant to virtual elimination of persistent toxic substances, is that of general prohibitions on the discharge of pollutants to any watercourse; and individualized, negotiated agreements between dischargers and regulatory authorities on exemptions from the general prohibition, which define permissible end-of-the-pipe effluent loadings. Both Canadian federal and Ontario provincial law place general prohibitions on the discharge of harmful substances to surface waters.

These laws and accompanying regulations, however, place overwhelming emphasis on end-of-the-pipe concentrations of PTSs, and pay little, if any, attention to other sources in the life-cycle of toxic contaminants. Focusing on emissions and point-of-impact, the burden of proof in controlling pollution often rests on regulators to demonstrate "unreasonable risk" to human and wildlife populations, and to identify specific sources, whether industrial or municipal or otherwise, of toxic substances. This has hindered the development of pollution-prevention regulations, which would address earlier stages in the life-cycle of a toxic substance.

In Canada, the regulatory framework affecting toxic substances (including persistent toxic substances) is based on:

- Canadian Environmental Protection Act (CEPA)

---

[3] Assuming that they are multi-media based criteria.

[4] One of the advantages of approval of works is that it may eliminate the need for monitoring. If the appropriate technologies were in place, the releases could be assumed to be adequately controlled.

[5] The Municipal Industrial Strategy for Abatement (MISA) underway in Ontario focuses primarily on allowable concentrations of contaminants. Allowable concentrations are established by assessments of best-available-technology at the point of release into receiving waters. The program addresses only specific sectors, such as the petroleum refining and processing sector and the pulp and paper manufacturing sector. This approach is not well-suited to the achievement of virtual elimination and only encourages pollution prevention (as opposed to pollution control) actions to achieve allowable contaminant concentrations in effluent (Rees 1992).

This law has the most potential for addressing "cradle-to-grave" sources of contaminants and the issue of inter-media transfer. The Canadian Environmental Protection Act superseded the Environmental Contaminants Act, and the Canadian Clean Water and Clean Air Acts.

- Federal Fisheries Act

  Canada's Fisheries Act has considerable potential for the reduction, if not the virtual elimination, of persistent toxic substances. In order to issue control orders under the Act, it is necessary to demonstrate that contaminants exist at, or above "effect levels" which are "deleterious to fish" and that receiving waters are "frequented" by fish species. In practice, however, very few prosecutions have been initiated under this authority for the control of persistent toxic substances. Individual agreements may be negotiated between polluters and the Department of Fisheries and Oceans wherein specific exemptions to provisions of the Act may be granted.

- Pest Control Products Act (PCPA)

  The PCPA, administered by the federal Department of Agriculture, requires that uses of specified harmful substances be registered with the Department, and outlines labelling and handling requirements, for substances used as pesticides, herbicides, fungicides and preservatives. Although the PCPA does not provide for bans or phase-outs of specific substances, the rejection of a registration application would have the same practical effect.

B.2.2 Provincial

In Ontario, persistent toxic substances are regulated under:

- Ontario Environmental Protection Act (OEPA)

  The OEPA provides general authority for the promulgation of regulations affecting persistent toxic substances, including Regulation 308 for the control of air contaminants, Regulation 309 which addresses the classification and registration of waste, and provides a manifest system for tracking wastes from generation to disposal, and the Municipal-Industrial Strategy for Abatement (MISA) comprising regulations for the abatement of contaminants discharged into waterways from municipal sewage treatment plants and specified industries, e.g. the pulp and paper industry, the organic chemical industry and the petroleum industry (Phyper and Ibbotson, 1991).

- Water Resources Act

  Ontario's Water Resources Act prohibits the discharge of any material into water "that may impair the quality of the water." Impairment is defined as causing injury to any person, animal, bird or other living thing as a result of the use or consumption of any plant, fish or other living matter or thing in the water or in the soil in contact with the water (Phyper and Ibbotson, 1991).

B.3 United States regulations

B.3.2 Federal

In the United States, water pollution control policy is based upon the application of administratively selected control technologies to achieve plant and industry-specific effluent limits. More stringent effluent limitations can be placed on point sources in order to achieve selected water quality standards, i.e. the 'national goal' to attain swimmable and fishable waters. The latter provide the basis for media quality-based restrictions on discharges.

"Political barriers in the committee structure of Congress constrain development of appropriate legislation [so] current efforts [to reduce releases of persistent toxic substances] are proceeding under existing law" (Botts and Paulson, 1991).

United States legislation includes:

- Toxic Substances Control Act (TSCA) 1986

  In 1976, the Toxic Substances Control Act was adopted to eliminate the introduction of chemicals that pose a human health or environmental risk and to identify and control existing toxic substances that pose a risk during manufacturing, processing, distribution, use, or disposal. Eight chemical products are exempted from this regulation because they are regulated under other laws: pesticides, tobacco, nuclear materials, firearms and ammunition, food, food additives, drugs, and cosmetics.

  Under TSCA, manufacturers of new chemicals are required to notify U.S. EPA 90 days before producing or importing a new substance. This allows U.S. EPA to require the manufacturer to assess the potential risks of the substance, if necessary. The Interagency Testing Committee may suggest the testing of certain chemicals. Good Laboratory Practices standards ensure consistency in assessing the chemical hazards. U.S. EPA may also refer the chemical to other agencies, including the Occupational Safety and Health Administration, the Food and Drug Administration, the Consumer Product Safety Commission or the Food Safety and Quality Service of the Department of Agriculture.

The substances may be regulated if they are determined to pose a risk. Some of the requirements that U.S. EPA may impose include requiring special labelling or the banning of the substance.

TSCA also requires U.S. EPA to keep an inventory of all chemicals used commercially. The inventory is based on information from the manufacturer, processor or importer. If a chemical is not on the inventory, U.S. EPA must review it before it can be manufactured or imported. TSCA also requires the chemical industry to submit reports to U.S. EPA on the manufacture, processing, use, and disposal of the toxic substances and the by-products generated among other general information.

In practice, TSCA has failed to realize its potential to virtually eliminate the release of persistent toxic substances, except in very targeted situations such as the manufacture of PCBs (written into the original legislation) and the use of chromium in cooling towers. This is a result of several factors: the lack of enforcement, and inherent problems in the legislation such as the difficulty of establishing "unreasonable risk" and the length of time, as much as thre or four years, required to establish rules (Chandler and Veschler, 1991).

- Clean Air Act 1990

The Clean Air Act, adopted in 1970 and most recently amended in 1990, guides the U.S. EPA in promulgating regulations to protect the public health and welfare from the adverse effects of air pollution. Under the Clean Air Act, U.S. EPA has set National Ambient Air Quality Standards (NAAQS) for six criteria pollutants: carbon monoxide, nitrogen oxides, sulphur dioxides, ozone, particulates, and lead. To ensure compliance with the air quality standards, states are required to submit State Implementation Plans (SIPS) to ensure that the air quality standards are maintained and the air quality does not deteriorate. The 1990 Amendments require many states to revise their SIPS for ozone and other pollutants.

The Clean Air Act also requires U.S. EPA to establish New Source Performance Standards (NSPS) to limit air pollution emissions from new and modifying stationary sources. The NSPS are technology-based standards which are meant to apply uniformly to all affected sources in the same source category.

Under the Clean Air Act, U.S. EPA must also define National Emissions Standards for Hazardous Pollutants (NESHAPS). The initial NESHAPS regulated asbestos, beryllium, mercury, vinyl chloride, benzene, and arsenic. The 1990 Amendments expanded the list to 189 toxic substances, including the PTSs of concern to this study. Section 112 of the Amended Clean Air Act includes specific requirements which will affect the emissions of persistent toxic substances which are the subject of this study.

Under the new 1990 Amendments, new acid deposition control provisions were added to the Clean Air Act which require the reduction of SO_2 and NO_x emissions from electric utilities. The Act's acid rain provisions may indirectly cause incidental reductions in certain air toxic substance emissions as a result of other emission reduction requirements.

- Clean Water Act (Section 404) [concentrations]

The original legislation for the control of water pollution was adopted in 1899 as the Rivers and Harbours Act. More recent legislation has been enacted with the most recent program being the Clean Water Act (based on the Federal Water Pollution Control Act Amendments of 1972). Significant changes in the Clean Water Act were included in 1977, 1981 and 1987 amendments. The purpose the Act is to restore and maintain the "chemical, physical, and biological integrity of the Nation's waters."

The Clean Water Act requires each state to adopt water quality standards for every significant body of water within its border. States are also given the responsibility of controlling pollution from nonpoint sources. This Act requires all publicly owned municipal sewage systems and industrial sources using public sewage systems to provide secondary treatment of the water with a bio-chemical process.

The National Pollutant Discharge Elimination System (NPDES) permits established under this Act ensure that industrial and municipal waste facilities are meeting effluent limitations. U.S. EPA establishes the minimum Federal technology-based effluent standards under this Act.

- Safe Drinking Water Act of 1974

  Congress passed the Safe Drinking Water Act of 1974 to deal with toxic substances including pesticides, inorganic chemicals such as lead, nitrate, and arsenic and other organic chemicals. This Act was amended in 1977 and 1986. Under the Safe Drinking Water Act, U.S. EPA has established national standards for drinking water from both surface and ground water sources.

  States are primarily responsible for enforcing these standards which establish maximum contaminant levels (MCLs) for pollutants in drinking water. U.S. EPA has developed ground water protection strategies to deal with contamination from such sources of toxics as leachate from hazardous waste landfills, leaking underground storage tanks, and pesticide use. In particular, the Wellhead Protection Program to protect public water supplies and the Sole Source Aquifer Demonstration Program to protect aquifers that are the sole source of a community or regional water supply and to establish a demonstration program for the sole source aquifer were set up.

- Resource Conservation and Recovery Act 1986 (RCRA)

  The Resource Conservation and Recovery Act provides the legislative authority for Superfund activities. Superfund is essentially a vehicle for the clean-up and remediation of specific polluted sites, having a "broad array of authority to compel clean-up by private parties and to facilitate cost recovery for direct action under the fund" (U.S. EPA 1989).

- Pollution Prevention Act 1990

  The Pollution Prevention Act (PPA) embodies a new trend in American legislation, augmenting traditional "command and control" approaches to pollution regulation with non-regulatory "persuasion and promotion" for source reduction. While the PPA has no specific Great Lakes provisions, William Reilly, U.S. EPA Administrator, has directed the U.S. EPA to adopt a *U. S. Pollution Prevention Plan for the Great Lakes*, as part of a larger Great Lakes initiative that designates the Great Lakes as a demonstration project for the U.S. EPA's risk-based, cross-media approach, and the integration of ecological and human health protection. This initiative transforms the Great Lakes from a regional priority to a national priority (Botts and Paulson, 1991).

- Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) 1984

  FIFRA, most recently amended in 1980, regulates the licensing and registration of pesticide products, requiring the all pesticides sold in the United States be registered with the U.S. EPA. The use of DDT in the United States was banned under FIFRA provision. The manufacture of DDT is, ironically, still allowed. The use of FIFRA to ban or phase-out persistent toxic substances by cancelling or suspending registrations is possible, though in practice it is a "tortuous mechanism fraught with procedural obstacles" (McCabe 1989, in Foran and Jarrel, 1991).

- Great Lakes Critical Programs Act 1990

  In the Great Lakes Critical Programs Act (GLCPA), Congress directed the U.S. EPA to incorporate objectives of the Great Lakes Agreement into its regulatory programs. The new amendment delivers guidelines for the development of consistent water quality standards throughout the Great Lakes basin, as well as for submission of Remedial Action and Lake-wide Management Plans to the International Joint Commission.

B.3.2 State

There are eight states within the Great Lakes basin, each of which shares responsibility with the federal government for the regulation of releases of persistent toxic substances. In a report to the International Joint Commission, the effect of state regulatory programs on water quality and discharges of persistent toxic substances were evaluated with the objective of comparing some of the "myriad procedures that the Great Lakes states and Ontario use to regulate the discharge of toxic pollutants from point sources" (Foran 1991).

Foran (1991) found that states generally approach the regulation of PTSs in a similar way, but that technical differences in their regulations result in "highly variable limitations on the concentrations and loads of toxic pollutants that are discharged from point sources."

Appendix C Sources of persistent toxic substances

C.1 Mercury

Mercury is naturally present in the environment as a result of the outgassing of the earth's crust, and runoff from natural erosion processes. Anthropogenic sources comprise about 50 percent of mercury emissions in the United States, and a much smaller proportion in Canada (Bloxam 1992; Voldner and Smith (1992).

Mercury is mined and used in a variety of products, including batteries, paints and electrical equipment. It is also released as a byproduct of industrial processes. The flowchart in Figure C-1 traces the emission of mercury to the environment from anthropogenic sources. The relative consumption of mercury in consumer goods is presented in Table C-1.

The sources, uses and fates of mercury in the Great Lakes basin have recently been documented for the International Joint Commission (IJC) (McCorquodale et al. 1992). That study provides a materials balance for mercury, based on the best available, though somewhat dated, data[6]. The findings of that study provide the basis for determining the major points of emission for mercury.

Table C-2 summarizes the findings of the material balance. Some adjustments have been made to McCorquodale's findings — the rationale for these amendments are provided in the notes accompanying the table. The points of release to the environment are indicated in the "uncontrolled emissions" portion of the table. The columns on the right ("waste management") refer to contained mercury which is not released to the environment, with a few noted exceptions pertaining to chlor-alkali plants and smelting operations.

Based on the data presented in the table, the major points of (uncontained) emissions of mercury to the environment are (in order of significance):

- paint volatilization
- air emissions and releases to land from smelting
- air emissions from fuel combustion, particularly oil and coal
- air emissions from incineration
- emissions to land from chlor-alkali plants
- air, water and land emissions from hazardous waste landfills
- land emissions from sewage treatment plants
- discharges to water from smaller sources, including catalyst, pharmaceutical, laboratory and fertilizer applications.

The quantities and fates of these, market trends, and technologies that could eliminate or reduce mercury emissions are discussed in Table C-3.

Examples of information and voluntary programs, and regulatory programs, are presented in Table C-4, Table C-5 and Table C-6.

Table C-1 Mercury consumption in the United States

USE	Quantity used in 1988 (tonnes)
chemical and allied products; chlorine and caustic soda	445
laboratory uses	25
paint	197
other chemical and allied products	86
electric lighting	31
electric wiring devices and switches	176
batteries	448
control instruments and related products	77
dental equipment and supplies	53
other uses	55
TOTAL	1 593

---

[6] The data are derived from various sources released over the last 15 years.

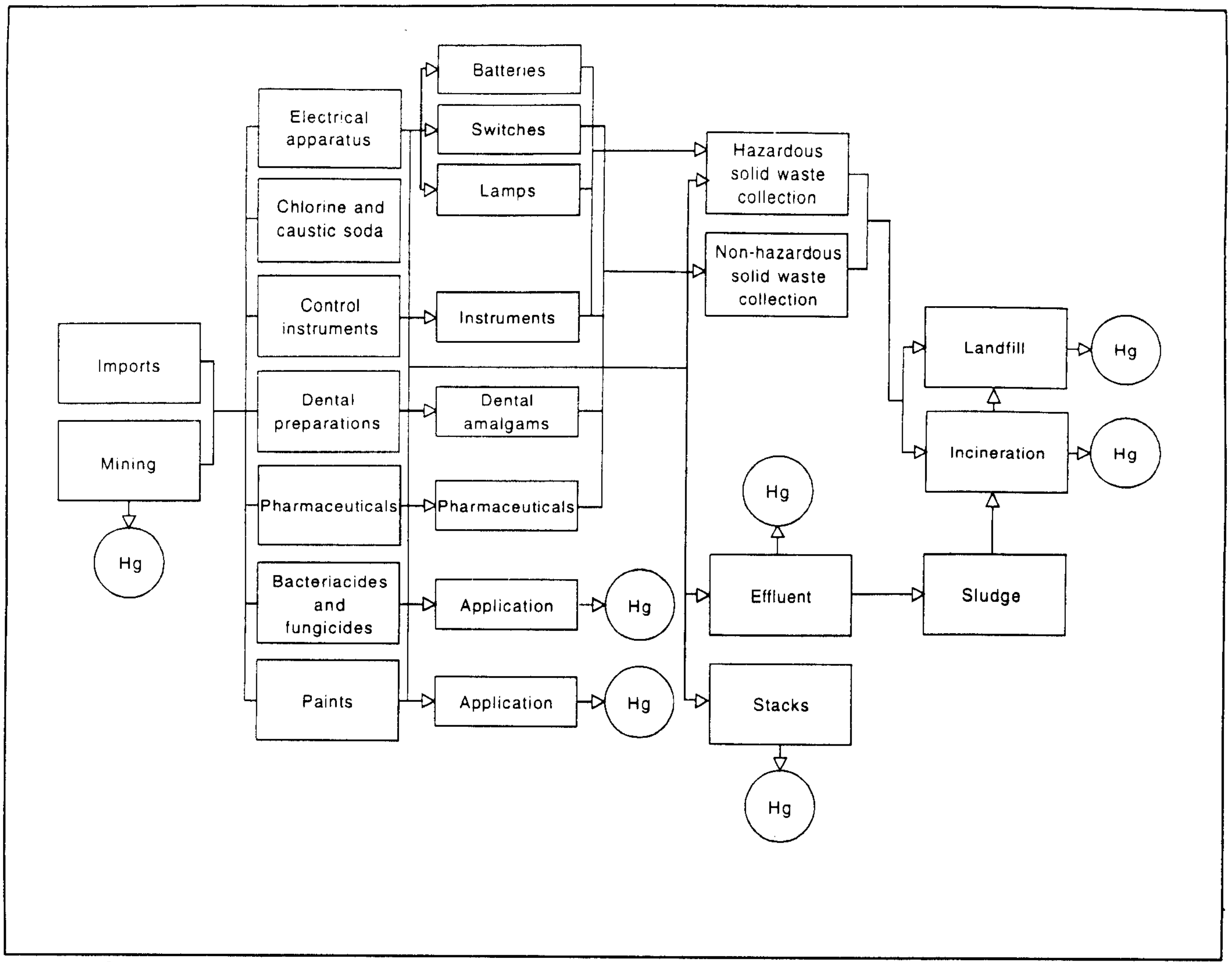


Figure C-1 The uses and fates of mercury

SOURCE: Hickling Corporation

Table C-2 Disposal and emissions of mercury in the Great Lakes basin

kg/a	uncontained emissions			waste management (method of disposal)				
	air	water	land	landfill	STP	incinerate	recycle	total
Primary sources of mercury								
batteries	225.6	46.4[a]		225.6	66.4[1]			564
paint	70.8	4.2[a]		20.2	5.9[a]			101.1
wiring devices	26.4	10.8[a]		211.2	15.6[a]			264
electrical lights	4.9	2.0[a]		39.2	2.9[a]			49
chlor-alkali	981.1	806.3[a]		95165.7[c]	1155.9[a]			98109
laboratories	1520.0	624.6[a]		760.0	895.4[a]			3800
control instruments	145.0	59.6[a]		1160.0	85.4[a]			1450
dental amalgams	7.0	2.9[a]		56.3	4.1[a]			70.3
fungicides	15.4	0.9[a]		4.4	1.3[a]			22
other (polymers, catalysts, pharmaceutical, fertilizers)	2970.0	1627.3[a]		2970.0	2332.71		9900	
coal combustion	12694.5	0.0		1410.5	0.0			14105
oil combustion	19200.0	0.0		0.0	0.0			19200
natural gas combustion	45.0	0.0		0.0	0.0			45
wood combustion	328.5	0.0		36.5	0.0			365
smelting	54000.0	1386.9[a]		10125.0[b]	1988.1[a]			67500
gold recovery	26.3	4.0[a]		3.1	5.8[a]			39.2
steel	111.6	15.3[a]		37.2	21.9[a]			186
Sub-total (primary)	92372.1	4591.1		112224.9	6581.5			215770
Secondary sources of mercury (consumer goods)								
paint	21199.0	893.0[a]	0.0	1324.9	1285.0[a]	1325.0	0.0	26026
batteries	0.0	0.0	0.0	47460.6	0.0	8375.0	0.0	55835
electrical equipment	0.0	0.0	0.0	24789.6	0.0	3099.0	3098.7	30987
fungicides	871.0	218.0	1089.0	0.0	0.0	0.0	0.0	2178
misc.	1821.0	4362.6[a]	0.0	18611.3	6278.0[a]	6676.0	404.6	38153
Sub-total (secondary)	23891.0	5473.6	1089.0	92186.4	7563.0	19475.0	3503.3	153181
Sub-total (primary and secondary)	116 263.1	10 064.7	1089.0	204 411.3	14 144.5	19 475.0	3 503.3	368 951
Fate of disposed mercury								
STP	1768.1	1768.1	10608.4	0.0	-14144.5			0
landfill	4531.6	4531.6	0.0	-9063.3				0
hazardous waste landfill	5688.9	5688.9	11377.9	-22755.7				0
incineration[d]	10817.0	2164.5	2164.5	4329.0		-19475.0		0
Sub-total	22805.6	14153.1	24150.7	-27490.0	-14144.5	-19475.0		0
Total	139 068.7	24 217.9	25 239.7	176 921.3	0.0	0.0	3 503.3	368 951

SOURCE:Adapted from McCorquodale et al. 1992

NOTES:Changes in the stock of mercury in use in products are not accounted for; mercury going into stocks is assumed to be equal to mercury coming out of stocks.

[a] McCorquodale (1992) does not distinguish between direct discharge to water and discharge to sewage treatment plants (STPs). U.S. EPA indicates that approximately 59 percent of water discharges are treated at STPs. In this report it is assumed that 59 percent of emissions to water go to STPs, with the exception of fungicides which are applied directly to crops and are not channelled through sewage treatment plants.

[b] In most cases slag from smelting is not sent to sanitary landfills, but is monofilled with minimal containment, allowing for significant releases of mercury to the surrounding terrain and groundwater.

[c] High emissions to landfill likely reflect deposition directly to land surrounding the plant as well as the disposal of solid waste in landfill.

[d] Adjustments to McCorquodale's estimates were made based on consideration of control technologies used at incinerators in the Basin.

Table C-3 Quantities, fates, market trends and technologies for major sources of mercury

Source category	Quantities and fates	Market trends	Technology
Smelting of non-ferrous ores	Trace amounts of mercury are found in nearly all minerals, with the most significant emissions associated with the recovery of zinc, copper and lead. Emission factors for these ores are provided in . Air emissions account for the largest source of mercury emissions from smelting operations. There are no regulations limiting the emission of mercury from non-ferrous smelting operations in North America, however smelters have agreed to the installation of control technologies by the end of 1994 (McCorquodale et al. 1992). Where installed, sludge generated from control technologies is disposed of in landfill, however the largest source of emissions to land result from the disposal of the mercury-laden slag.	Demand for copper, nickel, lead and zinc will affect the rate of release of mercury into the environment. Demand for these metals is strongly affected, in the short term, by their relative prices. In the long term, prices are expected to decline. Demand for non-ferrous metals, however, is predicted to remain relatively constant over time experiencing incremental increases with population growth and decreases with the development of substitutes (Anders 1991).	Source reduction can be achieved by reducing demand for zinc, lead and copper, either through product substitution or recycling. In response to sulphur dioxide regulations sulphur dioxide stripping technology is being installed in many of the larger smelters. This technology has a secondary effect of removing particulate mercury, however sulphur dioxide scrubbers do not remove the mercury which is emitted in gaseous form. The amount of mercury emitted in gaseous form depends upon: • the temperature of the stack gas • the degree of saturation of the gas and • the volumetric flow of the gas (McCorquodale et al. 1992a). Cooling the gas stream will result in condensation of mercury vapour which can then be reduced by chemical scrubbing or adsorption. Wet scrubbers can remove up to 98 percent of particulate and gaseous mercury from smelters (Copowlski 1992). Sludge is disposed of in landfill. No technology is currently in use to recycle the mercury contained within the sludge. Improved containment of slag, either through capping with concrete or disposal in safe landfills can be employed to reduce land emissions.
Paints	Volatilization of paint is a significant source. The U.S. EPA cancelled all registrations for the use of mercury compounds in paints and coating in both interior and exterior paints (Federal Insecticide, Fungicide and Rodenticide Act). Canadian legislation limiting the use of mercury in paints does not exist, however Canadian manufacturers have followed the American lead in eliminating mercury from paints manufactured in Canada.	The release of mercury from the application of old stock paint is likely still significant, but will decrease with the turnover of stock (McCorquodale 1992b), and therefore paint will not remain a significant source of mercury emissions.	Given existing legislation and probable action taken by paint manufacturers, consideration of additional measures to reduce the mercury content of paint is likely unnecessary.

Source category	Quantities and fates	Market trends	Technology
Manufacture and use of control instruments and other electrical instrumentation	Mercury is used in many scientific instruments, including thermometers, barometers, manometers, coulter counters, gas analyzers and vacuum systems. Mercury is also used in the manufacture of electrical equipment such as florescent lamps, mercury vapour street lamps, high pressure sodium lamps, neon lighting, rectifiers and switches. Mercury is released to the environment from these products through vaporization during manufacture and refilling, and as a result of breakage and leakage. Spent equipment is usually disposed of in landfill, although some incineration occurs. Control and electrical instruments used in institutions are more likely to be source separated and sent to a hazardous waste facility. Source separation of household goods is less likely.	Mercury thermometers are being phased out and replaced by electronic or alcohol based instruments. Electronic devices can replace most of the other instruments such as barometers and other pressure gauges (McCorquodale et al. 1992).	Mercury is being substituted in thermometers with electronic or alcohol based instruments. The technology also exists to substitute mercury use in switches, lamps and other electronic instruments. Another method for decreasing the release of mercury is to increase the life-expectancy of the equipment. This may be achieved through better construction and maintenance of control instruments. Finally the collection of mercury from spent instruments for reuse and recycling can easily be put in place in most institutions, and is already being undertaken by many laboratories (McCorquodale 1992b).
Combustion of fossil fuels	Large quantities of mercury are emitted from the combustion of fossil fuels in industry, particularly from the combustion of oil, and the combustion of coal in generating stations. The emissions of mercury from coal-fired power plants is not regulated, and while installed controlled technologies are generally effective in reducing SO_2 emissions, NO_x emissions and fly ash, they are ineffective in controlling gaseous mercury emissions.	Trends in mercury emissions are related to the demand for electricity, and to the fuels and processes used to generate electricity. The Energy Information Administration (U.S. DOE 1992) estimates that the growth of electricity will continue the trend established in the 1980's of expanding at a slightly slower rate than the GNP. It estimates that most of the electric generating capacity added before 2005 is expected to use natural gas, while after 2005, coal-fired generators will dominate capacity additions. The Energy Administration estimates that the use of all fossil fuels will increase from 76.3 EJ in 1990 to 93.1 EJ in 2010, and that the domestic consumption of coal will rise from 800 million tonnes in 1990 to about 1 000 million tonnes in 2010. Forecasts do not specify the types of coal to be used. Compliance with the Clean Air Act (and incentives established with the sulphur dioxide emission permit trading program in the 1990 amendments to that act) will probably increase the proportion of cleaner coals used. Given the greater use of coal, mercury emissions from this source are likely to increase over time even if a higher proportion of clean coal is burned.	Source reduction can be achieved by substituting coal with lower mercury content, and reducing energy demand. 'Cleaner' fuels such as natural gas may replace coal and oil. Effective control technologies to reduce mercury emissions from stack gas include wet scrubbing, wet flue gas desulphurization (using a lime slurry), electrostatic precipitators for particulate collection, cooling and condensation of stack gas and mist elimination. Staged combustion and flue gas recirculation may also be employed to reduce mercury emissions. Fuel switching provides another alternative for reducing mercury emissions from combustion.

Source category	Quantities and fates	Market trends	Technology
Household batteries	Mercury batteries are produced in button and regular style format for use primarily by households. The release of mercury from household batteries into the environment is to a large extent attributable to emissions from incinerators and landfills. Batteries account for 35 percent of mercury usage in Canada (McCorquodale et al. 1992a) and almost one third of mercury use in the U.S. (Murdoch 1990). Mercury is primarily used in mercury oxide batteries in which the mercury serves as cathode, however it is also used in other batteries (carbon-zinc, alkaline, silver oxide and zinc-air) as an anode or to inhibit corrosion.	Duracell Canada has voluntarily "responded to the toxicity concern" related to mercury contained in household batteries, by reducing the quantity of mercury used in batteries by over 90 percent since 1986 to the point where the mercury content in alkaline batteries does not exceed 0.025 percent by weight, and is pursuing efforts to reduce the mercury content to zero (Watts 1992). However although the quantity of mercury in individual batteries has declined over time, the number of batteries produced has increased steadily (Institute for Risk Research 1992). One factor that can mitigate the increased demand for mercury for batteries is the continued development of household battery recycling programs (such as one in Hennepin County, Minnesota). Given the growth in other types of residential recycling, it is likely that more such programs will develop over time where recycling systems are considered to be appropriate.	Source reduction requires the phasing out of mercury use in batteries, however the toxicity value of substitute products should be considered. Source reduction can also be achieved by reducing demand for batteries containing mercury, however once again the toxicity of substitute products, such as nickel-cadmium cell rechargeable batteries, must be considered. Increasing separate collection of batteries for disposal in hazardous waste landfills would likely reduce emissions. However, safer containment within hazardous waste landfills is also required. Improved pollution control equipment on incinerator stacks would result in a decrease of air emissions from stacks.
Chlor-alkali industry	The data presented in Table C-2 indicate that the largest source of emissions from chlor-alkali plants are attributable to emissions from material deposited in landfills. However chlor-alkali plants have been shown to exhibit high levels of mercury in immediate proximity to the plant, resulting from fallout from air emissions, and it is likely that the landfill data presented in Table C-2 capture direct emissions to land, as well as emissions from landfills. Emissions from chlor-alkali plants can be traced to: •ongoing disposal of mercury-contaminated sludges and waste products in landfill •leaching from mercury-rich sediments surrounding chlor-alkali plants. Significant reductions of emissions to all media have already been achieved in the chlor-alkali industry through the conversion to non-mercury processes and regulation of disposal. It is therefore likely that ongoing emissions to land have been significantly reduced since the time the data presented in Table C-2 were developed. Some containment of mercury-rich sediments has been accomplished in the process of decommissioning old plants, however the threat of leaching remains, particularly in areas with acidic subsurface water (McBeath 1983).	Demand for chlorine produced using the mercury diaphragm chlor-alkali process has been decreasing for a number of years and is expected to continue decreasing (Paine 1992). Since chlorine and caustic sodas are used in the manufacture of plastics, trends in plastics use will help determine future amounts of mercury produced by this industry. We expect that the demand for plastics will continue to increase with population. (Note, however, that environmental regulations and fees may provide firms with incentives to move production elsewhere.) The increase in plastics production may be slowed somewhat due to increased recycling. There may also be substitutes for chlorine and caustic soda in the manufacture of plastics.	Sludge created from the control of air emissions are landfilled at hazardous waste facilities. Alternately, the solid waste can be stabilized, put through a waste retort using activated carbon filters and recycled in the plant. Retorts are about 98 percent efficient in removing the mercury from solid waste. The mercury can then be condensed and recycled within the plant (Paine 1992). Increasingly stringent regulation and the trend towards conversion of plants to non-mercury processes has likely reduced the amount of solid waste going to landfills. Decontamination of sediments surrounding the plants is generally accomplished by cement containment. Removal of mercury rich soils is also undertaken in some cases. Virtual elimination of ongoing generation of mercury will requires complete conversion to non-mercury processes. As mentioned previously, many chlor-alkali plants have made this transition, however the investment required to convert remaining facilities may be prohibitive as the demand for chlorine is declining (Paine 1992).

Source category	Quantities and fates	Market trends	Technology
Incineration	Incineration accounts for almost two thirds of mercury emissions to air in the Great Lakes basin. Most incinerators are equipped with scrubbers or electrostatic precipitators to remove sulphur dioxide and trap fly ash. However this type of control is ineffective in trapping mercury vapours at high temperatures. When STP effluent is used as feed for the scrubbers, mercury compounds in stack gas dissolve and are released in the effluent of the scrubber. Incinerator ash also exhibits high concentrations of mercury (McCorquodale et al. 1992a).	The proportion of waste disposed of by incineration relative to that disposed in landfills has decreased in recent years due to Ontario's policy to discourage incineration. During that time, some incinerators have ceased operation. Ontario's target of 50 percent waste reduction by 2000 will likely result in a decrease in waste requiring disposal, and as a result, less waste being burned in incinerators. As of 1990 about 10 percent of municipal solid waste in the United States is incinerated. That percentage is expected to grow to up to 25 percent by the end of the century. Growth will take place predominantly in high population density areas, such as that surrounding the Great Lakes basin (Denison and Ruston, 1990). There have been isolated calls for bans on waste-to-energy incinerators in the U.S. (Electric Utility Week 1992) or in parts of the U.S. (Greenwire 1991), but it appears that incineration of hazardous wastes in the U.S. will increase (Christian Science Monitor 1991). Reasons for increased use of incineration for disposal of hazardous wastes include the continuing cleanup of Superfund sites, and the fact that the EPA continues to increase standards on the types of newly produced toxic wastes it allows to be buried.	Reducing emissions from incineration can be achieved by separating mercury-containing waste products (batteries, electric and control instruments) from the waste to be burned, or implementing control measures to reduce stack emissions. Controls include adapting more efficient burning techniques, and application of stack technologies such as wet scrubbing and mist elimination to remove gaseous mercury. Control technologies vary in their ability to capture mercury. Studies show that effectiveness varies from 25 percent of mercury captured to 85 percent mercury removal (through a spray dryer and baghouse system). Spray dryers and electrostatic precipitators can achieve 35 to 45 percent removal (IRR 1992).
Landfill	Landfills emit mercury to the surrounding land and groundwater through leachate, and to air by evaporation. Though metals are generally not released rapidly from landfills, the rate of deterioration increases under acidic conditions, and where there is high flowthrough (IRR 1992).	Mercury going to landfill can be expected to decrease as mercury in products falls and as incineration accounts for a larger share of waste disposal.	No control technologies to reduce PCBs in landfills were found. PCB wastes find their way into landfills illegally, and inadvertently through municipal/household wastes such as fluorescent lamp ballasts (which contain a capacitor and a small transformer), old electronic equipment and fridges, etc and through the landfilling of incineration residues. Single capacitors never containing greater then 1 kg of PCBs are exempt from Regulation 309 and may be disposed of in landfills. Through historical practices, PCBs have also found their way into landfill sites.

Source category	Quantities and fates	Market trends	Technology
Sewage treatment plants (STPs)	Mercury is contained in sewage treatment plant sludge, which is either landfilled or deposited directly on land as fertilizer. Guidelines exist limiting the application of such sludges to soils where metal concentrations are already high (OMAF 1986), however more stringent guidelines have been called for.		The complexity of the mechanisms related to the formation of PCDD/F in sewage treatment plants is similarly complex to those of incinerators. A source of chlorinated precursor to sewage treatment plants is PCP. The role of PCP in relation to the presence of PCDD/F in the sewage treatment cycle is described in Figure C-5. There are several options for reduction of PCDD/F from sewage treatment plants: elimination of PCP from entering waters seeking sewage treatment; and alternative non-chlorine using sewage treatment technologies (e.g. ozonolysis).
Miscellaneous sources	Organic mercury compounds are used as catalysts in the production of various polymer products (acetaldehyde, vinyl chloride monomers, urethane foams, amongst others). Mercury is also used in laboratories, where it is used for reagents, indicators, calibration, sealing, radioactive diagnosis and tissue fixatives. Pharmaceutical uses include mercuric oxide, mercuric chloride, mercuric iodide and some other products. Mercury is also present in rock phosphate fertilizers, where losses of mercury occur during crushing and grinding operations and released in the scrubber effluent. A small amount of mercury is used in the manufacture of mercury-based dyes used for glazing paper (McCorquodale et al. 1992). Data revealing the relative contribution of these products to total mercury use are not available.	Not available.	

Table C-4 Examples of voluntary programs to reduce mercury releases to the environment

Type of program	Name or Jurisdiction	Description
Reductions of toxic discharges	United States 33/50 program	To the extent that companies whose toxic releases affect the Great Lakes Region participate in the 33/50 Program, releases of mercury will be reduced on a voluntary basis. Not every participating company is required to reduce mercury releases by 33 and 50 percent—the national goal is to reduce total releases of all 17 high-risk compounds to *all* environmental media by 33 and 50 percent by 1992 and 1995, respectively. However there is very high participation in the program from industries that release mercury or ship it off-site for disposal; participating industries account for almost 93 per cent of total industrial mercury releases (USEPA 1992).
Environmental labelling	Canada Environmental Choice	Voluntary reductions in the amounts of mercury used in household batteries have been made. So-called "mercury-free" batteries, (so-called because they continue to contain mercury, albeit in much smaller proportions than previously), are now being marketed in Canada and have received the Ecologo label of environmental friendliness from the Environmental Choice program. Alkaline batteries, both cylindrical and button, and zinc-air batteries (used in hearing aids) are labelled with the Ecologo. These batteries are manufactured by Duracell Canada Inc., Eveready Division Ralston Purina Inc. and Rayovac Canada Inc. Alkaline batteries that qualify for the EcoLogo must not contain mercury in excess of 0.025 percent by weight. This limit will be reduced to 0.020 percent by 1 July 1993. Alkaline manganese button or coin batteries (used in watches, cameras, calculators and hearing aids) must not contain mercury which exceeds the limit of 25 mg per cell. Alkaline batteries in general contain from one-half to one percent mercury by weight (Murdoch 1990). The criterion for zinc-air batteries is that they must have a mercury content which does not exceed the limit 40 milligrams per ampere hour. This limit, however, without controlling the numbers of batteries manufactured, cannot limit the total amount of mercury that may be emitted from these sources. Alternatives to zinc-air battery applications are mercuric oxide and silver oxide batteries. Mercuric oxide batteries typically contain about 35 percent mercury by weight (Murdoch 1990).
Source separation	Button batteries in Guelph	In Guelph, Ontario, the local Kinsmen's Club is sponsoring a voluntary drop-off program for button batteries by setting up drop boxes in local jewellers and other retail outlets selling the batteries. Used batteries collected will be handled as hazardous waste by the municipality and disposed of by their hazardous waste contractor at a secure landfill in Sarnia. Although Guelph will soon have a materials recovery facility with mechanical source separation designed to remove household batteries from the waste stream, it is expected to have limited effectiveness in removing button batteries because of their small size.
Source separation	Button batteries in Hennepin County	Hennepin County, Minnesota, home to the state's largest city, Minneapolis, has also instituted a button battery collection program and a program to collect household batteries, in concert with an information program alerting citizens to the hazards of mercury-containing batteries to reinforce the success of the collection program. This program was instituted in response to the discovery of high mercury levels in stack emissions from the county's new waste incinerator. The Minnesota state legislature has also passed a law requiring that battery manufacturers lower the mercury content of alkaline batteries to 0.025 percent by 1993 (modelled on the agreement between battery manufacturers and the European Community).

Table C-5 Canadian regulations affecting mercury use or disposal

Legislation	Description
Pest Control Products Act (Canada)	The PCPA requires uses of specified harmful substances to be registered. Although the following registrations are considered acceptable for mercury-based products under the provisions of the PCPA, there are none currently registered or in use. • Turf - fungal disease control • Apple - for emergency use only as a post-infection eradicant spray for the control of apple scab • Blueberry highbush - for the control of Godronia stem canker • Douglas fir, pine, hemlock - treatment of lumber for the control of sapstain and mould • Wood product, rope, fabric - rot prevention • Seeds - for import and use by the Plant Protection Division, Agriculture Canada, or by others under its supervision, in the treatment of cereal and other seed for quarantine purposes. Mercuric chloride may be registered for use as a seed treatment for the control of bacterial diseases in beet, cabbage, chard, cucumber, sweet pea, tomato, turnip and zinnia, although no applications for such a registered use have been made.
Metallurgical Industries Mercury Information Regulations	These regulations, promulgated under the Clean Air Act, 13 April 1977, require metallurgical industries to submit information to the Environmental Protection Service on mercury emissions to the atmosphere.
Chlor-Alkali Mercury National Emissions Standards Regulations	These standards, promulgated under the Clean Air Act, effective 1 July 1988, are expressed in terms of daily emissions in grams per thousand kilograms of rated capacity per day. The total amount of mercury that may be emitted from these sources in any day must not exceed 1.68 kg. These standards (and the Act itself) have been replaced by provisions of the Canadian Environmental Protection Act.
Chlor-Alkali Mercury Liquid Effluent Regulations	These regulations, promulgated under the Fisheries Act in March 1972, were revised 27 July 1977. The regulations state that "the owner of a plant may deposit mercury contained in effluent if the actual deposit of mercury in any day does not exceed 0.0025 kilograms per tonne of chlorine times the reference production rate of that plant."
Chlor-Alkali Mercury Release Regulations	Promulgated under CEPA, February 1990, these regulations set release limits into ambient air based on rated capacity—the amount of chlorine a plant is designed to produce each day, with a notwithstanding clause limiting the total amount of mercury released to 1.68 kilograms per day.
Liquid Effluent Discharges from Smelters and Base Metal Refineries	These were developed by the Environmental Protection Service (EPS) under the Fisheries Act.

Table C-6 United States regulations affecting mercury releases to the environment

Legislation	Description
Clear Air Act	Under Section 112 of the Clean Air Act, the U.S. EPA has developed several National Emission Standards for Hazardous Air Pollutants (NESHAPs), one of which regulates emissions of mercury. The mercury standard applies to stationary sources which process mercury ore to recover mercury, use mercury chlor-alkali cells to produce chlorine gas and alkali metal hydroxide and incinerate or dry wastewater treatment plant sludge. Under this rule, emissions from mercury ore processing facilities and mercury cell chlor-alkali plants are limited to 2300 grams of mercury per 24-hour period. Emissions of mercury from sludge incineration plants, sludge drying plants, or a combination of these that process wastewater treatment plant sludges are limited to 3200 grams/24-hour period. The regulation also contains monitoring and testing requirements which must be followed in demonstrating compliance with the above air emission limitations. Another important provision of the Clean Air Act requires that the U.S. 2EPA list categories which account for 90 percent of the aggregate emissions of mercury by 1995. The EPA must then assume that these sources are subject to maximum available control technology within 10 years. The agency is then responsible for regulating each source category where appropriate. Electric utility steam generating facilities are exempt from this regulation, but are addressed separately within the act.
Federal (US) Insecticide, Fungicide and Rodenticide Act	USEPA has cancelled all registration for mercury compounds to be used in exterior and interior paints and coatings.

C.2 Hexachlorobenzenes

Hexachlorobenzene (HCB) is a synthetic organic compound with no natural sources. Figure C-2 traces the creation, and disposal of HCBs. There are no current commercial uses of hexachlorobenzene in the US. However, hexachlorobenzene was used as a pesticide until 1985, when the last registration of HCB as a pesticide was voluntarily withdrawn.

HCB is created as a by-product during the manufacture of chlorinated solvents, in particular perchloroethylene, trichloroethylene, carbon tetrachloride and chlorinated benzenes. The HCB remains in these solvents after their manufacture and enters the environment during their use or disposal.

Estimated emissions from contaminated pesticides are presented in Table C-7. HCB effluent emissions in Ontario, by source are presented in Table C-8.

Table C-9 discusses the major sources of HCB to the environment, their market trends and technologies available for eliminating or reducing emissions.

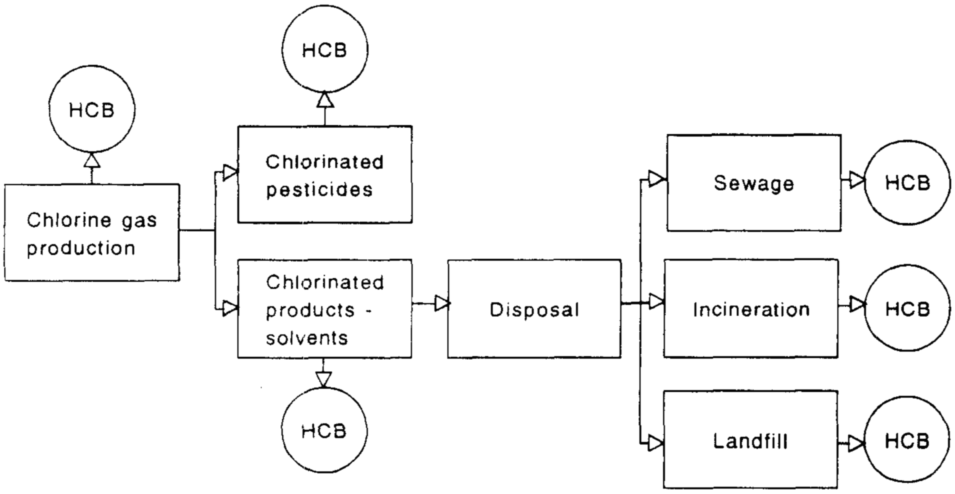
Other sources of HCB include its formation as a by-product in the production of chlorine gas by electrolysis of sodium chloride using a mercury electrode, the graphite conductors in the system furnishing the carbon (OMEE 1986).

There are presently no information or voluntary programs specifically directed at reducing emissions of HCBs in Canada or the United States.

HCB pesticides are required to be registered with Agriculture Canada, under the authority of the Pest Control Products Act. There are no current registrations of HCB, and HCB is neither produced nor used in Canada at this time. HCB continues to be created during the production of chlorinated solvents and pesticides, and during the combustion of fossil fuels and municipal and industrial waste.

In the United States, the last commercial registration of hexachlorobenzene (for use as a pesticide, registered under FIFRA) was voluntarily withdrawn in 1985: there are no other commercial uses of HCB in the United States.

Figure C-2 The creation and fate of hexachlorobenzenes



SOURCE: Hickling Corporation

Table C-7 HCB emissions from contaminated pesticides

Pesticide	% contamination of HCB[a]	HCB release in Ontario[b] t/a	HCB release in the U.S. (1985)[a] t/a
PCNB	0.5	n.a.	5.7
chlorothalonil	0.05	0.039	1.7
DCPA	0.3	n.a.	6.5
picloram	0.02	n.a.	0.09
pentachlorophenol	0.01	n.a.	3.4
total		0.039	17.4

SOURCES:

[a] Voldner and Smith, 1992

[b] Based on 1988 pesticide use data for Ontario. Moxley 1989.

n.a. not available

Table C-8 HCB effluent emissions in Ontario (1989-1990)

	loading	
	kg/d	kg/a
St. Clair river basin		
Dow Chemicals	0.005	1.8
Polysar	0.003	1.1
Lake Erie/Ontario basin		
none		
St. Lawrence river basin		
Cornwall		-
Dupont	0.001	0.4
Total	**0.009**	**3.3**

SOURCE: OMEE 1992.

Table C-9 Quantities and fates, market trends and technologies for HCBs

Source	Quantities and fate	Market trends	Technologies
Manufacture of chlorinated solvents	HCB air emissions are estimated at 3.4 to 11.3 t/a (Voldner and Smith, 1992). The total amount of HCB released from the organic chemical manufacturing sector in Ontario is reported as 3.3 kg/a (OMEE 1992). Ongoing sources of environmental release of HCB are as a byproduct in the production of chlorinated solvents: perchlorethylene; trichlorethylene; carbon tetrachloride; and chlorinated benzenes. Estimated release of HCB into water from U.S. manufacturing of all chlorinated compounds is 70 kg/a (Carpenter et al. 1986 as cited in U.S. Public Health Service 1989).	HCBs released as a by-product in the manufacture of solvents will decrease over time. Demand for carbon tetrachloride, used in the manufacture of CFCs, will continue to decrease as CFCs are phased out. The forecast for trichloroethylene indicates a decrease of 2-3 percent per year from 1992-1996 in demand in this market. Trichloroethylene's use in metal cleaning has been restricted because of VOC emissions. Renewed growth around mid-decade may occur as TCE is required as a potential feedstock for CFC alternatives and as a possible replacement for 1,1,1-trichloroethane. (Chemical Marketing Reporter 1992). The 1990 amendments to the Clean Air Act include more stringent regulations on the use of perchloroethylene (perc) by the dry cleaning industry, which consumes over half of all perc produced in the U.S. These regulations call for better maintenance and leak prevention. Decreased demand for perc for other uses is also expected. Use of perc as a degreaser for chemical feedstocks is expected to become more efficient or obsolete, and possibly subject to U.S. EPA regulations. (Chemical Week 1991). Other chlorinated solvents (chlorinated benzenes) are used in semiconductor production, degreasing, and for some medical purposes. Expected increases in output from these sectors will drive the demand for solvents that are considered less environmentally harmful.	Non-chlorinated substances or alternative processes are options for many applications in which chlorinated solvents are used. Recycling of many solvents, e.g. trichloroethylene is possible and increasingly widespread. Better maintenance and operating procedures can reduce the need for solvents.
Sewage treatment	Approximately 1 - 2 kg/a of HCBs are released into Lake Ontario from sewage treatment effluent in the U.S. (U.S. Public Health Service 1989).	Not available	

Source	Quantities and fate	Market trends	Technologies
Chlorinated pesticides	Pesticides containing HCB include: pentachloronitrobenzene (PCNB)[7]; chlorothalonil; dacthal; and picloram. PCNB use is limited primarily to greenhouse crops and there is a very small amount of acreage under glass (Hunter 1992). PCNB is registered for use on flowering plants, lawns and selected vegetable crops. Chlorothalonil's main use is in fruits and vegetables (Moxley 1989). Registered uses for chlorothalonil include greenhouse flowers, vegetables, a variety of fruits and outdoor flowers. Registered uses for picloram are grasses, non-crop land, and utilities' right-of-way. In the U.S., HCB release to the environment from pesticide usage is estimated at 17 t/a. Based on pesticide use data for Ontario, 0.039 t/a of HCB is released. The proportion of HCB which volatilizes, settles or cycles through the groundwater is not known. In addition, 3,500 to 11,500 kg of HCB were inadvertently produced in the manufacture of chlorinated solvents in 1984 in the U.S. (Carpenter et al. 1986 as cited in Life Systems 1989 draft).	HCB as a product, primarily as a fungicide, is no longer used in Canada or the United States. However, HCB is also produced as a contaminant in some pesticides. There is no evidence of decreased demand for these pesticides containing HCBs in the United States. California voters recently voted on a comprehensive environmental proposition (Proposition 128) that would have banned the use of chlorothalonil in California; the proposition was defeated. There has been a slight increase in PCNB use during the last 3 to 4 years. Picloram is a little-used product whose market share is declining. It is difficult to predict trends in the use of these pesticides. For example, the change in U.S. regulations 3-4 years ago restricting use of a competitive product prompted a significant increase in the use of chlorothalonil. (The market has since stabilized.) A label expansion for a significant crop can also cause the demand to increase. These types of events are difficult to predict.	All of these active ingredients have substitutes; most are more expensive and difficult to use. The market share of dacthal decreased significantly approximately 4 years ago. Dacthal is used for pre-emergence control of crabgrass and there are now post-emergence herbicides on the market which decrease the need for dacthal.
Incineration	Hexachlorobenzene is produced during combustion processes such as incineration of municipal and hazardous wastes. The U.S. EPA estimated the total HCB released to the air from municipal incineration using municipal incinerator data and a range of reported flue gas concentrations, to be 57 to 454 kg/a in the U.S. (Voldner and Smith, 1992). Canadian quantities are not available.	As noted in the sections on mercury, PCBs and PCDD/F, the quantity of waste incinerated in Ontario is expected to decrease.	Like dioxins and furans, HCB is a product of incomplete combustion, and the same technologies are applicable.

---

[7] The following discussion of pesticides relies extensively on information provided by Mr. Craig Hunter, Ontario Ministry of Agriculture and Food.

C.3 Polychlorinated biphenyls

In both the U.S. and Canada, the continued use of PCBs is allowed only in existing closed electrical systems. PCBs are primarily used as dielectric fluids in transformers and capacitors. The flowchart in Figure C-3 presents the life-cycle of PCBs.

Although no longer manufactured, there are significant quantities of PCB containing equipment in use or storage. Table C-10 and Table C-11 present data for Ontario. U.S. data are presented in Table C-12.

There are a large number of sources emitting PCBs to the air (see Figure C-3). ORTECH (1990) has calculated emissions of PCBs to the air in Ontario and Eastern North America based on emission factors and levels of activity within various sectors (e.g. various forms of incineration, combustion, power generation etc.). These emission estimates are provided in Table C-13.

The major source of PCBs to the air in both Ontario and the U.S. is volatilization of PCBs from open sources such as leakages from electrical equipment and from municipal landfills. Electric power generation is the second largest source of airborne emissions of PCBs in Ontario and Eastern North America.[8]

Market trends and alternative technologies to eliminate or reduce PCB releases to the environment are summarized in Table C-14.

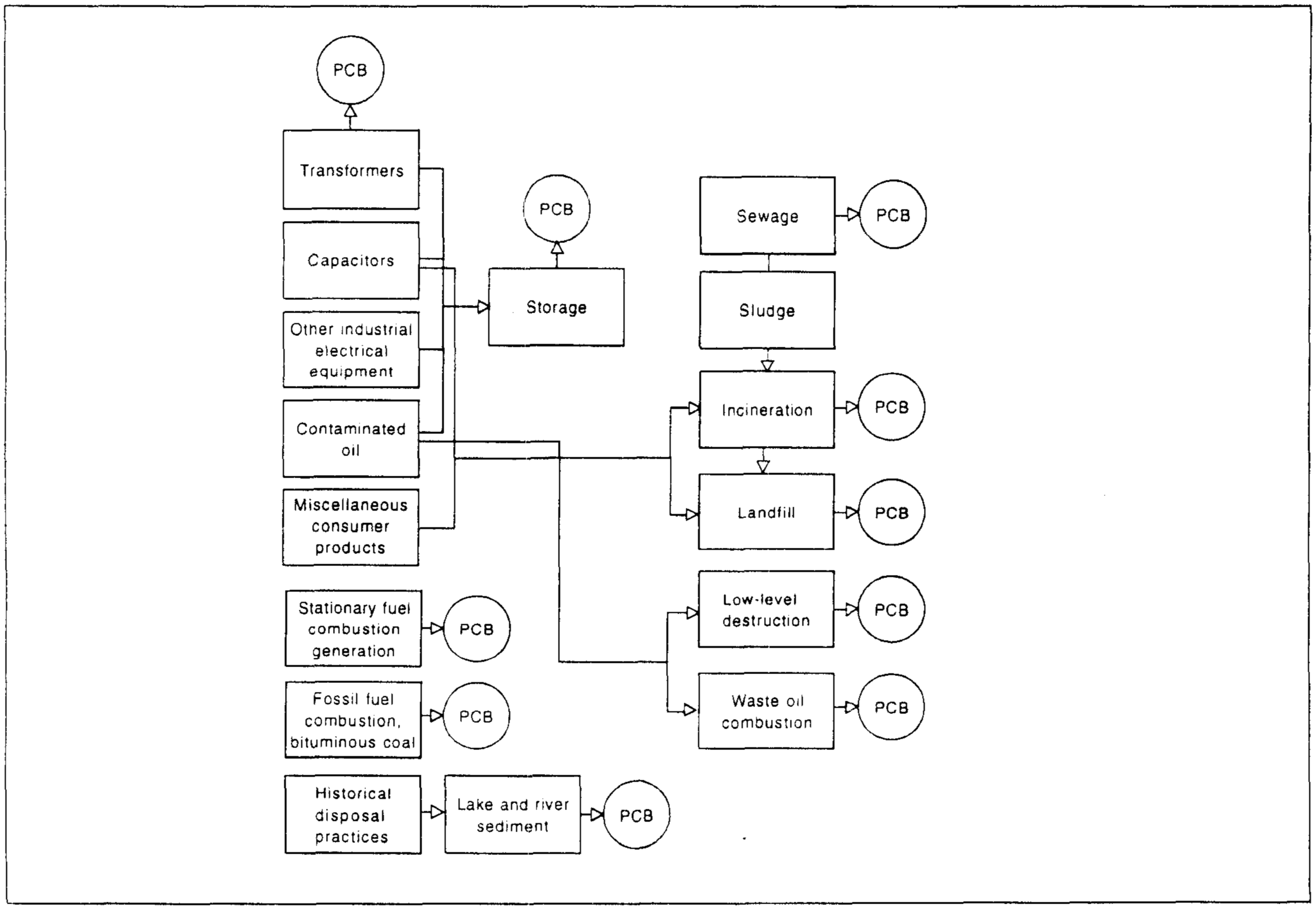
Major users of PCBs were the electric utilities, and many have voluntary programs to ensure that existing stocks are safely stored or destroyed. An example of one such utility program for Ontario Hydro is summarized in Table C-15.

PCBs are also highly regulated. Key regulations are identified in Table C-16 and Table C-17.

---

[8] ORTECH 1990 based on, Thorndyke, S.J., 1988. Airborne trace organic emission program at the Ontario Hydro Lambton Thermal Generating Station. Prepared by the Ontario Research Foundation (now ORTECH International) for Ontario Hydro.

Figure C-3 The sources and fates of Polychlorinated biphenyls



SOURCE: Hickling Corporation

Table C-10 Ontario PCB quantities in storage - October 1991

Type of PCB waste	High level (t)	Low level (t)
Liquids:		
Bulk liquids	1 354	3 508
Transformer liquids	918	298
Ballasts	5 813	0
Capacitors	383	0
Total	8 468	3 806
Solids:		
Drummed soil	623	9 018
Contaminated bulk soil	7 293	78 615
Misc. drummed solids	223	660
Misc. bulk solids	116	1 177
Total	8 255	89 470

SOURCE: OMEE inventory of Ontario PCB storage sites (does not include Federal PCB sites), October 1991.

NOTES: High level PCBs wastes contain >10 000 ppm PCB
Low level PCBs wastes contain 50 - 10 000 ppm PCB

Table C-11 Ontario Hydro inventory of PCBs in-use and in storage

		1990	1991
PCB contaminated oil	in service	6,150 tonnes	4,736 tonnes
	waste quantity in storage	2,850 tonnes	2,574 tonnes
PCB filled capacitors	number in service	21,100	20,975
	waste number in storage	11,300	14,706
PCB filled transformers	number in service	761	683
	quantity of askarel in service	1,061 tonnes	946 tonnes
Transformers and other equipment(excluding capacitors)	number in storage	1,398	1,630
	associated askarel quantity in storage	162 tonnes	277 tonnes
PCB-contaminated solid waste not included above	in storage	3,040 drums	3,635 drums

Source: Ontario Hydro 1992.

Table C-12 Summary of PCB quantities by source for Ontario and the United States

Disposition	Low level PCBs (t) (50-10,000 ppm)	High level PCBs (t) > 10,000 ppm
Air emissions - Canada[a]	n/a	.045
Air emissions - U.S.[a]	n/a	<1.0047[f]
Industry effluent - Canada	n/a	.0096[c]
Industry effluent - USA	n/a	.8795[d]
Sediment/environment	70,000[e]	undetermined
In-use - Canada [b]	10,794	6,250
In-use - U.S.[e]	340,000	n/a
In-storage - Canada[b]	3,806	8,468
In-storage - U.S.[e]	140,000	n/a
Solids - Canada[b]	89,470	8,255
Total	654,070	22,975

a ORTECH 1990
b VHB Research and Consulting Inc. 1992
c calculated from MISA 1992 and assuming 265 d/a operation
d U.S. GAO 1991
e Voldner and Smith, 1992 - all quantities are assumed to be low level PCBs. PCBs in-storage are taken to be landfilled
f Eastern North America
n/a not applicable

Table C-13 Sources of PCB emissions to air

Category/Sector	Ontario kg/a	Eastern North America kg/a
STATIONARY FUEL COMBUSTION		
Electric power generation	6.83	337.6
Industrial fuel combustion	0.05	108.1
sub-total	6.88	445.7
SOLID WASTE INCINERATION		
Municipal waste incineration	0.42	11.2
Sewage sludge incineration	0.77	3.6
Industrial waste incineration	0.01	6.9
Commercial/institutional waste Incineration	0.01	3.0
Waste oil combustion	-	17.0
sub-total	1.21	41.5
OPEN SOURCES		
On-site incineration	-	8.2
Transformer leakage	33.58	440.5
Municipal refuse - landfill	3.27	68.7
sub-total	36.85	517.4
TOTAL	45.0	1,004.7

SOURCE: ORTECH 1990

Table C-14 Quantities, fates, market trends and technologies for major sources of PCBs

Source	Quantities and fates	Market trends	Technologies
Volatilization from open sources	The major source of PCBs to the air in both Ontario and the U.S. is volatilization of PCBs from open sources such as leakages from electrical equipment and from municipal landfills. The quantities of PCB wastes in-use and in-storage in Ontario in general, and by Ontario Hydro in particular are provided in Table C-10 and Table C-11. On average, the annual leakage/spillage rate of PCB from transformers and capacitors is approximately 0.0024 tonnes of PCB per tonne of PCB. For Ontario, 1990 inventory data approximately 9 800 tonnes of high level PCBs in-use and in-storage in transformers and capacitors (Environment Canada 1990), which translates to roughly 22 tonnes of PCB leaked or spilled annually. At present, there is no method for estimating atmospheric emissions which result from spills; however, based on uncovered dredged spoils, a rough estimate of 7.2 mg/kg of total PCB in transformers and capacitors may be used. Based on 1990 in-use and in storage data, an annual emission of 63 kg of PCB is estimated to be emitted to the atmosphere in Ontario from this source. These quantities are greater than the 1985 estimates reported by ORTECH (1990). Since the manufacture of PCB equipment and the refilling with PCBs was banned in 1980, increased estimates can only be attributed to improvements in the inventory.	PCBs are used as dielectric fluids in transformers and capacitors. The continued use of PCB contaminated oils is allowed only in existing closed electrical systems. Demand for the continued use of these products may depend on the demand for electrical services, or for specialized functions that this equipment fulfils in providing electrical services. However the use of PCBs will decrease.	The removal of PCB equipment from service and its subsequent destruction would be the most desirable means to reduce emissions from this source. The only option for owners of PCB waste in Ontario is storage. Ideally, these wastes would be destroyed, but there are no facilities in Canada available to destroy high level (>12,000 ppm) PCB waste. Alberta, with the first and only permanent incineration facility, near Swan Hills, has closed its borders and the facility will only handle PCB wastes generated in province. The temporary incineration project at the Department of National Defence Base at Goose Bay in Labrador has been completed. The site has since been decommissioned and the mobile unit relocated to the United States. A mobile incinerator was recently licensed to incinerate the province's largest stockpile of PCBs at Smithville, Ontario. It is working on this inventory, but future plans for the facility are not known. Routine inspection of equipment containing PCBs for points of leakage, and remediation of rust spots or the use of drip trays can help reduce leakage from equipment in use.

Source	Quantities and fates	Market trends	Technologies
Electric power generation	Electric power generation is the second largest source of airborne emissions of PCBs in Ontario and Eastern North America[9]. External combustion fossil fuel-fired boilers are used for the production of electricity. There are several types of boilers and fuels used in this sector; however, few data are available on emissions from each source. PCBs are produced in the firing of bituminous, lignite and anthracite coal and distillate and residual oil.	Future emissions of PCBs will be influenced by the use of fossil fuels. As noted in the discussion above on mercury pollution, the Energy Administration estimates that the use of all fossil fuels will increase from 76.3 EJ in 1990 to 93.1 EJ in 2010. Therefore, emissions of PCBs from this source will continue to increase.	Emissions from electric power generation can be reduced in the following ways: • reduction in demand for electricity • interfuel substitution (e.g. to natural gas) • mixing of fuels for more efficient and hotter combustion to facilitate destruction of endogenous PCBs and prevention of PCB formation during combustion • boiler modifications that change the fuel/air stoichiometry and mixing, operating temperatures and other operational factors to facilitate destruction of endogenous PCBs and prevention of PCB formation during combustion • electrostatic precipitators, cyclones, baghouses and scrubbers are commonly used for particulate control and are effective for PCBs adsorbed to particulate matter.
Landfills	PCBs are emitted from landfills . Typical landfill emissions are 190 ng/m^3 landfill gas (Murphy et al. 1985). Based on this emission factor (ORTECH 1990) estimates that 10-100 kg of PCBS are released to the environment from landfills in the U.S. Emission of PCBs in landfill leachate are dependent on the quality of the waste being landfilled, the physical nature of the landfill, climate, the type of landfill liner and a host of other factors.	The leaching of PCBs from landfills occurs because of what is disposed of in landfills. Disposal of items such as lamp ballasts, capacitors, solenoids and other PCB contaminated electrical equipment contributes to the total amount of PCB available to leach out of the landfill. Source separation of these for special processing, until existing stock has turned over and been replaced with PCB free products, will reduce loadings.	No control technologies to reduce PCBs in landfills were found. PCB wastes find their way into landfills illegally, and inadvertently through municipal/household wastes such as fluorescent lamp ballasts (which contain a capacitor and a small transformer), old electronic equipment and fridges, etc. and through the landfilling of incineration residues. Single capacitors never containing greater then 1 kg of PCBs are exempt from Regulation 309 and may be disposed of in landfills. Through historical practices, PCBs have also found their way into landfill sites.

---

[9] ORTECH 1990 based on, Thorndyke, S.J., 1988. *Airborne trace organic emission program at the Ontario Hydro Lambton Thermal Generating Station.* Prepared by the Ontario Research Foundation (now ORTECH International) for Ontario Hydro.

Source	Quantities and fates	Market trends	Technologies
Solid waste incineration	The third largest source of airborne PCBs is solid waste incineration (ORTECH 1990)[10]. PCB emissions may occur as a result of PCBs in the input feed, or they may be a product of incomplete combustion. PCB generation may be related to waste composition. Hospital incinerators have emissions with significantly higher PCB concentrations, possibly accounted for by the higher concentration of plastics in the waste feed: 20% versus 3 to 7% for commercial incinerators.	As discussed in the mercury section, use of incineration for waste management is growing in the United States, but not in Canada. However, the PCB concentration of the feed can be expected to decline as PCB containing products are disposed of and replaced with non-PCB containing products. In addition, new incinerators have more effective pollution control equipment than existing incinerators.	Technologies for eliminating or reducing PCB releases include source separation for special processing PCB containing products, and other waste management approaches, control of operating conditions to ensure complete combustion, and pollution control equipment.
Contaminated sediments and soils	As PCBs have been released to the environment, they have accumulated in sediments. There are few quantitative data available on the total loadings of PCBs arising from such sediments. Erosion or leaching of PCBs from previously contaminated soils is thought to be a major source of PCBs to the environment. Soils that are typically contaminated are abandoned industry sites, transformer locations, abandoned chlor-alkali plants and pulp mills, and PCB storage sites.	There has been a dramatic decrease in the concentrations of PCBs in the Great Lakes following the bans and restrictions on the use of PCBs (Environment Canada et al. 1991). This decrease has levelled off and there is some evidence that the current concentrations of PCBs arise partially from resuspension of PCBs from contaminated sediments in tributaries feeding the Great Lakes and from sediments within the lakes themselves (Environment Canada et al. 1991).	There are no proven technologies available to remediate large areas of PCB contaminated sediment.

---

[10] These estimates for various types of incineration were based on the quantities of wastes burned in Eastern North America and Ontario and emission factors available in: U.S. Environmental Protection Agency (U.S. EPA), 1990. *Toxic air pollution emission factors a compilation for selected air toxic compounds and sources, 2nd ed.* Report prepared by Radian Corporation for the U.S. EPA. EPA-450/2-90-011

Table C-15 Example of voluntary programs to reduce PCB releases to the environment—Ontario Hydro's plans

Retrofill/decontamination program.	Ontario Hydro's stated objective is to decontaminate 80 percent (6.7 million litres) of all low-level PCB contaminated insulating oils (original inventory of 8.4 million litres) by the end of 1993. Most PCB-contaminated oil is still in operating equipment. In 1991, Ontario Hydro drained 331,936 litres of PCB oil from operating equipment. 1,061 million litres of PCB oil were decontaminated by Ontario Hydro's Mobile Processing Units (MPU) and an additional 40,459 litres were decontaminated by an external contractor. To date Ontario Hydro has decontaminated 3.70 million litres of oil.
Station capacitor bank program.	Ontario Hydro's objective is to replace all PCB filled capacitors at transformer stations. At the start of the program there were 143 PCB capacitor banks comprising 27,833 PCB capacitors. In 1991, 29 capacitor banks comprising 6,178 capacitors were replaced with non-PCB units, leaving 20,514 capacitors in service at year end. Ontario Hydro's target date for complete removal is 1996.
Polemount capacitor program.	254 polemount capacitors were removed from service. Ontario Hydro has a target to remove the remaining 427 units by 1994.
Polemount transformer program.	Of more than 350,000 such units 256,000 were made before 1979. Test have shown that approximately 17% (55,000) are contaminated with PCBs. In 1991, 711 of these units were replaced.
Hydroelectric generation equipment.	All PCB equipment has been removed from all hydroelectric equipment in Ontario except Otter Rapids Generating Station (3 capacitors) and Sandy Falls Generating Station (5 transformers).
Nuclear and thermal facilities.	Studies to cost and plan replacement existing PCB transformers have been completed. Replacement programs will commence between 1992 and 1995.

SOURCE: Ontario Hydro 1992.

Table C-16 Canadian regulations affecting PCB use or disposal

Regulation 11/82 of the Ontario Environmental Protection Act	All companies using and storing PCBs must register with the Ontario Ministry of Environment as a "PCB Waste Disposal Site"
Canadian Environmental Protection Act (CEPA)	The use, storage and disposal of PCBs in Canada are regulated by the following CEPA regulations: • *PCB Destruction Regulations* • *Export of PCB Waste* • *PCB Waste Storage Regulations*
Chlorobiphenyl (PCB) Regulations (and their amendments)	Equipment already in use at the time of promulgation are allowed to continue in use, so long as emissions during use do not exceed 1 g/d. Other releases covered by this regulation are releases in pulp and paper mill effluent, and from sewage treatment plants, which are limited to 50 parts per million (ppm) concentration in effluent. PCB concentration in oil-based road surface applications for the control of dust are limited to 5 ppm, although some provinces have more stringent requirements, for example Quebec sets a limit of 1 ppm in road surface applications. Proposed regulations are expected to revise the limits on PCB releases during use of electrical and non-electrical equipment to 10 grams total, in place of the 1 gram per day limit. This is expected to result in greater compliance with the regulations because of the increased ease of monitoring.

Table C-17 Subjects covered in U.S. Regulations for PCBs

Subpart	Description	Subjects
A	General	Applicability Definitions References
B	Manufacturing Processing Distribution in commerce Use of PCBs and PCB items	Prohibitions Authorizations
C	Marking of PCBs and PCB items	Requirements Formats
D	Storage and Disposal	Disposal requirements Storage for disposal Incineration Chemical waste landfills Decontamination
E	Exemptions	Manufacturing, processing, and distribution in commerce exemptions
F	Reserved	
G	PCB spill cleanup policy	Scope Definitions Requirements for PCB spill cleanup Sampling requirements Effect of compliance with this policy and enforcement
H, I	Reserved	
J	General records and reports	Records and monitoring Certification program and retention or records by importers and persons generating PCBs in excluded manufacturing processes Reporting importers and by persons generating PCBs in excluded manufacturing processes Maintenance of monitoring records by persons who import, manufacture, process, distribute in commerce, or use chemicals containing inadvertently generated PCBs

Source: U.S. Environmental Protection Agency (U.S. EPA). 1990. *Code of federal regulations - 40 Part 761.* U.S. EPA 40 CFR Ch. 1 (7-1-90 Edition) Washington D.C.

C.4 Dioxins and furans

Polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) are two families of compounds related in physical structure and chemical properties. Two of the more toxic of the congeners are 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8 TCDD) and 2,3,7,8, dibenzo-p-furan (2,3,7,8 TCDF).

Dioxins and furans are inadvertently produced from a host of different industrial activities and processes. The processes by which PCDD/F are created and released are presented in the life-cycle flowchart in Figure C-4. Pentachlorophenols (PCPs) have a similar chemical structure, and are precursors of PCDDs and PCDFs. PCDD/Fs are produced during the production, use and disposal of PCPs. This is illustrated in Figure C-5.

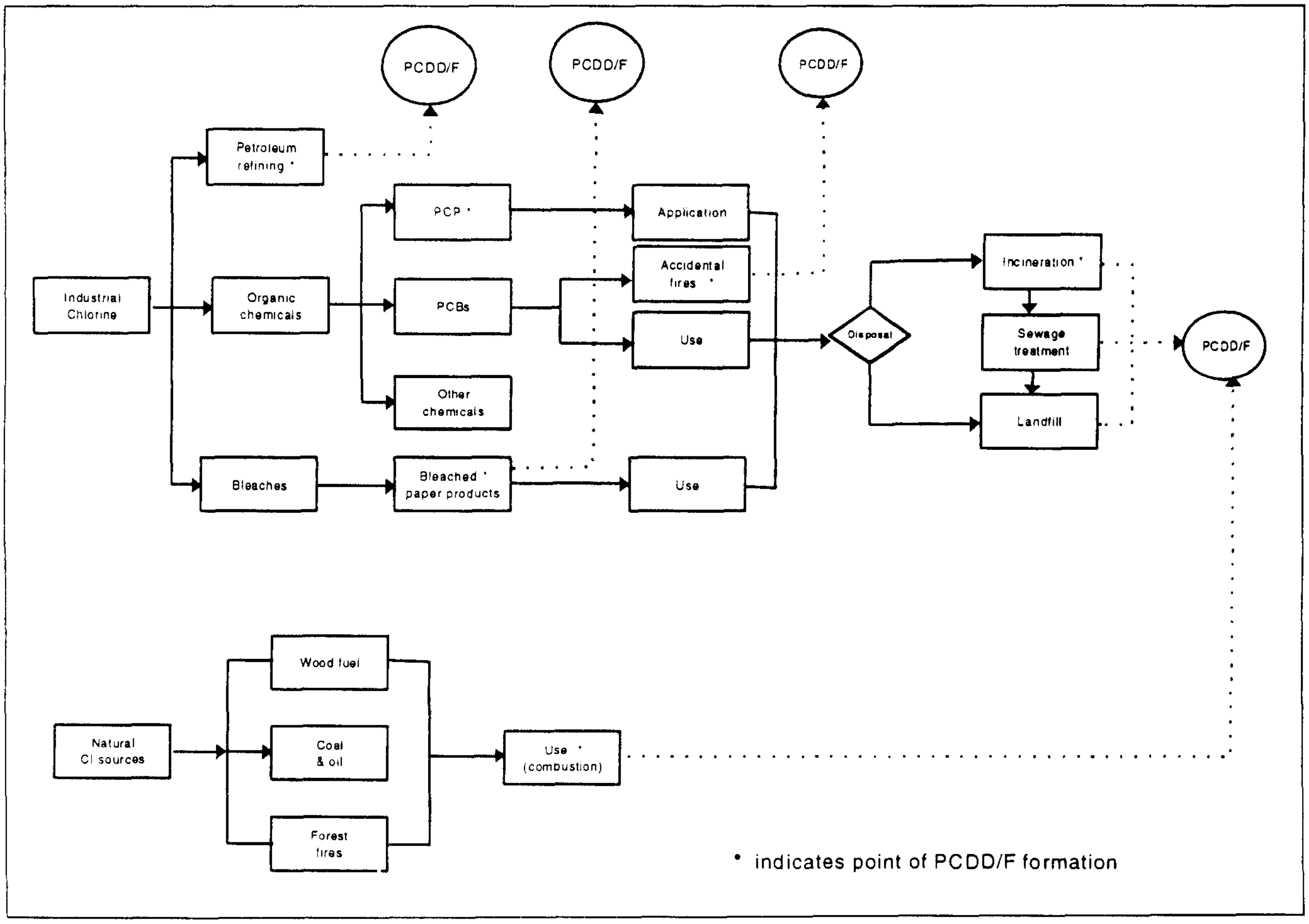
Incineration is the largest source of process derived PCDD/F. Additionally, dioxins and furans appear as byproduct contaminants of many chlorinated compounds. As such dioxins and furans are piggyback compounds; they often enter the environment along the pathways of their host compounds such as PCBs, pentachlorophenol and chlorinated pesticides.

Other sources include fossil fuel combustion, and industrial processes. Quantities of air emissions of PCDD and PCDFs in Ontario are presented in Table C-18 and Table C-19, respectively. Estimates of effluent sources from the organic chemical sector, and U.S. emissions from incinerators are presented in Table C-20 and Table C-21.

Table C-22 discussed the fates, quantities, market trends and technologies of the major sources of PCDD/F.

There are numerous industry and government programs to investigate the sources of dioxins and to develop control technologies. In addition, dioxins and furans are highly regulated. Some of the Canadian regulations that specifically target PCDD/Fs are identified in Table C-23. Of course PCDDs and PCDFs are also addressed by standard environmental protection legislation that covers multiple compounds, and PCDD/F control is a major issue in approval of new facilities in sectors where PCDD/F emissions have been identified.

Figure C-4 Sources and fates of dioxins and furans



SOURCE: Hickling Corporation

Figure C-5 The sources and fates of pentachlorolphenol

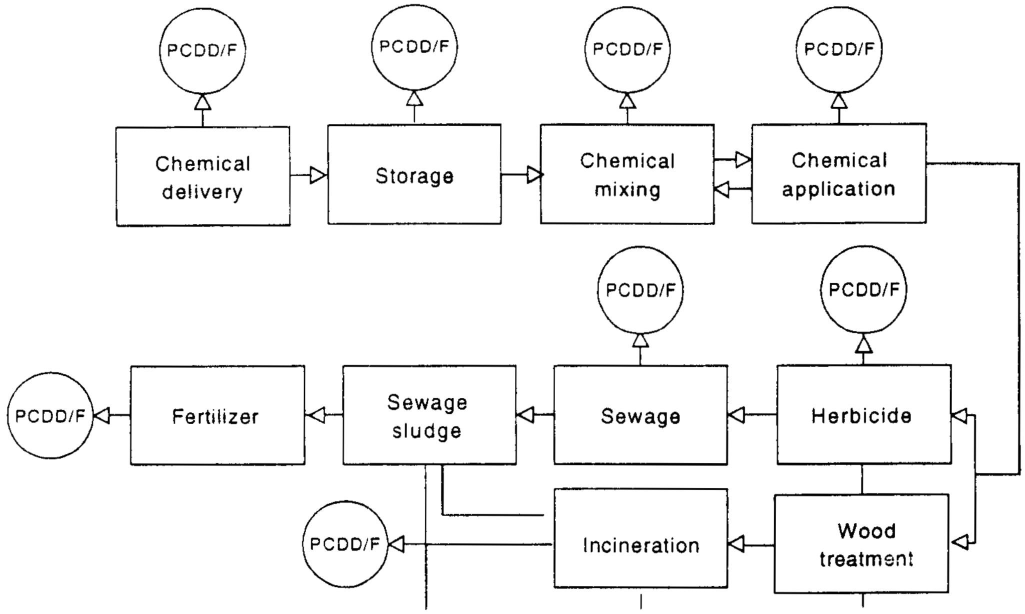


Table C-18 Total PCDD emissions to the air in Ontario for point, area and open sources and sector rank

Category/Sector	Estimated Point	Emissions (kg) Area	Total	Sector Ranking
Industrial				
Kraft Pulping	0.016		0.016	7
Sub-total	0.016		0.016	
Stationary Fuel Combustion				
Electrical Power Generation	0.186		0.186	3
Industrial Fuel Combustion		0.003	0.003	9
Residential Fuel Combustion		0.000	0.000	13
Residential Fuelwood Combustion		1.302	1.302	2
Sub-total	0.186	1.305	1.491	
Solid Waste Incineration				
Municipal Waste Incineration	4.175		4.175	1
Sewage Sludge Incineration	0.032	0.016	0.048	5
Industrial Waste Incineration	0.126		0.126	4
Comm./Inst. Waste Incineration		0.002	0.002	10
Sub-total	4.333	0.018	4.351	
Transportation				
On-Road Light Duty Gasoline Vehicles		0.040	0.040	6
Off-road Gasoline Vehicles		0.001	0.001	11
Sub-total		0.041	0.041	
Open Sources				
Forest Fires		0.001	0.001	12
Prescribed Burning		0.006	0.006	8
Municipal Refuse - Landfill		0.000	0.000	14
Sub-total		0.007	0.007	
TOTAL:	**4.535**	**1.371**	**5.906**	

SOURCE: ORTECH 1990

Table C-19 Total PCDF emissions to the air in Ontario for point, area and open sources and sector rank

Category/Sector	Estimated Point	Emissions (kg) Area	Total	Sector Ranking
Industrial				
Kraft Pulping	0.009		0.009	7
Sub-total	0.009		0.009	
Stationary Fuel Combustion				
Electrical Power Generation	0.634		0.634	3
Industrial Fuel Combustion		0.002	0.002	10
Residential Fuel Combustion		0.000	0.000	13
Residential Fuelwood Combustion		5.165	5.165	2
Sub-total	0.634	10.968	11.602	
Solid Waste Incineration				
Municipal Waste Incineration	6.027		6.027	1
Sewage Sludge Incineration	0.068	0.056	0.124	4
Industrial Waste Incineration	0.047		0.047	6
Comm./Inst. Waste Incineration		0.002	0.002	9
Sub-total	6.142	0.058	6.200	
Transportation				
On-Road Light Duty Gasoline Vehicles		0.057	0.057	5
Off-road Gasoline Vehicles		0.001	0.001	11
Sub-total		0.058	0.058	
Open Sources				
Forest Fires		0.001	0.001	12
Prescribed Burning		0.008	0.008	8
Sub-total		0.009	0.009	
TOTAL:	**6.785**	**11.093**	**17.878**	

SOURCE: ORTECH 1990

Table C-20 Effluent sources of dioxins and furans from the organic chemical manufacturing sector

Company	Chemical	Loading range of sampling points (pg/L)
Dow Chemical, Sarnia	Octachlorodibenzo-p-dioxin	27.9 – 21 613.0
	H6CDD	3.0 – 430.
	H6CDF	7.1 – 11 538.6
	H7CDD	13.2 – 1101.0
	H7CDF	10.7 – 17 742.4
	PCDD	9.9 – 115.9
	PCDF	5.7 – 5190.
	TCDD	2.8 – 95.7
	TCDF	3.4 – 2090.9
B.F Goodrich, Thorold	Octachlorodibenzo-p-dioxin	250. – 380.
Uniroyal Chemical, Elmira	Octachlorodibenzofuran	22. – 160.5
	H7CDF	20. – 145.0
Dupont, Kingston	2,3,7,8 TCDD	20. – 27.5
	Octachlorodibenzo-p-dioxin	30. – 55.5
	Octachlorodibenzofuran	30. – 65.
	H7CDD	21. – 30.5
	TCDD	20. – 210.
	TCDF	10. – 27.
Dupont, Maitland	Octachlorodibenzo-p-dioxin	30. – 220.
	Octachlorodibenzofuran	30. – 165.5
	2,3,7,8 TCCD	20. – 27.5
	PCDD	10. – 28.
	TCDD	20. – 1310.

SOURCE: OMEE 1992b. *Six months monitoring data report organic chemical manufacturing sector.* OMEE, Toronto.

Table C-21 Estimate of annual production of PCDD/F by incinerators in the United States

Congener	Mass burn kg/a	Modular kg/a	Refuse-derived fuel kg/a	Total
2,3,7,8-TCDD	21.86	.02	.26	22.13
TCDD	55.51	.56	19.76	75.83
PCDD	59.96	.18	13.08	73.22
2,3,7,8-TCDF	10.06	.00	.53	10.59
TCDF	332.68	.18	112.52	445.38

NOTES: The calculations above were based on 216,097,023 t/a (Murdoch 1992) waste of which 16% is incinerated by 157 incinerators in the U.S. with 68% of waste going to mass burn facilities, 9% to Modular and 23% to RDF (Denison and Ruston, 1990). Emission factors were taken from U.S. EPA 1990c. Emission factors used were the highest ones provided for each congener. Total PCDD is less that the sum of the individual congeners because a separate emission factor was used.

SOURCE: Murdoch 1990, Denison and Ruston, 1990, U.S. EPA 1990c.

Table C-22 Fates, quantities, market trends and technologies for PCDD/Fs

Sources	Quantities and fate	Market trends	Technologies
Incineration	Incineration is the largest source of PCDD/F in the Great Lakes basin. Most dioxin is generated within the incinerator as a product of incomplete combustion (Benefenati et al. 1991; OTA 1989, Shaub et al. 1983). Synthesis may occur by three mechanisms: conversion of chlorinated precursors, including chlorophenols, chlorobenzenes and PCBs; from non-chlorinated precursors (e.g. benzene, toluene etc.) and inorganic chlorine or from unrelated chlorinated compounds such as PVC (Shaub et al. 1983); or post-combustion catalysis of undestroyed precursors in the presence of fly ash (U.S. OTA 1989). Laboratory data show that plastic, especially PVC, is a PCDD/F precursor in laboratory experiments (Penner 1987). Although tests in Europe have indicated a correlation between plastic quantity and emissions of PCDD/F (Benefenati et al. 1991), others in Pittsfield, MA found none (U.S. OTA 1989). Studies done as early as 1982 found that controlled source separation of chlorinated precursors such as paper, plastic and vegetable materials caused elimination of most of the dioxins, and pushed furan concentrations below detectable limits (Harless and Lewis, 1982).	Market trends for incineration are discussed above in the mercury section of this appendix. In general, use of incineration for management of municipal solid waste is increasing in the United States. However, new incinerators can generally be expected to result in lower dioxin emissions than many existing incinerators due to designs allowing more efficient combustion, better operating controls, and pollution control equipment.	The major sources of chlorine (elemental or chlorinated precursors) in feedstocks to incinerators are plastics, chlorine bleached papers, wood and organics (all contain chlorine) or chlorinated compounds. Removal of these materials means removing most of the combustible material from incinerators. The removal of these materials may eliminate incineration as a viable solid waste management alternative. Combining the life-cycle approach and the traditional "end-of-pipe" approach to incineration the final set of options for eliminating PTSs from incineration are: • do not use incinerators for municipal waste management • phase out inefficient incinerators and replace them with new high efficiency (high temperature, high turbulence, long residence time) incinerator technologies (which may have to apply emissions controls). Maintaining high combustion efficiency keeps emissions low.
Residential fuelwood combustion	Residential wood combustion is a source of airborne PCDD/F in Ontario, resulting from the burning of wood in wood stoves, fireplaces and furnaces (ORTECH 1990). Based on an emission factor of 0.28 ng/m^3 2,3,7,8 TCDD for dry salt laden wood (U.S. EPA 1990a) and an estimate of 1,033 kt of residential wood burned in Ontario each year (Senes 1992) it is estimated that 0.58 mg 2,3,7,8 TCDD are emitted each year from residential wood combustion. This value is significantly higher for other congeners.	Not available	Newer wood stoves are designed to reduce emissions through the promotion of more complete combustion. These technologies could be expected to decrease dioxin and furan emissions. Operating procedures that promote a high burn efficiency, and minimize chlorine inputs can be expected to reduce emissions. For example, such procedures may include avoiding burning paper and plastics in the stove and burning dry wood.
Petroleum refining and organic chemical plants	Dioxins and furans have been found in the internal gaseous waste streams of petroleum refineries. At the Petro-Canada refinery in Mississauga, Ontario, they were found to contain 2,3,7,8 - TCDD in concentrations ranging from 7.8 ng/m^3 to 14.0 ng/m^3 (OMEE 1992b).	Many facilities have adopted control technologies at significantly reduced dioxin and furan emissions. For example, at the Shell refinery in Corunna Ontario, emissions fell by about three orders of magnitude to 15 ppq (OMEE 1990) due to addition of control technology.	As noted under market trends, control technologies can substantially reduce PCDD/F concentrations.

Sources	Quantities and fate	Market trends	Technologies
Kraft pulp and paper	Black liquor recovery furnaces used in Kraft pulp and paper mills to generate steam and recover process chemicals as well as mills employing waste wood and hog fuel combustors are sources of airborne PCDD/Fs. PCDD/Fs are also released in wastewaters from Kraft pulp and paper mills. The PCDD/F that is contained in the effluent is created during the bleaching process. PCDD/F are formed when nonchlorinated precursors e.g. dibenzodioxins and dibenzofurans enter the bleach plant along with the pulp and are chlorinated in the chlorination process (OMEE 1992).	These operating conditions have been modified by most mills in Ontario and there has been a general effort in the North American Kraft pulp industry to modify processes to reduce PCDD/F (OMEE 1992).	Chlorine free bleaching processes The following operating conditions can also contribute to minimizing formation of PCDD/Fs: • thorough washing of pulp prior to chlorination • effective mixing of the chlorine and pulp • careful control of the chlorine dosages effectively • avoiding chlorinated water use in the bleach plant.
Sewage treatment plants	PCDD/F are generated in sewage treatment plants using chlorine treatment technologies (Gihr et al. 1991; Ho et al. 1990; Naf et al. 1990). The PCDD/F that is generated is released in treated waters and adsorbed to organic materials in sewage sludge. Pathways for PCDD/F creation in sewage treatment have been identified as: • biogenous creation of PCDD/F by enzymes from PCP (Svenson et al. 1990) • from pentachlorophenol (PCP) treated wood in the presence of hypochlorite • via phosphorous elimination as impurities in Fe, Al salts, produced from scrap • formation of sulphur analogues to PCDD/F from pentachlorothiophenol.	Not available	A range of technologies and practices can eliminate or reduce PCDD formation from sewage treatment plants, including avoiding chlorine-based treatment technologies, incineration of sewage sludge, or both.
Landfilling	PCDD/F are hydrophobic and are generally insoluble. Based on solubility data from Shiu et al.(1988), the largest pathway to the environment from a landfill would likely be through volatilization to the air rather than through leachate. However, leaching of PCDD/Fs has occurred from landfills (e.g. Hooker Chemicals in New York State) and will continue to be a significant pathway away from landfills. Given the complex nature of the pathways of PCDD/F to the environment it is difficult to provide estimates of data regarding loadings of PCDD/F to the ground. There is extensive literature indicating that some of the PCDD/F generated in the incineration process may be catalyzed by fly ash (Shaub et al. 1983) and then adsorbed on to it. This fly ash is removed by emissions control technologies and subsequently landfilled.	The major source of dioxins going to landfills is from incinerator flyash. Thus landfill loadings are linked to incinerator use, which is increasing in the United States portions of the Great Lakes basin. In addition, there are major sources associated with closed landfills which continue to release PCDD/Fs. This can be expected to decline as sites are remediated.	Avoid loadings, particularly to insecure landfills.

Sources	Quantities and fate	Market trends	Technologies
Pentachlorophenol production and use	Dioxins and furans may be released during the application of PCP and are released during incineration of PCP treated products.	Specific trends in the demand for treated wood, with estimates of the proportion of wood treatment provided by PCP and PCP-containing treatments would not be released by individual producers. However, the demand for PCP treated wood is decreasing, and major buyers (like electric utilities) are switching to other products. For example, Ontario Hydro reduced the percentage of PCP treated poles purchased in 1992 by 25% (Ontario Hydro 1992).	Non-PCP containing wood preservers are available to substitute for PCP. Ontario Hydro, in conjunction with the University of Toronto and the University of Waterloo is developing a method to biodegrade PCP treated wood. This effort is to avoid stockpiling of PCP treated poles that are out of service in non-hazardous industrial solid waste sites.
Spills and landfarming	There are two primary sources of PCDD/F emitted to land. Emissions occur when host chemicals or products such as PCBs, PCPs, chlorinated pesticides are spilled or applied and when products containing PCDD/F (e.g. some papers) and residues from combustion, incineration and sludges from various processes are disposed of in landfills. An example of this is the biological sludges from Shell Canada's petroleum refining operations in Corunna which were found to have concentrations of PCDD/F ranging from 75.4 ppb to 125 ppb and which are landfilled onsite (OMEE 1990).	With the increasing recognition of the potential hazards associated with PCDD/F greater control is exercised over materials containing these compounds and releases to the environment from spills can be expected to continue to decrease. Use of landfarming can be expected to decline over time.	Spills can be minimized with vigilance and careful operating, inspection and monitoring procedures. Proper waste disposal practices can reduce risks of environmental releases of PCDD/Fs.
Sediments	Though the general solubilities of PCDD/Fs favour sedimentation they do maintain an equilibrium constant with the Great Lakes. As the concentrations in the lakes drop there will be some PCDD/F leaving sediment and entering solution. The quantities of PCCD/F reentering the waters of the Great Lakes is not available due to the uncertainty of many of the associated factors (e.g. temperature effects, total PCDD/Fs in sediment etc.)	Will increase as other sources of PCDD/F decline	No proven technologies.

Table C-23 Canadian regulations affecting dioxins and furans

Act/regulation	Contents/description
Canadian Environmental Protection Act	Regulations under CEPA for dioxins and furans include: • *Chlorinated organic substances* • *Chlorinated Dioxins and Furans Release in Pulp and Paper* • *Mills' Effluent Pulp and Paper Product Regulation*
Canada Fisheries Act: Pulp and Paper Effluent Regulations	These regulations limit the amount of dioxins and furans in pulp mill effluent to non-detectable concentrations, and, in the case of the Fisheries Act regulations, generally prohibit the deposition of "acutely lethal" substances, where acutely lethal means that the effluent at 100 percent concentration kills more than 50 percent of the rainbow trout subjected to it during a 96 hour period. (Dioxins and furans are generally thought to be chronically toxic, i.e., they cause toxic effects after prolonged exposure to concentrations not acutely toxic.) The *Chlorinated organic substances* regulation limits emissions of organochlorines (AOX) to 2.5 kilograms per bone-dry tonne of pulp product.
Canada Fisheries Act: Pulp and Paper Mill Defoamer and Wood Chips Regulations	Environment Canada's December, 1991, regulations prohibit the use of a defoamer at a mill that uses a chlorine bleaching process, unless an analysis of each batch of the defoamer indicates that it contains 40 parts per billion (ppb) by weight of furans and 10 ppb by weight of dioxins. The regulations also prohibit the manufacture, import or sale of defoamers with concentrations of dioxins and furans exceeding these limits. The import, sale or use of wood chips made from wood treated with polychlorinated phenols is also prohibited by these regulations.
Canada Pest Control Products Act	Pentachlorophenol (PCP) is used exclusively as a wood treatment for the prevention of insect and fungal damage, and decay. In Ontario, these uses are required to be registered by regulations promulgated under the Pest Control Products Act, administered by Agriculture Canada.

Appendix D Incineration in the Great Lakes basin — Action summary sheets

Municipal solid waste incinerators in the Great Lakes basin action summary information sheet	BATTERY1
PTS affected	Mercury
Type of action	Source reduction
Action	Reduce the mercury content of batteries
Description	Already under pressure from citizen groups and the federal government, industries that use mercury in their products, especially the battery and paint industries, have begun source reduction programs to reduce or eliminate their mercury use. Assuming 50% of the mercury reductions from mercury-zinc batteries in MSW are due to reductions in the mercury content of mercury-zinc batteries (and 50% due to product substitution for low mercury batteries) established industrial source reduction programs will reduce battery mercury discards in MSW by 53% from 1989 to 1995 U.S. EPA 1990b). Since industry has already paid for these programs the cost of this action is assumed to be zero. Reduce the mercury content of household batteries thereby reducing the mercury content of MSW. The cost of the action is assumed to be zero since industry has already paid for these reduction efforts.
References	U.S. EPA 1990b
Emissions in Great Lakes basin (tE/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	22%
Percent source emission reduction	53%
Potential emissions reduction (tE/a)	1.8
Capital cost (per tE)	na
Operating cost	$0.00
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	6.00%
Net cost of action (per tE)	$0.00

PTS affected	Mercury
Type of action	Product substitution
Action	Use batteries with lower mercury levels
Description	Switch from mercury-zinc batteries to batteries that have lower mercury content such as lithium and nickel-cadmium. The cost of this action is assumed to be zero. As part of its move away from mercury use, the battery industry is, to a limited extent, substituting mercury-zinc batteries for batteries that have a lower mercury content for high-mercury batteries. Mercury-zinc batteries can be substituted with lithium and nickel-cadmium (rechargeable) batteries thereby decreasing emissions of mercury from Municipal solid waste incineratorss. However, emissions of other heavy metals could potentially increase. Assuming 50% of the mercury reductions from mercury-zinc batteries in MSW are due to substituting mercury-zinc batteries for batteries with low mercury the U.S. EPA estimates that mercury from battery discards in MSW will decrease 17% from 1989 to 1995 (U.S. EPA 1990b). The cost of this action is assumed to be zero.
References	U.S. EPA 1990b
Emissions in Great Lakes basin (tE/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	22%
Percent source emission reduction	17%
Potential emissions reduction (tE/a)	0.6
Capital cost (per tE)	na
Operating cost	$0.00
Benefits	na
Unquantified costs or benefits	Potential increases in emissions of other heavy metals such as cadmium.
Lifetime	na
Discount rate	6.00%
Net cost of action (per tE)	$0.00

PTS affected	Mercury
Type of action	Source separation
Action	Collection and disposal of batteries in landfill
Description	Several communities have initiated programs to collect household hazardous wastes, including batteries and paints. They have had limited success thus far, achieving under 30 percent participation, and collecting approximately 10 percent of mercury-containing products such as batteries before they enter the MSW stream. The cost of disposing of these items in hazardous waste landfills is about 1 160 $/t (900 US$/ton), plus approximately 129 $/t (100 US$/ton) for collection, or about 1 289 $/t ($1 000/ton) total. Collect batteries for disposal in hazardous waste landfill. The cost of the action is the sum of the cost of collection and disposal. Based on efficiency of existing hazardous waste collection programs, mercury reduction efficiency is
References	Apotheker 1991b; Bagby et al. 1992; Cohen 1993; Dubois 1992; Hurd 1992; Reutlinger and de Grassi, 1991
Emissions in GLB (tE/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	43%
Percent source emission reduction	50%
Potential emissions reduction (tE/a)	3.4
Capital cost (per Te)	na
Operating cost	$45 740
Benefits	na
Unquantified costs or benefits	Risk of explosion of batteries in storage.
Lifetime	
Discount rate	6.00%
Net cost of action (per Te)	$45 740

BATTERY4

PTS affected	Mercury
Type of action	Source separation
Action	Collection and recycling of mercury containing batteries
Description	Several communities have initiated programs to collect household hazardous wastes, including batteries and paints. They have had limited success thus far, achieving under 30 percent participation, and collecting approximately 10 percent of mercury-containing products such as batteries before they enter the MSW stream. A Japanese company has developed a battery recycling technology that costs about 644 $/t (500 US$/ton), or about 773 $/t ($600 US$/ton), including collection costs. However, large capital investments would be required to make this option realistic in the United States. The cost of the action is the sum of the cost of collection and recycling. Based on efficiency of existing hazardous waste collection programs, mercury reduction efficiency is assumed to be 10%.
References	Apotheker 1991b; Bagby et al. 1992; Cohen 1993; Dubois 1992; Hurd 1992; Reutlinger and de Grassi, 1991
Emissions in GLB (Te/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	43%
Percent source emission reduction	50%
Potential emissions reduction (Te/a)	3.4
Capital cost (per Te)	na
Operating cost	$32 018
Benefits	na
Unquantified costs or benefits	Since certain batteries may contain substances which are hazardous, the distribution of special containers to hold the batteries may be necessary. Risk of explosion of batteries in storage.
Lifetime	
Discount rate	na
Net cost of action (per Te)	$32 018

Municipal solid waste incinerators in the Great Lakes basin
action summary information sheet CA

PTSs affected	All types
Type of action	Pollution control
Action	Activated carbon adsorption
Description	Activated carbon absorption has control efficiencies and costs similar to those for Na_2S injection.
References	Berenyi and Gould, 1991.
Emissions in GLB (tE/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	100%
Percent source emission reduction	55%
Potential emissions reduction (Te/a)	8.6
Capital cost (per Te)	na
Operating cost	$103 642
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per Te)	$103 642

PTS affected	Mercury
Type of action	Pollution control
Action	Mercury pollution control using dry sorbent injection with fabric filters
Description	Several control technologies affect all PTSs. Dry sorbent injection and fabric filters do not reduce dioxin and furan emissions from Municipal solid waste incinerators, but do control mercury emissions. Fabric filters (baghouses) contain woven bags of fabric which collect the particulates when the flue gas is drawn through the it. Fabric filter typically have removal efficiency of 99% for various sizes of particles. Particulates as small as 0.1 microns can be captured. The fly ash (accumulated particulates) fall into a hopper, and then the fabric filters are cleaned and the ash is disposed of properly. In dry sorbent injection scrubbers, an alkaline agent such as lime is injected into the flue gases to react with acid gases. Tests have shown the control efficiencies of dry injection scrubbers to be 99% for hydrogen chloride under optimal conditions (110°C) with lower efficiencies at higher temperatures. DSI/FF have average mercury control efficiencies of 69% at a cost of 8.4 million $/t (6.5 million US$/ton) (Berenyi and Gould, 1991).
References	Berenyi and Gould, 1991
Emissions in GLB (tE/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	100%
Percent source emission reduction	61%
Potential emissions reduction (Te/a)	9.5
Capital cost (per Te)	na
Operating cost	$999 149
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per Te)	$999 149

PTS affected	Mercury
Type of action	Source separation
Action	Collection and disposal of electrical and electronic equipment at landfill
Description	Collect electrical and electronic equipment for disposal in hazardous waste landfill. The cost of the action is the sum of the cost of collection and disposal. Based on efficiency of existing hazardous waste collection programs (Batteries), mercury. Reduction efficiency is assumed to be 10%.
References	Apotheker 1991b; Bagby et al. 1992; Cohen 1993; Dubois 1992; Hurd 1992; Reutlinger and de Grassi, 1991
Emissions in GLB (tE/a)	15.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	16%
Percent source emission reduction	10%
Potential emissions reduction (tE/a)	0.2
Capital cost (per tE)	na
Operating cost	$18 433
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	6.00%
Net cost of action (per tE)	$18 433

PTSs affected	Chlorinated organics
Type of action	Source separation
Action	Remove food, yard and other organic wastes from incinerator feed
Description	Dioxin and furans can be produced through inefficient combustion of elements of the MSW stream. Typically, parts of the MSW stream that burn inefficiently are "wet" organics, such as yard waste with a high moisture content. This problem can potentially be relieved by collecting those elements that hinder combustion efficiency and preventing them from entering a MSWI facility. Generally this can be done by collecting and composting yard waste. Prohibiting yard waste from entering a MSWI facility will enhance the operation of the facility and help prevent the formation of dioxin and furan. The costs for collection, processing, and composting yard waste is about $90 per ton, which is approximately the same cost for normal collection and landfilling or incineration. Lack of reduction efficiency data prevented the consideration of food, yard and other organic waste source separation actions.
References	U.S. EPA 1987; U.S. EPA 1991; Apotheker 1991a; Taylor and Kashmanian, 1988; Michigan Waste Industries Association; Illinois Department of Energy and Natural Resources 1989.
Emissions in GLB (tE/a)	74.8
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	100%
Percent source emission reduction	na
Potential emissions reduction (tE/a)	na
Capital cost (per tE)	na
Operating cost	na
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per tE)	na

PTSs affected	All types
Type of action	Source reduction
Action	Landfill instead of incinerate
Description	By sending all MSW previously destined for MSWIs to landfill, one could achieve 100% reduction efficiency for mercury, dioxin and furan at a cost of 1.2 M$/t (0.9 million US$/ton PTS).
References	U.S. EPA 1990b
Emissions in GLB (tE/a)	230.6
Number of municipal solid waste incinerators affected	33
Proportion of EQU emissions affected	100%
Percent source emission reduction	100%
Potential emissions reduction (tE/a)	230.6
Capital cost (per Te)	na
Operating cost	$2 733 795
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per tE)	$2 733 795

PTSs affected	All types
Type of action	Pollution control
Action	Injection of sodium sulphide into the flue gas
Description	Injecting sodium sulphide (Na_2S) into the flue gas has an average control efficiency of 90% for mercury, dioxin and furan. The capital costs associated with this technology range from $190 000 to $317 000 (150 000 to 250 000 US$) while the operating costs due to chemical costs range from 0.13 to 0.64$/t MSW (0.10 to 0.50 US$/ton MSW). The annualized cost of the action ranges from 0.64 to 1.30$/t MSW (0.50 to 1.00 US$/ton MSW) or 0.8 M$/t PTS (600 000 US$/ton PTS)(Berenyi and Gould, 1991).
References	Berenyi and Gould, 1991
Emissions in Great Lakes basin (tE/a)	15.6
Number of MSWIs affected	33
Proportion of EQU emissions affected	100%
Percent source emission reduction	55%
Potential emissions reduction (tE/a)	8.6
Capital cost (per tE)	na
Operating cost	$103 642
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per tE)	$103 642

PTS affected	Mercury
Type of action	Source reduction
Action	Reduce mercury content of other product
Description	Reduce the mercury content of other products thereby reducing the mercury content of MSW. The cost of the action is assumed to be zero since industry has already paid for these reduction efforts. No source reduction actions were identified for this product category. The U.S. EPA predicts mercury disposal from this product category will increase 31% from 1989 to 1995 (U.S. EPA 1990b).
References	U.S. EPA 1990b
Emissions in Great Lakes basin (tE/a)	15.6
Number of MSWIs affected	33
Proportion of EQU emissions affected	34%
Percent source emission reduction	27%
Potential emissions reduction (tE/a)	1.4
Capital cost (per tE)	na
Operating cost	$0.00
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	6.00%
Net cost of action (per tE)	$0.00

PTS affected	Mercury
Type of action	Source reduction
Action	Reduce the mercury content of paints
Description	Historically, mercury was used in exterior latex paint as a paint preservative, however the paint industry has already made significant progress in reducing the mercury content of paints. The U.S. EPA estimates that established industrial source reduction programs will reduce paint mercury discards in MSW by 87% from 1989 to 1995 (U.S. EPA 1990b). Since industry has already paid for these programs, the cost of this action is assumed to be zero. Reduce the mercury content of exterior latex paints thereby reducing the mercury content of MSW. The cost of the action is assumed to be zero since industry has already paid for these reduction efforts.
References	U.S. EPA 1990b
Emissions in Great Lakes basin (tE/a)	15.6
Number of MSWIs affected	33
Proportion of EQU emissions affected	7%
Percent source emission reduction	87%
Potential emissions reduction (tE/a)	0.9
Capital cost (per tE)	na
Operating cost	$0.00
Benefits	na
Unquantified costs or benefits	
Lifetime	
Discount rate	6.00%
Net cost of action (per tE)	$0.00

PTS affected	Mercury
Type of action	Source separation
Action	Collection and disposal of paints in landfill
Description	Collect paints for disposal in hazardous waste landfill. The cost of the action is the sum of the cost of collection and disposal. Based on efficiency of existing hazardous waste collection programs, mercury reduction efficiency is assumed to be 10%.
References	Apotheker 1991b; Bagby et al. 1992; Cohen 1993; Dubois 1992; Hurd 1992; Reutlinger and de Grassi, 1991
Emissions in Great Lakes basin (tE/a)	15.6
Number of MSWIs affected	33
Proportion of EQU emissions affected	7%
Percent source emission reduction	23%
Potential emissions reduction (tE/a)	0.23
Capital cost (per tE)	na
Operating cost	$1 650
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	6.00%
Net cost of action (per tE)	$1 650

PTS affected	Mercury
Type of action	Source separation
Action	Collection and recycling of mercury containing paints
Description	Collect paints for recycling. Reduction efficiency is assumed to be 10%. No recycling cost data are available for these product groups which prevented the consideration of these actions.
References	Apotheker 1991b; Bagby et al. 1992; Cohen 1993; Dubois 1992; Hurd 1992; Reutlinger and de Grassi, 1991
Emissions in Great Lakes basin (tE/a)	15.6
Number of MSWIs affected	33
Proportion of EQU emissions affected	7%
Percent source emission reduction	50%
Potential emissions reduction (tE/a)	0.5
Capital cost (per tE)	na
Operating cost	na
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	6.00%
Net cost of action (per tE)	na

Municipal solid waste incinerators in the Great Lakes basin
action summary information sheet

PAPER1

PTSs affected	Chlorinated organics
Type of action	Source separation
Action	Remove paper, paper products and wood from incinerator feed
Description	Paper products comprise the largest proportion of MSW. Paper products are also sources of chlorine. However, it is not known to what extent removal prior to combustion would reduce chlorine levels and since paper is the primary fuel source in the incineration of MSW combustion performances may decline if a high proportion of paper is removed, possibly resulting in higher emissions of dioxins and furans and other pollutants resulting from poor combustion (U.S. EPA 1991). Lack of reduction efficiency data prevented the consideration of paper, paper products and wood source separation actions.
References	U.S. EPA 1991
Emissions in Great Lakes basin (tE/a)	74.8
Number of MSWIs affected	100%
Proportion of EQU emissions affected	33
Percent source emission reduction	na
Potential emissions reduction (tE/a)	na
Capital cost (per tE)	na
Operating cost	na
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per tE)	na

PTSs affected	Chlorinated organics
Type of action	Source separation
Action	Separate PVC from waste to be incinerated
Description	PVC is the most prevalent chlorine-containing plastic in MSW and has been shown to be a precursor for formation of dioxins, furans and other chlorinated organics in laboratory tests. The third largest source of airborne PCBs is solid waste incineration (ORTECH 1990)[11]. PCB emissions may occur as a result of PCBs in the input feed, or they may be a product of incomplete combustion. PCB generation may be related to waste composition. Hospital incinerators have emissions with significantly higher PCB concentrations, possibly accounted for by the higher concentration of plastics in the waste feed: 20% versus 3 to 7% for commercial incinerators. Plastic's role in dioxin and furan emissions from MSW incinerators is not clear (U.S. EPA 1991). Lenoir et al. (1991) and five published reports cited in Lenoir that the addition of PVC to municipal waste and waste paper did **not** increase dioxin and furan emissions. In addition to PVC there are many other sources of chlorine in MSW, including wood, bleached paper, chlorinated solvents and treated textiles. Since the gas stream chlorine concentration is several thousand times greater than concentrations of dioxin and furan, it is unlikely that separating any specific chlorine-containing material will sufficiently lower the level of available chlorine to a point where dioxin and furan formation is eliminated (U.S. EPA 1991). Lack of reduction efficiency data prevented the consideration of PVC source separation actions.
References	Lenoir et al. 1991; U.S. EPA 1991
Emissions in Great Lakes basin (tE/a)	74.8
Number of MSWIs affected	100%
Proportion of EQU emissions affected	na
Percent source emission reduction	na
Potential emissions reduction (tE/a)	na
Capital cost (per tE)	na
Operating cost	na
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per tE)	na

---

[11] These estimates for various types of incineration were based on the quantities of wastes burned in Eastern North America and Ontario and emission factors available in: U.S. Environmental Protection Agency (U.S. EPA), 1990. *Toxic air pollution emission factors a compilation for selected air toxic compounds and sources, 2nd ed.* Report prepared by Radian Corporation for the U.S. EPA. EPA-450/2-90-011

PTSs affected	All types
Type of action	Pollution control
Action	Spray dry scrubbers and fabric filters
Description	Spray-dry or semi-dry scrubbers are similar to wet scrubbers except the acid gas is captured when they come into contact with an alkaline substance such as lime. The residue is a dry fly ash/lime mixture and does not contain water thus it is easier to treat and dispose of. Also, it requires less power and is not as corrosive. Spray-dry or semi-dry scrubbers typically have a control efficiency of 99% for hydrogen chloride and SO_2 under optimal conditions (temperatures less than 300°F, high lime/acid ratios, and high gas residence time in the scrubber). Mercury, dioxin and furan are also reduced. SD/FF have average mercury control efficiencies of 84% and average dioxin/furan control efficiencies of 98% at a cost of 8.4 M$/t PTS reduced (6.5 million US$/ton PTS reduced)(Berenyi and Gould, 1991).
References	Berenyi and Gould, 1991
Emissions in Great Lakes basin (tE/a)	230.6
Number of MSWIs affected	33
Proportion of EQU emissions affected	100%
Percent source emission reduction	54%
Potential emissions reduction (tE/a)	124.6
Capital cost (per tE)	na
Operating cost	$764 932
Benefits	na
Unquantified costs or benefits	na
Lifetime	na
Discount rate	na
Net cost of action (per tE)	$764 932

Appendix E Polyvinyl chloride in the Great Lakes basin — Action summary sheets

---

Polyvinyl chloride in the Great Lakes basin - action summary information sheet VINYL1

Source affected	PVC
Type of action	Substitution
Major product category	Building and construction
Product	Vinyl siding and accessories
Action	Replace PVC used for vinyl siding with aluminum. The cost of the action is represented by the difference in cost between vinyl and aluminum siding (not counting transportation or installation costs). It was assumed that PVC comprises 80 percent of vinyl siding by weight. It was assumed that the effective lifetime of aluminum siding is equal to that of vinyl siding.
References	Duess 1993; Vinyl Siding Institute 1993a; Vinyl Siding Institute 1993b
Proportion produced in Great Lakes basin	12.5%
PVC content	80.0%
Potential reduction in PVC:	
proportion	100.0% of siding
total	10.0% of PVC in Great Lakes basin
Capital cost ($/kg)	$4.13
Operating cost	na
Benefits	na
Unquantified costs or benefits	na

Source affected	PVC
Type of action	Substitution
Major product category	Building and construction
Product	Vinyl windows
Action	PVC is used in the manufacture of all-vinyl and composite vinyl or vinyl clad windows. It was assumed that one-half of the PVC used in the manufacture of vinyl windows is used to manufacture all-vinyl windows (of which the PVC content by weight is assumed to be 80 percent) and that the other half is used in the manufacture of composite vinyl windows (of which one-half of 80 percent, or 40 percent, is assumed to be PVC by weight). The cost of the action is the cost difference between vinyl-clad and aluminum-clad windows, assuming that the vinyl and aluminum content, respectively, are the same, and that price differences are attributable to the material used.
References	Bregar 1993.
Proportion produced in Great Lakes basin	4.7%
PVC content	60.0%
Potential reduction in PVC	
proportion	100.0% of windows
total	2.8% of PVC in Great Lakes basin
Capital cost ($/kg)	($38.00)
Operating cost	na
Benefits	na
Unquantified costs or benefits	na

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 0.5 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC	
proportion	15.70%
total	1.02%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$9.51
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 0.75 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.14%
Potential reduction in PVC:	
proportion:	27.69%
total	1.70%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$6.33
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 1.00 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC	
proportion	14.63%
total	0.95%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$5.97
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 1.25 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	5.78%
Potential reduction in PVC:	
proportion	12.12%
total	0.70%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$6.95
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 1.50 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC:	
proportion	2.67%
total	0.17%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$4.50
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 2.0 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC:	
proportion	11.35%
total	0.74%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$5.84
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 2.5 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC	
proportion	12.20%
total	0.79%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$6.75
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 3.0 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC:	
proportion	3.23%
total	0.21%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$7.51
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Electrical conduits
Type of action	Substitution
Action	Substitute 4.0 inch diameter rigid steel for same diameter PVC. Cost difference is difference in product list prices. The relative proportion of each action in reducing PVC production is based on sales by PVC pipe size from 1 January 1993 to 27 April 1993, from a major Canadian electrical supplies company. The action assumes complete interchangeability of conduits in every application. Separate actions to reduce the PVC content of pipe fittings were not identified. Instead this product category representing 2.2% of PVC use was divided and added to the different pipe and conduit product category according to each category's relative consumption of PVC. PVC pipes and conduits are made from a combination of PVC and additives. Determining the type, amount and cost of these additives for each product category and factoring them into the cost equations was beyond the scope of this study.
References	Deangelo 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	6.50%
Potential reduction in PVC:	
proportion	0.42%
total	0.03%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$3.31
Benefits	na
Unquantified costs or benefits	Rigid steel is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 4 inch diameter ductile iron for same diameter PVC. List prices of both PVC and pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$3.26
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 6 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$1.15
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 8 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	$0.48
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 10 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($0.29)
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 12 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($0.60)
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 14 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($0.39)
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 16 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993

Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($0.55)
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 18 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($0.88)
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Water main pressure pipes
Type of action	Substitution
Action	Substitute 20 inch diameter ductile iron for same diameter PVC. List prices of both PVC and DI pipes for 4-20 inch range and PVC pipe weights for less than 14 inch diameter were provided by a major Canadian pipe distributor (Neilson 1993). Cost of action is difference in product list price. Weights for PVC pipes greater or equal to 14 inch diameter were estimated. The action requires the following assumptions: equal production of each PVC pipe size in the Great Lakes basin; no production of PVC pipe for hot and cold water applications in the Great Lakes basin; and PVC pipe of other diameters is not used in water main applications in the Great Lakes basin.
References	Neilson 1993; Modern Plastics 1993

Number of units	na
Proportion produced in Great Lakes basin	13.80%
Potential reduction in PVC	
proportion	11.11%
total	1.53%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($1.00)
Benefits	na
Unquantified costs or benefits	Ductile iron is less corrosion resistant and heavier which may impact on transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Sewer pipes - sanitary
Type of action	Substitution
Action	Substitute all concrete pipes with PVC pipes in sanitary sewer applications. Cost information based on differences in list prices for 15 inch piping (the most common size). The action requires the following assumptions: production of stormsewer pipe production in Great Lakes basin is ten times the production of sanitary sewer pipe; 20% of sanitary sewer applications are PVC; 98% of storm sewer applications are PVC (estimates from Lister 1993); complete interchangeability of pipes in every application; and the difference in list price for the different pipe sizes is directly related to the PVC content of the pipe.
References	Lister 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	9.10%
Potential reduction in PVC	
proportion	32.89%
total	3.00%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($0.21)
Benefits	na
Unquantified costs or benefits	Concrete pipes are heavier which may result in higher transportation and installation costs.

Source affected	PVC
Major product category	Building and construction
Product	Sewer pipes - storm
Type of action	Substitution
Action	Substitute all polyethylene (PE) pipes with PVC pipes in storm sewer applications. Cost information based on differences in list prices for 15 inch piping (the most common size). The action requires the following assumptions: production of stormsewer pipe production in Great Lakes basin is ten times the production of sanitary sewer pipe; 20% of sanitary sewer applications are PVC; 98% of storm sewer applications are PVC (estimates from Lister 1993); complete interchangeability of pipes in every application; and the difference in list price for the different pipe sizes is directly related to the PVC content of the pipe.
References	Lister 1993; Modern Plastics 1993
Number of units	na
Proportion produced in Great Lakes basin	9.20%
Potential reduction in PVC	
proportion	67.11%
total	6.20%
Capital cost (per kg PVC)	na
Operating cost ($/kg)	($1.09)
Benefits	na
Unquantified costs or benefits	na

Appendix F Environmental equivalences of PTSs considered

A system employing environmental equivalence factors of the persistent toxic substances (PTSs) included in discharges from incinerators is used. Such a system is necessary, whether explicit or implicit, when designing a tax that applies to multiple emissions, as is considered for incinerator emissions. In these circumstances, either a tax can be placed on quantities of emissions, without consideration of the type of emission (suggesting that— for tax purposes— all compounds are treated equally), or the tax can be applied at different rates to different compounds, reflecting differences in hazard, abatement costs or other factors.

Since many actions affect more than one PTS, the allocation of costs must be dealt with, and we have elected to rate the PTSs considered on the basis of "hazard".

Although governments and government agencies in Canada and the United States have developed systems to determine the environmental significance of PTSs, these systems and their results are inadequate for the determination of equivalence factors of the PTSs under consideration in this report for the following reasons:

- equivalences have not been generated for all of the PTSs under consideration
- scoring systems employed are not additive

The Office of Pollution Prevention and Toxics of the U.S. EPA has developed a method of generating profiles of relative toxicity for each molecular species of a variety of organic PTS, however these toxicity profiles are not available for metals making determination of mercury's equivalence factor impossible (Nabholz 1993). Further, toxicity is only one component of hazard, others include mobility and persistence.

Health and Welfare Canada are determining exposure potency indices for a variety of substances, but not for any of the PTSs under consideration in this study (McBain 1993).

Governments in both Canada and the United States have developed scoring systems for assigning PTSs to pollutant lists such as CEPA's "Priorities Substance List", OMEE's "Candidate Substance List" (CEPA has not developed a scoring system but has adopted The Ontario Ministry of Environment and Energy's scoring system for the production of a second "Priority Substance List" (Socha 1993)) and Michigan's "Critical Materials Register". These systems score each PTS for parameters such as ability to bioaccumulate, persistence, chronic and acute toxicity, mutagenicity and carcinogenicity and any PTS that meets any one of the criteria established for inclusion on that list (i.e. above a threshold for one or more parameter) is placed on that pollutant list. Even though these systems employ numerical scoring for each parameter, these scores are not additive and there is insufficient information to weight the level of environmental concern associated with each substance. In the case of Michigan's Critical Materials Register, the highest score registers as no score.

Regulatory guidelines for each of the PTSs might be employed as a measure of their relative environmental significance. This however would overestimate the equivalence factor of bioaccumulative PTSs which have significantly lower guideline values than other PTSs (Mackay 1993). Also, the adoption of regulatory guidelines as a basis of establishing equivalence factors would be inconsistent with this report which focuses on the virtual elimination of PTSs from air emissions, whereas the regulatory guidelines represent "acceptable" or "tolerable" levels.

Due to the lack of any system to determine environmental equivalence factors for the five PTSs under consideration, the environmental significance relationships based on the PTSs relative general toxicity and provided by Donald Mackay were adopted (Mackay 1993).

1 *Dioxin* ≃ 10 *Furan* ≃ 50 *Mercury* ≃ 500 *PCB* ≃ 500 *HCB*

In the design of the economic policy instrument, the relative environmental significance relationship is used to determine the level of the tax. For example, a tax of $1/kg HCB is equal to a tax of $500/kg of dioxin.

The design of the modelling framework permits the relative environmental significance of PTSs to be changed.