CASE STUDY

APPLICATION OF A VIRTUAL ELIMINATION STRATEGY TO AN INDUSTRIAL FEEDSTOCK CHEMICAL

CHLORINE

A DRAFT REPORT TO THE
VIRTUAL ELIMINATION TASK FORCE

BY

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1) INTRODUCTION: THE COMMISSION'S POSITION

The Virtual Elimination Task Force (VETF) is charged by the Commission to investigate means of implementing the Great Lakes Water Quality Agreement's requirement that inputs of persistent toxic substances into the Great Lakes Basin Ecosystem be virtually eliminated. The purpose of this report to the Task Force is to recommend a strategy to achieve virtual elimination of persistent chlorinated organics, a class of chemicals that dominates both the Commission's list of 11 Critical Pollutants and the IJC's Working List of Chemicals in the Great Lakes Basin. (International Joint Commission, Water Quality Board, 1987).

This class, also called organochlorines, is defined as those compounds in which chlorine is bound to carbon-based organic substances. When referring to compounds containing carbon and chlorine or one of the other halogens (fluorine or bromine), this class is sometimes referred to as halogenated organics. Chlorinated organics are produced intentionally as thousands of chemicals products (e.g. pesticides, plastics, and solvents), and as thousands of unintentional by-products of industrial processes that use chlorine or other organochlorines (e.g., in pulp bleaching, waste incineration, or chemical manufacturing).

The weight of evidence, summarized in "The Injury" section of the Commission's Sixth Biennial report, clearly links persistent toxic substances, particularly organochlorines, in the Great Lakes to injury, disease, and death in a variety of life forms, including humans. This information is also summarized in "The Injury" section of the Task Force's April, 1993 draft report. Of the 11 Critical Pollutants for which the evidence of large-scale effects is strongest, eight are organochlorines. Of the 362 on the Water Quality Board's list of chemicals that have been found in the Great Lakes, about half are organochlorines. The Agreement requires that virtual elimination be achieved for these chemicals, if they are determined to be persistent toxic substances.

In the VETF's 1991 interim report, it was stated that many of the chlorinated organics on the WQB's Working List of Chemicals in the Great Lakes Basin, "because of their persistence, many will ultimately appear on the list of chemicals to be sunset." Because these substances are produced in diverse industrial processes, all of which involve the use of chlorine or its secondary products, the task force thus recommended all uses of chlorine be investigated.

The Commission's Science Advisory Board came to similar conclusions in its 1989 and 1991 reports. The Board has found that the weight of evidence indicates that persistent toxic substances, particularly halogenated organics, are a hazard to human health and ecosystem integrity in the Great Lakes. The Board found that the class of chlorinated organics tends to exhibit persistence and toxicity, and that evaluating and regulating these substances on a chemical-by-chemical basis is impractical and unscientific. The Board thus concluded that organochlorines should be treated as a class and should be subject to phase-out, except in individual cases in which the weight of evidence supports the view that a chemical does not threaten health and the integrity of ecosystems.

Based upon these recommendations and its own deliberations, the Commission found, in its Sixth Biennial report (1991), that

> "it is prudent, sensible, and necessary to treat these substances as a class rather than as a series of isolated individual chemicals."

Because chlorine is the common precursor in the diverse set of industrial processes that produce this class of substances, the Commission concluded that

> "the use of chlorine and its compounds should be avoided in the manufacturing process."

Specifically, the Commission 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 means of reducing or eliminating other uses be examined."

The Commission recognized that such a recommendation involves many industrial processes (and some non-industrial ones, as well) and that the socio-economic consequences of a phase-out program must be considered in determining the timetable. The purpose of this chapter is to propose elements of a framework for implementing a chlorine sunset program that is practical and consistent with the Commission's recommendation and findings.

2) FRAMEWORK FOR VIRTUAL ELIMINATION

A virtual elimination framework must be based on the following elements:

(a) the tactic of zero discharge from human activities,
(b) an integrated multi-media approach,
(c) consideration of the full life-cycle of products and processes,
(d) the weight of evidence, and
(e) the reverse onus approach.

Each of these elements is already well established by the Agreement and the Commission, its boards or its task forces as necessary and appropriate policy responses to the problem of persistent toxic substances in the Great Lakes. This framework, however, represents a significant departure from the regulatory policies currently used by the Parties.

"ZERO DISCHARGE" means the elimination of all inputs of persistent toxic substances into the environment from human activities. This approach is based on the understanding that "acceptable" discharges of persistent toxic substances into an ecosystem will eventually build up to levels that will cause harmful effects. Zero discharge also means that it is not acceptable to transfer discharges of toxic substances from one medium to another (i.e., from air emissions to water discharges), using pollution control devices or other methods. Thus zero discharge implies an integrated multi-media approach.

Ultimately, zero discharge means sunsetting the products and processes that lead to persistent toxic pollution. As the VETF wrote in its 1991 report, "zero discharge does not mean less than detectable or best available technology or other means of treatment or control which, after application, continue to release some residual level." Because no existing methods of pollution control or disposal are absolutely effective, the only truly effective means of achieving zero discharge of persistent toxic chemicals is not to use or produce them in the first place.

The zero discharge approach must be applied to the full "LIFE-CYCLE" of products and processes. Many persistent toxic substances, for instance, occur as unintentional by-products during the process of manufacture, use, or disposal of other products that are not themselves persistent toxic substances. Moreover, many chemicals are transformed in the environment into forms that are more persistent and/or toxic than the original. Thus, virtual elimination must not focus on the properties of individual chemicals in isolation; instead, it must consider the entire life-cycle of chemicals and industrial processes, from the beginning of manufacture to transformation in the environment.

In its Sixth Biennial report, the Commission recommended that the Parties adopt a "WEIGHT-OF-EVIDENCE" approach to persistent toxic pollution. The effects of chemicals upon health and ecosystem integrity are extremely complex, and the tools currently available to toxicologists, epidemiologists, and other scientists are unable to untangle the complex webs of cause and effect. Incontrovertible proof of causal links between individual chemicals and individual effects is not a reasonable standard, since the substances in the environment act together in complex mixtures to produce complex suites of effects.

"REVERSE ONUS" shifts the burden of proof, transforming a reactive policy into a precautionary approach. The current regulatory framework requires proof of harm before an industrial chemical is restricted. As the Science Advisory Board wrote in its 1989 report, this reactive approach is unscientific and dysfunctional, for a number of reasons. First, the vast majority of industrial chemicals in use have not been tested for adverse health effects, and new chemicals are being introduced at a rapid rate. Second, the introduction of man-made chemicals into natural systems is more likely than not to cause harm. Third, science proceeds not on the basis of proof but by establishing and disproving null hypotheses. The Board thus recommended that the burden of proof be shifted, so that those promoting the use of industrial chemicals must prove there is no reason to believe that those chemicals will threaten human and ecosystem health, before their use and discharge is permitted.

3) APPLICATION OF THE FRAMEWORK TO CHLORINATED ORGANICS

This Case Study of chlorinated organics illustrates how the above framework can be applied to a class of persistent toxic substances.

Under the current regulatory approach, the Parties have instituted sunset programs for individual or small groups of chlorinated substances, including polychlorinated biphenyls (PCBs), chlorinated fluorocarbons (CFCs) and the pesticides DDT and dieldrin. These phase-outs have been largely effective at reducing inputs of the targeted substances into the environment. The inadequacy of the current framework is illustrated by the fact that these phase-outs have been adopted only after irrefutable evidence, gathered over the course of years or decades, has proven that the substance in question had already caused irreversible damage to human health and/or the environment. The current framework is also inadequate because contamination from these substances continues due to the amounts of them that were previously released.

The Virtual Elimination framework departs from this reactive, chemical-by-chemical approach, substituting a precautionary, pro-active policy that reverses the onus of proof for organochlorines as a class, for the reasons detailed below.

A) Zero discharge and the multi-media approach.

Zero discharge means that there can be no "acceptable" discharges of persistent toxic substances into the environment, and a multi-media approach is necessary to ensure that pollution control approaches do not merely shift discharges from one environmental medium to another. Under these two principles, processes and products that create persistent toxic substances must be phased out, not merely controlled or reduced.

The use of chlorine and chlorine compounds in the pulp and paper industry provides a useful example. The use of these chemicals as bleaching agents inevitably produces a spectrum of hundreds of chlorinated organic by-products, many of which have been shown to be persistent and toxic, and many more of which are yet to be identified or investigated. Existing or proposed regulations have sought to require that effluent discharges of a few individual compounds, such as 2,3,7,8-TCDD (dioxin), or of total organochlorine discharges (measured, for instance, as AOX) be brought to some specified "acceptable" level through improved effluent treatment systems and reductions in the use of chlorine.

A zero discharge standard must apply to the release of chlorinated organics in wastewater discharges, air emissions, sludges, and the products themselves. Because the use of chlorine and chlorine-based bleaches gives rise to a multiplicity of identified and unidentified substances that are persistent and toxic (or the breakdown products of which are or may be persistent and toxic), the use of these chemicals as feedstocks must be eliminated. Attention must be focused on the process that produces persistent toxic substances (the bleaching stage), not on measuring and controlling discharges after the substances have been formed.

B) The life-cycle approach.

A life-cycle approach does not merely focus on the properties of an individual product, as most phase-outs to date have; it also considers the formation of persistent toxic substances as by-products, breakdown products, or transformation-products during the manufacture, use, and disposal of a product and its wastes.

In the case of chlorinated organics, it is especially important to consider the entire life-cycle, because many of the most persistent and toxic organochlorines are not manufactured intentionally at all, occurring instead as by-products in many different chlorine-based processes. Because chlorine is highly unstable, it tends to react quickly with organic matter, producing a broad spectrum of hundreds or thousands of by-products. Thus, organochlorines are not produced singly but in complex mixtures, and this phenomenon takes place throughout the life cycle of chlorine and its products: complex by-products are generated when chlorine is produced through brine electrolysis, when chlorine is used in bleaching, disinfection, and metallurgical uses, whenever organochlorines are manufactured, and when chlorine-containing products are disposed by burning.

Because chlorinated organics are formed as mixtures, not singular chemicals, a sunset approach that evaluates and targets individual products based on their chemical characteristics is not adequate. Rather, the focus should be on processes and industrial sectors, which should be evaluated based on the generation of persistent toxics throughout their life-cycle. Because the available evidence indicates that chlorine-based processes produce a spectrum of persistent toxic substances, it is sensible to target these processes (and the pollutants that result) as a class.

For instance, three of the eleven Critical Pollutants targeted for immediate sunsets are produced as by-products in many chlorine-based processes (2,3,7,8-TCDD (dioxin), 2,3,7,8-TCDF (furan), and hexachlorobenzene). 2,3,7,8-TCDD and 2,3,7,8-TCDF, in fact, are never produced intentionally, but appear to be formed as by-products of the chlorine industrial cycle and as products of incomplete combustion during incineration. The formation of these by-products throughout the life-cycle of chlorine is not surprising from a chemical or thermodynamic perspective, given the reactivity of chlorine and the stability of these by-products once they are formed.

Because of their great persistence, toxicity, and ubiquity, the Commission recommended in it Sixth Biennial report (1992) that "the Parties, in consultation with industry and other affected interests, alter production processes and feedstock chemicals so that dioxins, furans and hexachlorobenzene no longer result as by-products."

But sunsetting substances that occur as by-products does not mean banning the individual chemicals; rather, it means phasing out the many processes that generate them unintentionally. Virtual elimination of these by-products requires the phase-out of many industrial uses of chlorine.

C. The weight of evidence approach.

A weight-of-evidence approach involves evaluating available information from multiple disciplines, recognizing data gaps, and using a precautionary approach that does not require absolute proof of cause-effect linkages before action is taken.

The weight-of-evidence shows that organochlorines -- as a class -- threaten the Great Lakes ecosystem. Over 150 organochlorines have been identified in the Great Lakes ecosystem, according the Water Quality Board's Working List. It has been estimated that there are thousands of organochlorine products in commerce, plus thousands more produced as unintentional by-products. The majority of the compounds emitted from pulp mills and incinerators remain unidentified. In addition, identified compounds make up only a small fraction of the organochlorines and other pollutants present in biological samples (human and wildlife tissues) in the Great Lakes and elsewhere. (Norstrom et al. 1981; Onstot et al. 1987).

It would take generations to gather adequate data on the identity, sources, environmental behavior and effects of these hundreds or thousands of compounds to develop chemical-by-chemical regulations. Such an approach is not practical. Further, because the Commission has found that persistent toxic substances in the Great Lakes already pose a hazard to health and the environment, a program that would require decades of data-gathering before implementation must be rejected.

Moreover, organochlorines do not exert their effects in the environment on a chemical-by-chemical basis. Chlorinated organics are often transformed into a spectrum of breakdown products, many of which are more persistent or more toxic than the original compounds. Above all, organochlorines cause their effects in complex mixtures that add to or multiply the effects of individual compounds. If we wait for proof of harm on a chemical-by-chemical basis, we will not act in time to prevent further unacceptable damage to the health of the ecosystem, its wildlife, and its human residents.

The Virtual Elimination framework thus requires approaching chlorinated organics as a class. The weight-of-evidence shows that members of this class of compounds tend to be persistent toxic substances or to be associated with such substances during their life-cycle. While each compound has its own chemical and biological properties, organochlorines tend to be persistent and toxic; in fact, no other class of industrial or natural chemicals is known that exhibits so many detrimental properties.

The chemistry of chlorinated organic substances supports this weight of evidence. In fact, the characteristics that make chlorine and organochlorines useful in industrial applications are the same ones that make them problematic from an environmental perspective. For example, (adapted from Okopol 1990).

- Reactivity. Chlorine's utility in bleaching, disinfection and chemical manufacture arises from its reactivity. For the same reason, however, by-products are produced in all chlorine-based processes.

- Persistence. The addition of chlorine to a hydrocarbon "backbone" forms a more or less "impenetrable screen" that shields the molecule from chemical, physical, and biological breakdown. The more halogen atoms on a hydrocarbon, the longer it will remain intact (Canadian Environmental Protection Act (CEPA), 1991). Thus, chlorinated organics are attractive for use as pesticides, plastics, solvents, and dielectric fluids. For the same reason, they tend to be highly persistent once released to the environment.

- Chlorinated organics also tend to be resistant to fire, making them excellent flame retardants and extinguishers but nearly impossible to incinerate without producing significant quantities of toxic "products of incomplete combustion", or PICs.

- Fat-solubility. Many chlorinated organics are far more soluble in fats than in water, and adding chlorine to a hydrocarbon backbone tends to increase a compound's lipophilicity. These substances thus find wide application as solvents, degreasers, etc. This same property, however, makes them subject to accumulation in the food chain, where they build up in increasing concentrations in fatty tissue, mother's milk and nerve membranes with their very high fat content (Asimov, 1962).

- Toxicity. Organochlorines are useful as pesticides and antibiotics precisely because they are toxic. Once released into the environment, however, this toxicity will affect all exposed organisms, not simply the target "pest." Adding chlorine atoms onto a carbon skeleton increases lipid solubility, and increases toxicity on a molar basis (CEPA, 1991, Hutchinson, et al, 1981, MacKay, 1992).

The weight of evidence is strengthened by the fact that organochlorines are largely foreign to nature. A significant number of organochlorines are known to be produced naturally, mostly by fungi and algae, but these are produced in relatively small quantities and have been detected only in or adjacent to the cells that produce them. The only organochlorine produced naturally in large quantities is the simplest organochlorine, the relatively non-persistent chloromethane, which is thought to lay a role in the natural regulation of the ozone layer (Lovelock, 1974).

Most importantly, virtually all natural organochlorines are produced precisely for their toxicity; they are used by the organisms that produce them as chemical defenses, antibiotics, natural pesticides, etc. (Gribble, 1992). This fact further supports the inherent toxicity of this class of compounds and the need for human restraint in their industrial production.

For all these reasons, the weight of evidence supports the conclusion that organochlorines as a class tend to be associated with persistence and toxicity. This evidence suggests that organochlorines that have not yet been evaluated are more likely than not to turn out to share these characteristics.

D. The reverse onus approach.

Accordingly, the class of organochlorines should be subject to reverse onus -- the presumption that these compounds should be phased out unless evidence is presented to demonstrate that individual compounds or processes do not produce persistent toxic substances.

A virtual elimination program would thus begin with the presumption that processes that produce chlorinated organics -- the use of elemental chlorine and the production, use, and disposal of organochlorines -- should be phased out. The onus would shift to industry or other advocates to show that a given product or process does not result in the generation of persistent toxic substances during its life-cycle. After such a determination, a product or process could be removed from the phase-out list.

4) ELEMENTS OF A SUNSET STRATEGY FOR CHLORINE

The virtual elimination framework thus requires "reversing the onus" for chlorinated organics and phasing out the chlorine-based processes that produce these substances. Implementing such a sunset program is a complex task, since so many products and processes are involved.

The sunset program should begin with a process of strategic prioritization to identify those sectors responsible for the largest discharges of persistent toxic substances in which a sunset program can be most effectively implemented. The following information is required:

(a) a systematic and comprehensive identification of those activities that constitute "chlorine chemistry" (the set of industrial and other activities that produce, use, and generate organochlorines);

(b) a chlorine use-tree;

(c) a process/use life-cycle matrix; and

(d) additional criteria of a social and economic nature.

With this information, the following questions should be answered:

- Which products or processes, throughout their life-cycles, are most significant in contributing to releases of persistent toxic substances?
- What are the available alternatives for each sector? What are the environmental, health, safety characteristics of the alternatives? What are the socio-economic implications of implementing them?
- If no alternatives are currently available, how difficult is the alternative to develop?

This information can then be used to prioritize which sectors should be sunset first, to set timelines for phase-out, and to implement measures to accomplish the phase-out.

The sunset program can be implemented with a series of "sunset permits" for each process that produces or uses chlorinated organics, including a sunset date after which the permit expires and the process is no longer allowed. The permit would include a timetable for implementing necessary process changes and may include interim limits on the quantity of chlorine or organochlorines that may be used or produced. It is not necessary that such permits require the use of a specific alternative process -- merely that they eliminate the use of processes that generate persistent toxic substances and implement new ones that do not do so. When alternatives are not currently available, research programs should target the development of chlorine-free, environmentally sound processes.

5) OVERVIEW OF INDUSTRIAL USES OF CHLORINE

For the purpose of the use-tree and life-cycle matrix that follows, industrial uses of chlorine include the following activities:

1. Production of chlorine (along with hydrogen and sodium hydroxide) in chlor-alkali electrolysis.
2. Uses of elemental chlorine, e.g.:
   - pulp and paper
   - inorganic chemical production
   - water and wastewater treatment
   - certain metallurgical processes
3. Production of chlorine containing bulk products e.g.:

- Polyvinyl chloride (PVC)/vinyl chloride (VC)/ethylene dichloride
- Chlorinated solvents and other chlorinated methanes, ethanes and ethylenes
- Chlorinated fluorocarbons (CFCs) and HCFCs
- Neoprene (polychlorobutadiene)

4. Production and use of chlorinated feedstocks for specialty products, e.g.:
   - Chlorinated benzenes, nitrobenzenes, and other aromatics (for pesticides, dyes, plasticizers, etc.)
   - Chloroacetic acid (for pesticides and other uses)
   - Cyanuric chloride (for pesticides and other uses)

5. Use of chlorinated pesticides and other specialty products;

6. Production of chlorinated intermediates for chlorine-free bulk products:
   - propylene chlorohydrin for propylene oxide (for polyurethane, brake fluids, anti-freezes, etc.)
   - epichlorohydrin (for epoxy resins and other uses)
   - phosgene (for isocyanates for polyurethane and other uses)
   - methyl chloride (for methyl cellulose, silicones, etc.)

7. Production of chlorine-containing auxiliary products/additives:
   - plasticizers (in plastics)
   - flame retardants (in plastics)
   - scavengers (in fuels)
   - stabilizers (in lubricating and cutting oils)
   - PCBs

8. Production of inorganic compounds, e.g.:
   - Bleaches
   - Detergents
   - Cleaners and powders
   - Metallic chlorides

9. Disposal or reprocessing of chlorinated wastes, e.g.:
   - municipal waste incinerators
   - hazardous waste incinerators
   - hospital waste incinerators
   - metals recovery smelters processing electric, electronic, and cable scrap containing PVC and other chlorinated organics
   - other disposal or reprocessing facilities.

6) THE CHLORINE USE-TREE

This list initially appears highly complex, involving thousands of substances, dozens of industrial processes, and thousands of individual users. Attempting to regulate effectively at this level of complexity is impractical, and would lead to regulatory gridlock.

Clearly, another approach is necessary. A use-tree allows us to view chlorine-based substances and processes more holistically. The tree organizes the many chlorine-based processes into a series of activities from the most basic to the more specialized. The initial processes begin with the trunk and its roots; as processes and substances become more specialized, they are represented as limbs, branches, and finally twigs. The chlorine use-tree begins at the root -- the production of chlorine -- and then traces the various processes and products in which chlorine and its secondary products are used and finally disposed.

Figure 1 is a chlorine use-tree with a high degree of detail on substances and process branchings (Davis, 1991). Figure 2 presents a simpler use-tree that identifies major bulk products, processes, and application categories. This simpler use-tree is still detailed enough to work with for purposes of choosing points of intervention based upon major problem categories of products, processes, and applications relatively early in their life-cycle.

Generally, the farther out in the tree one goes, the later it is in the life-cycle, the greater the specialized branchings and multiplicity of possible release points, the greater the problem complexity and transaction costs, and the less likely that intervention or remedial action will be practical, feasible, or effective. It is obviously much easier to intervene, and "prune" the use tree of undesirable processes and products at the points where they emanate from the roots and trunk to the 5 to 10 or so main branches, representing the bulk products and processes, than to allow the multiple specialty product/application branchings to proliferate into the hundreds and thousands, and then try to work at that level.

The use-tree allows full life-cycle evaluations of products and processes. It is particularly important to trace products that contain substantial quantities of persistent toxic substances or their precursors, that are not released immediately, but sometime later in their life-cycle. Figure 3 is an example of a process/use life-cycle matrix that considers the industrial and environmental transformations for important aspects of chlorine chemistry.

7) THE CHLORINE USE-TREE ANALYSIS

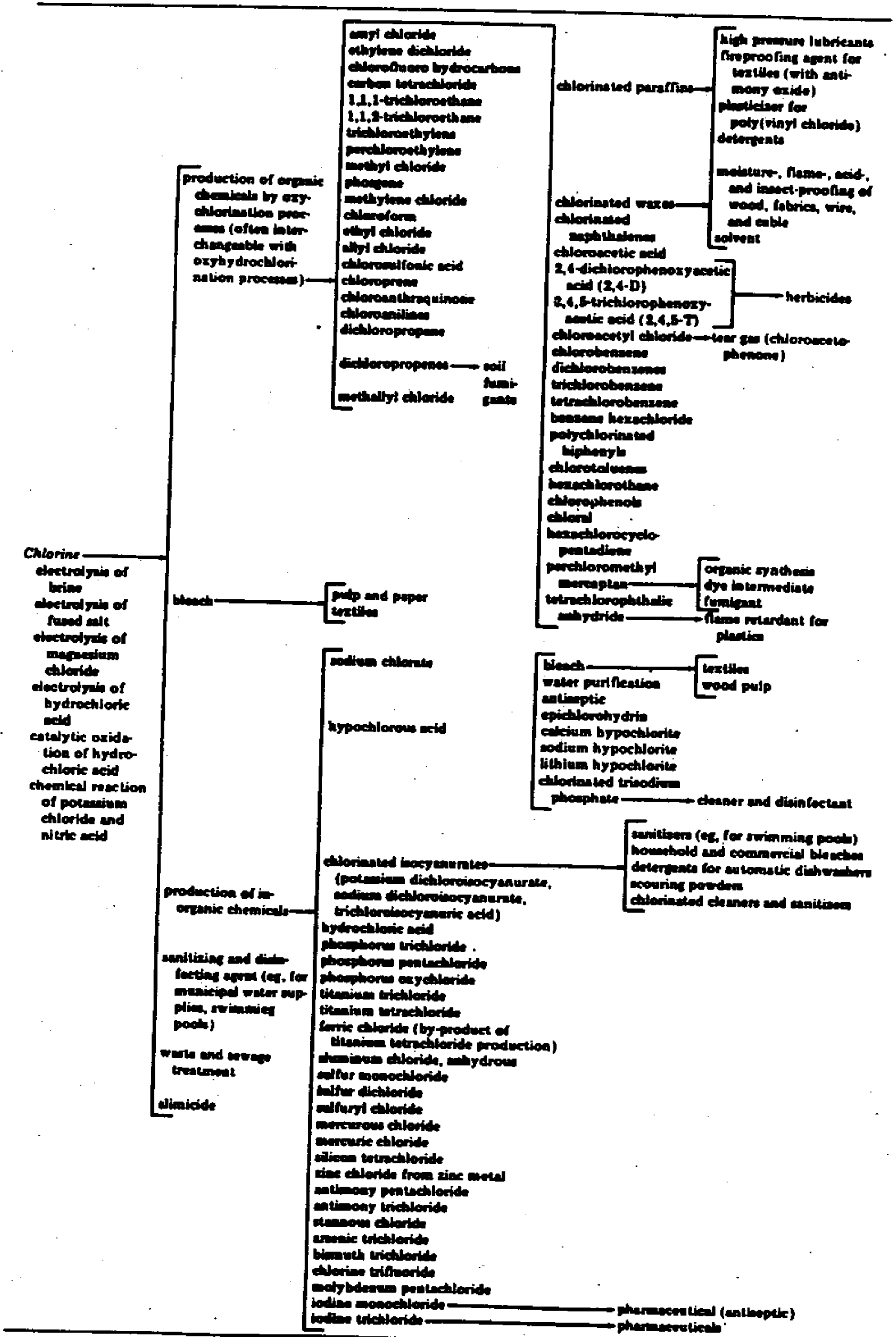
A) Production and Use.

Tables 1 and 2 show data on recent trends and levels of chlorine production and major bulk user groups (Camford Information Services, 1991). North American chlorine production now totals about 13 million tons per year.

By far, the largest single use of chlorine in both the U.S. and Canada is the production of polyvinyl chloride plastic. Second in each country is the use of chlorine as a bleaching agent in the paper industry, followed by the production of chlorinated solvents and precursors for polyurethane. Disinfection of wastewater and drinking water account for about 5 percent

FIGURE 1.

Chlorine and Hydrochloric Acid Derivatives*



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* Ref. 87.

FIGURE 1 (CONTINUED).

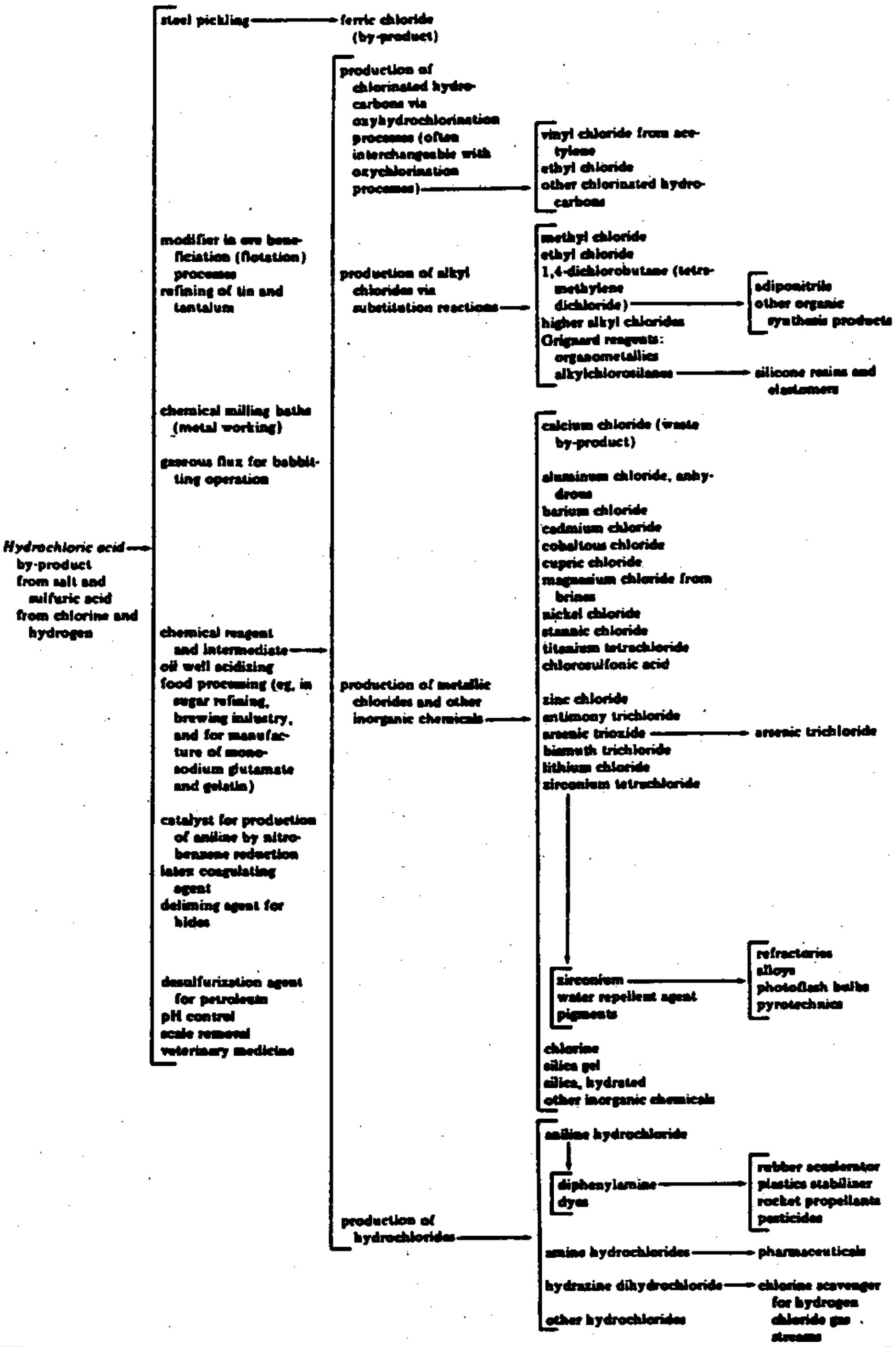

FIGURE 2.

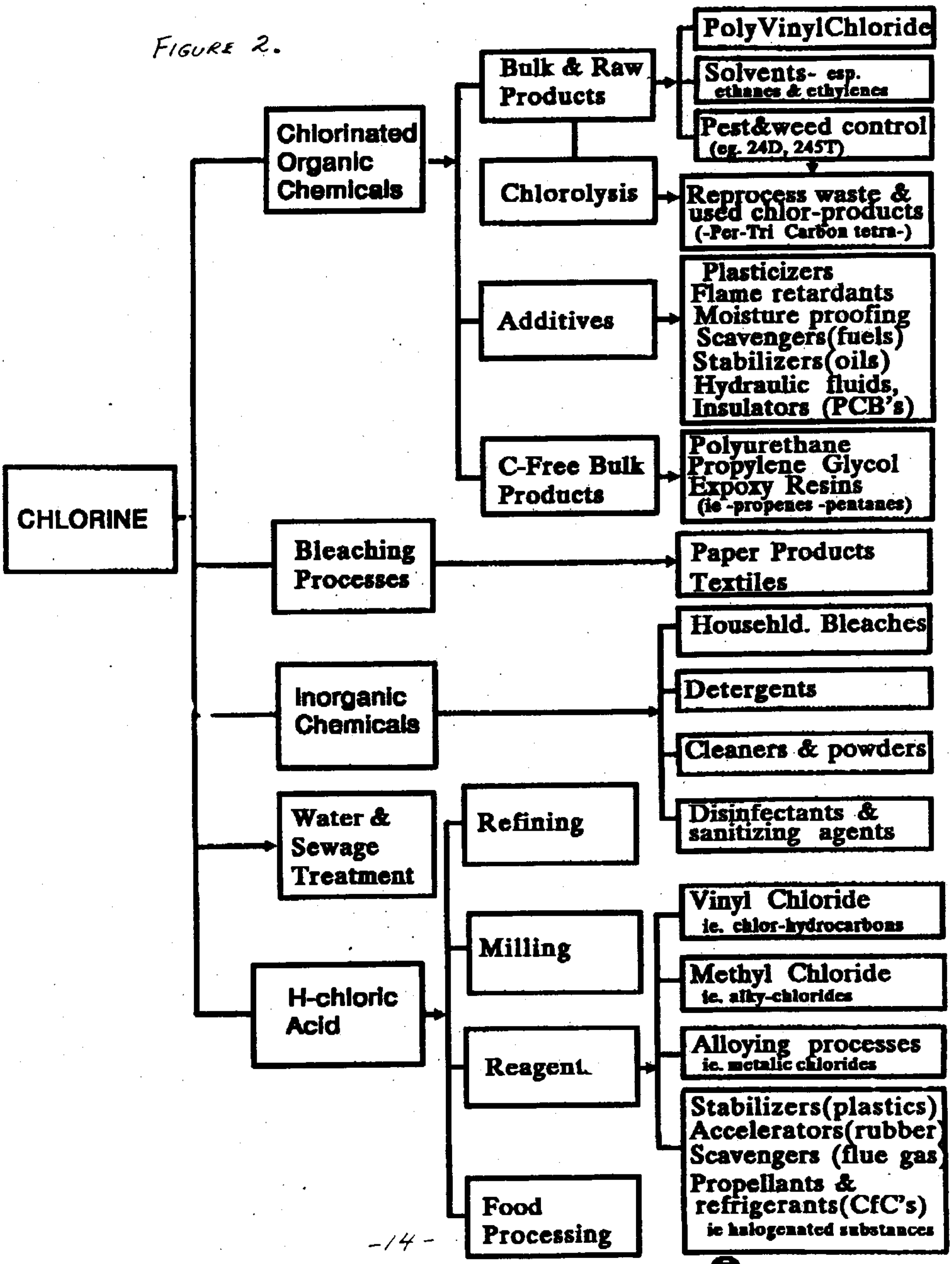
CHLORINE
Chlorinated Organic Chemicals
Bulk & Raw Products
PolyVinylChloride
Solvents- esp. ethanes & ethylenes
Pest&weed control (eg. 24D, 245T)
Chlorolysis
Reprocess waste & used chlor-products (-Per-Tri Carbon tetra-)
Additives
Plasticizers
Flame retardants
Moisture proofing
Scavengers(fuels)
Stabilizers(oils)
Hydraulic fluids,
Insulators (PCB's)
C-Free Bulk Products
Polyurethane
Propylene Glycol
Expoxy Resins
(ie -propenes -pentanes)
Bleaching Processes
Paper Products
Textiles
Inorganic Chemicals
Househld. Bleaches
Detergents
Cleaners & powders
Disinfectants & sanitizing agents
Water & Sewage Treatment
H-chloric Acid
Refining
Milling
Reagent
Food Processing
Vinyl Chloride ie. chlor-hydrocarbons
Methyl Chloride ie. alky-chlorides
Alloying processes ie. metalic chlorides
Stabilizers(plastics)
Accelerators(rubber)
Scavengers (flue gas)
Propellants &
refrigerants(CfC's)
ie halogenated substances

Figure 3. PROCESS/USE MATRIX OF PERSISTENT TOXIC SUBSTANCES IN THE GREAT LAKES (Mercury & Chlorine)

LIFECYCLE STAGE	Utilities & Smelters	Manufacturing Activity & Product Use	Municipal & Industrial Waste Management
Production Process ● Input	● Utility Coal(Hg)	● Chloralkali Electrolysis (Cl & Hg) ● Kraft Paper & Textile Bleaching Processes (Cl)	
● Output		● Polyvinyl Chlorides (PVC's); Propylene & Epoxy's ● Solvents (esp. Ethanes & Ethylenes), ● Chlorolysis (-Per,-Tri, Carbon Tetrachloride) ● Chlorinated Methanes (CCL4, CHCL3)	
Direct Discharge ● Effluents		● Pulp wastes - Absorbable Organic Halide (AOX) ● Secondary Treatment Lagoons - (AOX)	
● Emissions	● Thermal Power Generation (Hg & PCB's) ● Non-ferrous Metal Production (Hg etc)	● Industrial fuel combustion (Hg & PCB's) ● Incineration of Sludge (AOX) ● Pulping processes - Dioxins & Furins (2,3,7,8 - TCDD & 2,3,7,8 - TCDF)	
● Solids			● Copper, Lead,& Zinc slag (Hg etc.)
Indirect Release ● Spills & Dumping ● Incineration ● Evaporation ● Leachate ● Sediments		● Open Manufacturing & Thermal Processes (Hg,Pyrolysis) ● Electrical Generators & Transformers, Hydraulic Fluids, & Lubricants (spills & volatilization of PCB's) ● Chlorinated Solvents, Pesticides, Phenols & Benzines (HCB's, PCB's, TCDD's & TCDF's,)	● Landfills & building sites (eg. pumps, transformers, used oil &parts, materials) ● Incinerators (Misc.) ● Water Purification (Cl) ● Waste Water Treatment (Cl) ● Sewage sludge (Hg. etc.)
End Uses ● Products		● Aerosols & refrigerants (CFC's) ● Herbicides (eg. Chlorophenoxyl, 24D, 245T), Fungicides (eg. HCB's), & Chlorinated Organic Pesticides; ● Plastics, textiles & fuels (Use of Halogenated additives)	
Disposal ● Mechanical & Source Separation ● Containment/Recovery ● Reduce/Recycle/Reuse			● Batteries & Paint (eg. Hg Pb) ● Scrap Metal (eg. electronic parts, autos, electric cable & wire) ● Plastics & Packaging (eg. PVC) ● Household Bleach & Cleaners; Pest & Weed Control; Used Solvents & Oil ● Bleached Paper Products & Textiles

Table 1 - Canadian Demand Pattern

	1985	1988	1990	1992
		Kilotonne (%)		
Ethylene dichloride	594.0 (39.0)	645.0 (36.6)	675.0 (41.1)	NA
Pulp and paper	430.0 (28.0)	505.0 (28.6)	420.0 (25.5)	NA
Mining and smelting	7.0 (0.5)	8.0 (0.5)	7.0 (0.4)	NA
Water treatment	18.0 (1.2)	19.0 (1.1)	18.5 (1.1)	NA
Hydrogen chloride	32.5 (2.1)	32.0 (1.8)	30.0 (1.8)	NA
Aluminum chloride	11.5 (0.8)	12.0 (0.7)	14.0 (0.9)	NA
Sodium hypochlorite	12.0 (0.8)	13.0 (0.7)	13.5 (0.8)	NA
Chlorinated solvents	71.0 (4.7)	74.0 (4.2)	70.0 (4.3)	NA
Propylene oxide	82.0 (5.4)	82.0 (4.7)	850.0(5.2)	NA
Miscellaneous	5.4 (0.4	9.7 (0.6)	9.0 (0.6)	NA
Total Cdn Demand	1263.4	1399.7	1342.0	
Exports	257.6 (17.0)	363.4 (20.6)	322.5 (19.6)	NA
Total disappearance	1521.0	1763.1	1644.5	

Table 2 - U.S. Demand Pattern

	1985	1988	1990	1992
		Kilotonne (%)		*% est.
Ethylene dichloride	2037.0 (21.0)	2590.0 (24.4)	2820.0 (26.6)	30%
Pulp and paper	1554.0 (16.0)	1740.0 (16.4)	1470.0 (13.80)	11%
Inorganic chemicals	1165.0 (12.0)	1172.0 (11.1)	1210.0 (11.4)	11%
Chlorinated methanes	778.3 (8.0)	790.4 (7.5)	780.0 (7.3)	5%
Chlorinated ethanes	918.3 (9.5)	864.7 (8.2)	850.0 (8.0)	5%
Water treatment	425.3 (4.4)	527.2 (5.0)	540.0 (5.1)	5%
Propylene oxide	628.3 (6.5)	685.4 (6.5)	706.0 (6.7)	8%
Other organics	1705.6 (17.6)	1715.3 (16.2)	1750.0 (16.5)	16%
Miscellaneous	454.9 (4.7)	459.8 (4.3)	450.0 (4.2)	4%
Total U.S.demand	9666.7	10544.8	10576.0	
Exports	51.3 (0.5)	58.2 (0.6)	44.0 (0.4)	5%
Total disappearance	9718.0	10603.0	10620.0	

* Note: 1992 data adapted from Chlorine Institute report - Chlorine Chemistry and Society. Other inorganics include titanium dioxide, and other organics includes epichlorohydrin. U.S Exports in 1992 are ethylene dichloride.

Source: Camford Information Services, CPI Product Profiles, July 1991.

of total chlorine use, with drinking water a relatively small portion of that amount. By comparison, all other specialty uses are relatively minor.

The major trends include the following:

- Increases in total chlorine production between 1985 and 1988, due mainly to increased consumption in pulp and paper demand, and increases in the production of PVC and its precursors ethylene dichloride (EDC) and vinyl chloride (VC).

- Recent declines in the use of chlorine in pulp and paper since 1988.

- Reductions in production of chlorinated solvents, due to phase-outs of CFCs and replacement of chlorinated solvents in manufacturing industries with process changes or non-chemical methods of cleaning, coating, and extraction.

- Substantial recent and projected growth in PVC production -- the only major sector expected to expand. U.S. exports of PVC precursors are also on the increase.

B) Chlorine and caustic soda production: The root.

Virtually all chlorine in North America is produced by the chlor-alkali process, in which brine (salt water) is subjected to an intense electric current to produce chlorine and the co-products sodium hydroxide (also called caustic soda) and hydrogen. This process is the root of the chlorine chemistry tree: the chlorine produced here is the basic feedstock in the production of all other organochlorine products and by-products.

The coupling of chlorine and caustic soda production has important implications for the phase-out of chlorine. Caustic soda, which itself is not known to be associated with the production of persistent toxic substances, is used in diverse industrial activities, including the manufacture of aluminum, glass, chemicals, and textiles, as well as in water treatment and petroleum refining.

Indeed, a main stimulus to the early development of chlorine chemistry was the need to make use of the chlorine surpluses from sodium hydroxide production. Today, chlor-alkali producers continue to make virtually all their profits from alkali, not from chlorine. Because alkali demand continues to increase, and because chlorine is difficult to store, producers need a "sink" for chlorine -- other industrial processes and products, such as PVC and pulp and paper. Thus, production of at least some persistent chlorinated organics is currently driven by demand for caustic soda.

Chlorine producers are counting on PVC growth to offset decreases in other major sectors as PVC becomes the "sink" into which chlor-alkali producers dump excess chlorine in order to keep pace with growing demand for caustic soda. (Vonkeman and Maxson, 1991; Christiaens, 1990; Chemical Business, 1990; Chemical Business, 1989; Anderson, 1990; Johnson 1991).

Sunsetting chlorine could result in a sharply curtailed supply of sodium hydroxide. This issue can be resolved in a number of ways. First, caustic soda consumption can be reduced significantly through conservation and recycling. Second, caustic soda consumption can be reduced through the use of alternative alkalis or sodium sources. Finally, caustic soda can be produced through methods other than the chlor-alkali process. The production of chlorine and caustic soda can thus by uncoupled.

Caustic is produced raw in three main ways: by the chlor-alkali process; by recausticising sodium carbonate using lime by the old Solvay process; and by causticization of sodium carbonate mined as trona ore (a natural mineral that is mostly sodium carbonate). There are reports of shifts to these latter two processes, with the Solvay method leading (Christiaens, 1990).

There are trona deposits in a number of locations around the world. The largest deposit by far is in Wyoming (Kostick, 1989). Several companies are currently exploiting these resources for soda ash and/or caustic, including the Solvay company, which is a large chlor-alkali producer. Other large companies are reportedly looking into the possibility. The potential for further development of this process is just beginning to be tapped, and estimated trona reserves are enough to supply world caustic demand for several hundred years (Kostick, 1989).

Caustic soda can also be produced from electrolysis or electrodialysis of sodium sulfate, and this process is already in use at pilot facilities. Sodium sulfate is an abundant natural mineral and is also present in the wastewater streams of a number of industries, for example, pulp mills, rayon production, and chemical plants (Bar and Mani, 1991). According to EPA's Toxic Release Inventory, industry discharged more than 4.5 million tons of sodium sulfate to surface waters in 1987, some of which could presumably be recovered for reuse.

Measures to reduce caustic demand are also available. Efficiency and recycling programs can substantially reduce the need for caustic. The caustic loop in the pulp and paper industry can be almost closed if chlorine (and its corrosive by-products) are eliminated from the bleaching process, reducing caustic demand by up to 80 percent in this sector. Opportunities for significant reduction (50 percent or more) are also reported in other sectors, such as aluminum oxide production and petroleum refining.

Other chemicals can often take the place of caustic soda, further reducing demand. Carbonates, lime and magnesium hydroxide can be used for many purposes requiring an alkaline environment (Christaens, 1990). It is reported that Dow Chemical successfully substituted lime for 500,000 tons per year of caustic in the production of propylene oxide. If the need is for sodium ions, sodium carbonate or sulfate can often be substituted.

Together, conservation, substitution, and "chlorine-free caustic" should allow a substantial decrease in demand for caustic produced by the chlor-alkali process in the short term. In the long term, these methods appear adequate to substitute for chlor-alkali caustic entirely.

C) Moving up the chlorine use-tree.

Since chlorine and caustic soda production can be de-coupled, it is possible to contemplate a drastic reduction in chlorine production, and to freely analyze the main trunk and branches of the chlorine use-tree. The majority of chlorine production (80% to more than 90%) is used in just 8 to 10 easily discernible product groups or applications. A much smaller amount (5% to 20%) finds its way into the specialty chemicals segments (excluding solvents) with more highly diversified product groups, and correspondingly complicated phase-out scenarios.

The relatively few major product groups are shown in Tables 1 and 2. In Canada, the use of chlorine is dominated by ethylene dichloride (EDC for production of VC/PVC) (41.1%), pulp and paper (25.5%), exports (which may be as EDC, as it is reported to be in the U.S.) (19.6%), propylene oxide (5.2%), and chlorinated solvents (4.3%). These uses account for 95.7% of the total (Camford Information Services, 1991).

In the U.S., chlorine use within the chemical industry is more specialized, leading to a more complex tree. Nevertheless, the bulk of total chlorine use still falls into relatively few groups. Use of chlorine in EDC-VC-PVC (35 percent, including exports), pulp and paper (14 percent), chlorinated methanes and ethanes (e.g., solvents, 10 percent), propylene oxide (8 percent) and water treatment (5 percent) account for 67 percent of total chlorine use. The remainder is in inorganic chemicals (11 percent), other organics (16 percent), and miscellaneous (4 percent) (Camford Information Services, 1991).

Even within the "specialty chemicals", major products, such as chlorinated pesticides, tend to dominate and are thus relatively easy to classify. There are other major products and applications that are also easily discernible. The use-tree branchings become complicated, rather than simple, only in those specialty uses associated with organic and inorganic chemical production (Figure 1). Addressing the problem at this highly fragmented resolution will likely be ineffective as a regulatory approach.

Disposal activities in the life-cycle (for example, waste incineration and scrap metals recovery) are also part of the chlorine chemistry family, and contribute substantially to the loading of persistent toxic substancesinto the environment. Because these activities are largely downstream of production and use, they will ultimately be reduced as chlorine use declines. However, these sectors require specific and immediate attention, as there is a large existing inventory and will be an ongoing supply of chlorinated materials that can become feedstock for these processes, resulting in continuing discharges of persistent toxic substances to the environment.

A detailed discussion of each major sector is beyond the scope of this report. However, a few major product and process groupings can illustrate the application of the strategy. For each, the relative significance as a source of persistent toxic substances will be considered, along with the availability of alternatives and the implications of their implementation.

D) Ethylene dichloride/vinyl chloride/polyvinyl chloride.

1) Significance as a source of persistent toxic substances.

Polyvinyl chloride -- along with its precursors ethylene dichloride (EDC) and vinyl chloride (VC)-- is by far the largest single use of chlorine. It is also the only major use sector that is growing. As long as industry is wedded to the coupled production of chlorine and caustic, PVC is likely to remain the sink for the chlorine surplus due to declines in other uses.

Thus, the industry has sought to expand PVC markets in the last 10 to 15 years and have made significant inroads into uses in which traditional materials were formerly used, such as packaging, pipes, flooring, siding, and furniture. For future expansion, markets in developing countries are reportedly targeted for significant growth (Johnson, 1991).

Some have suggested that PVC is not of environmental concern, because the products are relatively inert and non-toxic. A consideration of the full life-cycle of PVC, however, indicates substantial releases of persistent toxic substances to the environment. The most significant releases take place during manufacture and disposal.

The basic feedstocks for PVC -- ethylene dichloride and vinyl chloride -- are both extremely toxic, with effects including cancer, birth defects, cardiovascular toxicity, and damage to the liver, kidneys and nervous system. Once released to the air, vinyl chloride is degraded into a number of other chlorinated organics and inorganics; in water, it is extremely persistent. EDC is also highly persistent in water and is far more persistent in the air, with a half-life estimated at four months. (ATSDR Toxicological Profiles for EDC and VC).

Production facilities emit these feedstocks into air and water in large quantities, with self-reported air emissions of VC by U.S. industry totalling 1.3 million lbs/yr, plus an additional .6 million lbs/yr to off-site waste facilities (ATSDR). Worker exposures are also of significant concern, and excess rates of cancer (especially angiosarcoma) have been documented among vinyl chloride workers (ATSDR).

Manufacture of these feedstocks involves the generation of large quantities of waste (including light ends, heavy ends, and oxychlorination tars) that include a range of persistent toxic substances such as hexachlorobenzene, hexachlorobutadiene. Recently, very high concentrations of PCDD/Fs have been discovered in the wastes from the production of ethylene dichloride by oxychlorination (Vonkeman and Maxson, 1991; Christiansen et al, 1990, Claus et al, 1991, SEPA 1992). If the concentrations of PCDD/Fs found in oxychlorination tars to date (in the hundreds of parts per billion) are representative of other plants, this process may be the largest single source of dioxin formation.

A large portion of these wastes are incinerated, leading to dispersal of some portion of the persistent toxic substances while also creating further quantities of persistent toxic substances as products of incomplete combustion. PCDD/Fs have also been documented in air emissions and water discharges from these processes; the majority of dioxins in sediments of the River Rhine in the Netherlands have been attributed to wastewater discharges from EDC-VC production processes. Some portion of the wastes are also redirected to onward use in the production of chlorinated solvents.

The pure PVC resulting from this production process is reported to be a poor quality plastic in pure form, and cannot be used without a range of additives (Johnson, 1991; Ainsworth, 1992). These additives include plasticizers, heat stabilizers, pigments, biocides, flame retardants, and others (Ainsworth, 1992). Many of these additives are themselves persistent toxic substances: use as PVC additives account for significant proportions of total use of such ubiquitous substances as di-2-ethyl-hexyl phthalate and other phthaltes, cadmium, lead, organo-tin compounds, and chlorinated paraffins. U.S. production of all plastics additives was 10,230 million pounds in 1991 (Ainsworth, 1992). The additives escape to the environment through emissions and wastes in their production and in the production of PVC products, through leaching during the lifetime of PVC products, and in disposal of the products.

Large quantities of persistent toxic substances are released to the environment during the final stage of the life-cycle of PVC -- disposal. Because of the complexity of PVC product mixes, recycling of significant quantities of PVC is not practical. (Johnson, 1991; Ainsworth, 1992; Claus et. al., 1991; Christiansen et. al., 1990). In landfills, additives may be leached, particularly in the presence of organic solvents. Plasticizers are of particular concern in this regard, as they do not form a stable chemical bond with the PVC.

When burned, the chlorine in PVC is transformed into hydrogen chloride and chlorinated products of incomplete combustion, including hexachlorobenzene, PCBs, and the PCDD/Fs . PVC is the largest single source of chlorine in incinerators for municipal waste and hospital waste. It is also the largest source of cadmium and a significant source of lead (Johnson, 1991.) Short-term PVC uses, such as packaging, are especially problematic from the point of view of the feed of chlorine into incinerators. However, at some point in the near future, the millions of tons of PVC now in medium- and long-term uses (siding, pipes, toys, etc.) will ultimately be turned over and become a waste disposal burden in the future.

The burning of PVC in house and building fires is also a significant source of persistent toxic substances. When PVC pipes, siding, flooring, furniture, and other materials burn in such fires, a full range of PICs are formed (including PCDDs and PCDFs); unburned phthalates, heavy metals, and other additives are released, as well. The health and safety threat to firefighters facing such "chemical fires" are well known. A report published in 1991 by the German EPA shows a link between dioxin formation and chlorinated plastics, especially PVC, in fire (Theisen, 1991).

PVC is also the major source of chlorine in metals recovery smelters for used cables, electric and electronic scrap. These smelters have been identified as major sources of PCDDs, PCDFs, and other persistent chlorinated substances.

PVC is thus associated with the formation and discharge of large amounts of persistent toxic substances to the environment throughout its life-cycle. On this basis PVC is reputed to be the most environmentally unfriendly of all major plastics. Recent reports by the Tellus Institute (1992) and the German EPA have concluded that PVC causes greater environmental problems than chlorine-free plastics like polyethylene and polypropylene. (Tellus Institute, 1992).

2) Availability of alternatives.

PVC uses in the U.S. are described below.

Figure 4: PVC use patterns in the U.S.

Pipe and fittings	39 %
Siding	10
Wire and cables	4
Extruded profiles (i.e. window frames)	6
Roll goods	11
Coating and flooring	6
Packaging	5
Furniture	1.2
Appliances	1.8
Toys	0.4
Housewares	0.9
Exports	13
Others	2

(Source: D. Hunter, "PVC makers study expansions to meet demand growth," Chemical Week 2/10/93 p 8; Johnson, 1991).

Alternatives to PVC are specific to individual uses, and include wood, linoleum, non-chlorinated plastics, metals, glass, paper/cardboard, etc. For instance, in piping (the largest single PVC use), pipes made of metal or chlorine-free plastics can completely substitute for PVC. As noted above, "traditional" materials have fulfilled most uses that are now PVC until very recently. Uses in which plastics are "necessary" (for example, cars and cable insulation), can be replaced with non-chlorinated plastics, such as ABS (acryonitrile-butadiene-styrene), SAN (styrene-acryonitrile), polyethylene, polypropylene, polyvinyl alcohols, polyamines, chlorine-free polycarbonates, acrylics, and so on, depending on the properties needed.

A growing environmental awareness of PVC in Europe has led to successful efforts to phase out PVC in a wide range of uses, including construction, commercial and medical packaging, automobiles, and furniture. Two years after adopting a policy to strive to eliminate PVC in public construction projects, the German town of Bielefield has achieved 90 percent substitution of PVC in its construction activities. At least 80 other local authorities in Germany, plus two states and half the regional capitals in Austria, also have PVC phase-out policies in public construction. The recently reconstructed Vienna public transportation system is virtually PVC-free, and the automobile manufacturer Volkswagen has stopped using PVC in its products. Other manufacturers of appliances and electronic goods (AEG) and office supplies (Herlitz) have also eliminated PVC in their product lines. The Swedish furniture maker IKEA has announced a PVC phase-out policy. In packaging, a Danish supermarket chain has achieved 99 percent reduction of PVC in all its product lines, and PVC packaging has been phased out entirely in all Austrian supermarkets. As for medical uses, a newly opened hospital in Vienna is reported to be virtually PVC free, and such uses as infusion bags and tubings have been replaced with chlorine-free plastics; other hospitals in the same district now have adopted PVC-free policies.

There may be environmental concerns about some of the alternatives, such as non-chlorinated plastics. In many cases, the simplest alternatives are the most environmentally sound, such as the elimination of unnecessary packaging and the use of traditional materials in construction and furniture. As noted above, other plastics have also been reported to be less environmentally damaging than PVC (Tellus, 1992). Because they do not contain chlorine or the same quantity of additives, these plastics are generally associated with much less severe discharges of persistent toxic substances. (Johnson, 1991; Christiansen et al, 1990).

3) Implementation of a PVC sunset.

As demonstrated by European efforts, phase-out programs can successfully concentrate on major use-sectors of PVC, based on the relative importance of each sector and the availability of alternatives, achieving significant reductions in PVC consumption.

Implementing a phase-out will, of course, require action by the Parties. The following measures are available to a sunset program:

1. Sunset permits for the manufacturers of PVC;

2. Rapid phase-outs of PVC in uses that are quickly disposed (i.e., packaging).

3. Prohibition of the incineration of PVC in municipal and hospital waste incinerators.

4. Rapid phase-outs of PVC in uses that are susceptible to fire (i.e., construction and automobiles).

5. Requirement for mechanical separation of PVC from metal scrap or rapid phase-out of PVC in such uses.

6. Phase-out on specified timelines for other medium and long-term uses.

7. Other measures, including environmental taxes on PVC; product labeling and consumer education; government procurement of PVC-free products and PVC-free construction in public buildings; disposal surcharges on PVC products.

The socio-economic impacts of phasing out PVC are beyond the scope of this review. The European experience suggests that the alternatives are well within the range of affordability. Methods of addressing the impacts on workers currently employed in PVC production should be investigated along with phase-out programs (i.e., worker compensation, re-education and retraining; public investment in development of alternative economic activities; etc.).

E) Pulp and paper

1) Significance as a source of persistent toxic discharges.

The use of chlorine and chlorine compounds in the pulp and paper industry is the second largest use of chlorine in the U.S. and Canada. These bleaching agents are used to remove residual lignins from wood pulp to make the resulting paper bright white.

Chlorine combines with this organic material to produce thousands of organochlorines, about 300 of which have been identified, including chlorinated aliphatics, acids, phenols, guiaicols, and dioxins. As much as 97% of the total organically-bound chlorine, however, is associated with unidentified medium- and high-molecular weight organics, which have been shown to break down into lower-weight chlorinated organics, many of which are persistent toxic substances. Organochlorines formed in the bleaching process are discharged to the environment via effluent discharges, air emissions of volatile compounds, disposal of treatment sludges (commonly by incineration or land-disposal), and the paper products themselves.

In 1989, cumulative discharges to Canadian receiving waters by bleaching pulp mills have been estimated at 1,000,000 tons (CEPA, 1991); even if persistent, toxic and/or bioaccumulative substances make up only a small percentage of these total organochlorine discharges, these are highly significant releases. The chlorine content of bleached paper is second only to PVC as a source of chlorine to waste incinerators in North America; dioxins and other persistent toxic substances have been detected in the emissions from incinerators for sludge from bleached pulp mills.

Unbleached pulp mill effluents also contain a wide variety of organic compounds, and heavy metals, which may also be toxic to fish and other aquatic organisms. Effluents from bleached mills contain these compounds plus the chlorinated by-products of chlorine bleaching, many of which are toxic, persistent, and/or bioaccumulative (CEPA, 1991; Ontario Ministry of the Environment, 1991; Sodergren and Wartiovaara, 1988; Paasivirta, 1991). The non-chlorinated organic compounds in unbleached mill effluents are not known to be highly persistent or bioaccumulative; however, they have been associated with biological responses in fish, such as the induction of liver detoxification enzymes, although with considerably less severity than in fish exposed to bleached mill effluents (Sodergren, 1993).

The finding that unbleached mill effluents can cause biological effects underscores the need to move towards closed-loop effluent free mills; such changes can be made only if chlorine is not used (Paasivirta, 1991; McCubbin, 1992). When chlorine bleaches are eliminated, many process loops can be closed, effluents can be eliminated, and water consumption and discharges can be substantially reduced. Lower quantities of treatment sludges are also generated, with far lower degrees of contamination, thus lowering treatment and disposal costs and impacts. Moreover, caustic soda that would otherwise have been discharged can be recycled, thus reducing chemical costs, eliminating the energy consumption associated with caustic production, and lowering total demand for caustic, a necessary parallel action in the phase-out of chlorine.

2). Availability of alternatives.

Pressure to reduce the emission of chlorinated organic compounds, initially focused on dioxins and furans, has led pulp mills to make a number of process changes, including decreasing the use of chlorine in general, and elemental chlorine in particular. From 1988 to 1991, elemental chlorine use in Canada has been cut almost in half (Paprican, 1992). Trade predictions are for continued declines in the industry consumption of chlorine in North America, Scandinavia, and Europe. Totally chlorine-free pulps are being manufactured on an increasing scale, as are recycled fibers with mechanical pulp (McCubbin, 1992).

The alternative technologies to produce high-quality paper without chlorine or chlorine-based compounds have been developed and are in use throughout the world, including the following:

- Manufacture and use of unbleached, off-white paper for most uses;
- Improved housekeeping (better debarking, washing and chipping methods);
- Extended delignification, rapid displacement heating, modified continuous cooking, and solvent pulping to remove more lignin before bleaching;
- Oxygen and hydrogen peroxide pre-bleaching;
- Oxygen-based bleaching, including oxygen, ozone, and hydrogen peroxide;
- Addition of naturally produced enzymes during bleaching to improve the performance of oxygen-based bleaching.

Also, one hundred percent substitution of elemental chlorine with chlorine dioxide substantially reduces the amount of organochlorines in pulp and paper mill effluent. However, the extent to which this achieves the goal of zero discharge over the life cycle has not been demonstrated.

These methods are now in use in mills throughout the world for production of numerous types and grades of pulp and paper, including the highest quality market pulp. Twenty six mills worldwide are now producing totally chlorine free market pulp, including 17 that make kraft pulp. The majority are in Scandinavia, with a few in other nations. Three mills in Canada are now producing totally chlorine-free market pulp, and one U.S. kraft mill in California recently announced plans to market high-brightness chlorine-free kraft pulp produced through a combination of the methods listed above.

For most applications, equal brightness, strength and other qualities are now being achieved without chlorine or other chlorine-based bleaches. Rapid development of alternative bleaching methods indicates that, within a short time, any remaining technological barriers to full use of chlroine-free papers will probably be eliminated. Der Spiegel, the largest-circulation top-quality news magazine in Germany, is now printed on totally chlorine-free paper, as are numerous other publications.

3) Implementation of alternatives.

The following measures are available to a sunset program:

1. Sunset permits for pulp mills, setting timelines for the reduction and eventual elimination of chlorine and chlorine-based bleaches.

2. Other measures, including consumer education and government procurement policies to accelerate demand for chlorine-free paper products; surcharges on chlorine-bleached papers; economic incentives to mills to invest in chlorine-free processes.

The socio-economic impacts of implementing these alternatives do not appear prohibitive, given the current trend to eliminate chlorine use in Europe. Following an initial investment, production of chlorine-free pulp involves lower chemical costs, lower costs for treatment and disposal of organochlorine-contaminated effluents and sludges, and -- if process loops are closed -- additional cost savings.

Demand for totally chlorine-free pulps are growing in both European and America markets. Mills that invest to meet changing market demand will be far better positioned to compete with European and other mills over the next decade. Because of the initial investment involved, it may be necessary for the Parties to ensure that regulatory policies apply to mills through the U.S. and Canada rather than just to those in the Great Lakes region.

F) Other chlorine uses.

A brief overview suggests that for most uses, a similar picture emerges: alternatives are currently available and practical to allow the phase-out of most major uses of chlorine.

1) Chlorinated solvents.

Chlorinated solvents account for an estimated 10 percent of chlorine use in the U.S. Used for cleaning, coating, and extraction in manufacturing industries, the chlorinated solvents are ubiquitous as atmospheric and groundwater contaminants. It has been estimated that almost the entire quantity of chlorinated solvents used ends up being released into the atmosphere. Much of that which is controlled ends up being incinerated as waste. The persistence and toxicity of chlorinated solvents and their chlorinated breakdown products (i.e., vinyl chloride, chloroacetic acids) in the air and groundwater have been well documented. Worker and community exposures to air emissions of these volatile chemicals are also of serious concern, and halogenated solvents are primary causes of depletion of the stratospheric ozone layer. Chlorinated solvents are also a primary source of chlorine feed in hazardous waste incinerators.

Total demand for other chlorinated solvents is also expected to decline over the next decade as industries seek to minimize costs for chemical procurement, disposal and liability and concern over worker and community health effects grows. Already, major manufacturers, such as IBM and GE have announced plans to phase-out the use of chlorinated solvents.

Alternatives to chlorinated solvents include process changes to eliminate the need for cleaning with solvents; water-based cleaning, coating and extraction; use of non-chemical cleaning agents such as soaps and citrus-based chemicals; and mechanical or dry cleaning and coating processes. The U.S. EPA is now investigating a solvent-free, steam-based alternative to dry cleaning (the major use for perchloroethylene) that is now in use in England.

Chlorinated solvent use is already declining. The ozone-depleting solvents and refrigerants chlorofluorocarbons, hydrochlorofluorocarbons, carbon tetrachloride, and 1,1,1,-trichloroethane are already subject to worldwide phase-out agreements. In Sweden, carbon tetrachloride, methylene chloride, trichloroethylene, and 1,1,1-trichloroethane have been placed on phase-out timetables.

2) Pesticides.

Pesticides account for only an estimated 2 percent of total chlorine use but, because they are intentionally introduced directly into the environment are responsible for severe contamination on a global basis. While some chlorinated pesticides have already been restricted, others, such as alachlor, atrazine, and 2,4-D remain in widespread use. Of the top five pesticides used in the U.S. today, all are chlorinated (atrazine, alachlor, 2,4-D, metolachlor, and dichloropropene). These pesticides and their breakdown products are also ubiquitous contaminants of surface waters, groundwaters, and food supplies. In addition, pesticide manufacture - a complex, multi-step process -- tends to be associated with the production of large quantities of halogenated wastes. Pesticides are a major use for the aromatic chlorinated feedstocks which are themselves associated with significant persistence and toxicity and with the production of high quantities of the by-products of greatest concern, such as HCB, PCDD, and PCDFs. Some non-chlorinated pesticides, such as the highly toxic parathions, paraquat, and others, are made via chlorinated intermediates that are associated with the production and release of persistent, toxic chlorinated wastes.

The alternatives to synthetic pesticides are well-documented and are in use by organic farmers throughout North America. Methods include improved crop choice, rotation and mixing; maintenance and introduction of natural predators; and use of biological pesticides. These methods often involve greater labor costs which are offset by reduced costs for chemical procurement. In a 1989 review, the U.S. National Academy of Sciences found that chemical-free agricultural methods can result in yields and productivity as high or higher than pesticide-intensive farming. That review recommended a national program to remove financial and political barriers that encourage farmers to rely on pesticide-based methods.

There is ample precedent for restricting or banning the manufacture and use of persistent toxic pesticides, especially organochlorines. Such policies could be extended, on phase-out timetables, from individual compounds to the class of pesticides that contain chlorine, with exceptions made according to the principle of reverse onus.

3) Chemical intermediates.

The use of chlorinated organics within the chemical industry to produce chlorine-free products, such as polyurethane and epoxy resins, accounts for as much as 20 percent of chlorine use in the U.S., and a lower amount in Canada. Although the final products do not contain chlorine, these production processes involve the generation of large quantities of chlorinated wastes and by-products, along with environmental releases and worker exposures to chlorinated feedstocks and their wastes (Vonkeman 1991).

PCDD/Fs have been detected in chlorinated intermediates and the products made from them, including epichlorohydrin, chlorobenzenes, and phthalocine dyes made through chloro-aromatic intermediates. Many of the intermediates -- such as phosgene and epichlorohydrin -- are themselves recognized for their extreme toxicity. Based on the well-documented generation of highly persistent toxic by-products, the chlorinated aromatic intermediates (chlorobenzenes and derivatives) may be top candidates for prioritization within this sector.

This sector tends to be highly specialized, but alternatives are known to be available for at least some major uses. For instance, Dow Chemical uses approximately 8 percent of all the chlorine produced in the U.S. to manufacture propylene oxide (used for onward production of polyurethane, brake fluids, and other chemicals); however, another major U.S. chemical company, ARCO, produces propylene oxide through a chlorine-free oxidation process using the catalyst tert-butyl peroxide.

Phosgene (used primarily to produce isocyanates for polyurethane production) and epichlorohydrin (used to produce epoxy resins and other chemicals) each account for about 5 percent of total chlorine use in the U.S. As for propylene oxide, because chlorine does not appear in the final product, there is no theoretical reason that other methods of chemical synthesis -- including oxidation with organic or metal catalysts and electrochemical oxidation -- cannot substitute for chlorine-based process. For instance, dimethyl carbonate substitutes for phosgene and metal-catalyzed oxidation substitutes for epichlorohydrin are in use or development.

Continued research and development in this area can be expected for those uses for which alternatives are not now established. Such research would be hastened in the anticipation of sunset timetables for these chlorinated intermediates.

4) Disinfection.

Disinfection of water and wastewater accounts for about 5 percent of total chlorine use in the U.S.; of this, an estimated 4 percent is wastewater treatment, with less than 1 percent being used for drinking water disinfection .

When chlorine is used as a disinfectant for wastewater or drinking water, hundreds of chlorinated organic by-products result, including toxic and persistent chlorinated acids, aliphatics, ketones, and aromatics, such as chlorophenols and chlorobenzenes. In addition, a significant portion of the by-products are composed of unidentified compounds. Emerging evidence suggests that exposure to these by-products may be linked to increased incidence of certain cancers, birth defects, and developmental toxicity; further studies are needed to confirm and clarify the role of chlorinated by-products in these and other possible effects.

Alternative disinfection methods are available to reduce or eliminate chlorine use in this sector. For wastewaters, available alternatives that cut chlorine use to zero are in worldwide use. The most common methods are ultraviolet and ozone treatment. Ozone is an extremely effective disinfectant, but the process is energy intensive and produces chemical by-products that, though apparently less persistent than those produced by chlorination, may be problematic from a health and environmental perspective. Ultraviolet treatment is also an effective disinfectant, based on the destruction of bacteria and viruses with a narrow frequency of intense light; no chemical by-products are produced, and energy requirements are less than those for chlorine.

Several hundred wastewater treatment plants in the U.S. and Canada have installed UV systems and eliminated chlorine in the last decade. Capital costs are estimated to be equal to or less than those for chlorine, and operating costs are lower.

These alternatives are effective disinfectants for drinking water, as well, and can replace chlorine for in-plant disinfection. However, where drinking water has a high content of organic matter and travels through long delivery systems, a residual is necessary to prevent regrowth of pathogens after initial treatment. Neither ozone nor UV provides such a residual, and many North American treatment works that have installed these methods must continue to use chlorine for residual disinfection. In Europe, where several thousand plants use ozone or UV systems, the use of sand- or carbon-filtration to remove organic matter and more carefully designed delivery systems make the chlorine residual unnecessary.

Thus, alternative disinfectants appear feasible to eliminate the use of chlorine entirely for wastewater treatment and for in-plant disinfection of drinking water. Smaller amounts of chlorine will continue to be necessary until larger changes are possible in water treatment and delivery systems. This "residual" chlorine use that should be maintained, however, represents a very small percentage of chlorine use.

8) CONCLUSION

Chlorinated organic persistent toxic substances represent a unique class of compounds. When implementing the strategy to achieve the Agreement's goal of virtual elimination, it is necessary that these substances be treated as a class of chemicals. The properties of these substances which require that they be treated as a class includes their extreme toxicity, the fact that they are virtually entirely foreign to natural systems, and the fact that roughly half of the chemicals found in the Great Lakes are chlorinated. Both the Commission and the IJC's Science Advisory Board have recognized the importance of treating chlorine as a class of persistent toxic substances, rather than attempting to deal with them individually.

This analysis indicates the utility of applying a use-tree to investigate phasing out an industrial feedstock chemical such as chlorine. The use tree analysis indicates the wide variety of uses of chlorine. It also indicates the importance of reducing industrial demand for caustic soda. This can be accomplished in a number of ways, including through conservation and recycling, through the use of alternative alkalis or sodium sources, and by producing caustic soda through methods other than the chlor-alkali process.

The information in this review suggests that phasing out many industrial uses of chlorine is practical and feasible. For the two main uses of chlorine, production of PVC and chlorine bleaching in the pulp and paper industry, alternatives are available. In fact, it is encouraging to note that many European and North American firms are currently making this transition.

The strategy recommended in this report includes issuing sunset permits for current industrial users of chlorine. These permits would specify the date in the future after which no chlorine could be used in the process and would include progressively more stringent limits to reduce chlorine use (and release of organo-chlorine wastes) in the interim.

The Commission recommended in its Sixth Biennial report that the Parties develop timetables to sunset the use of chlorine and chlorine containing compounds as industrial feedstocks. This analysis provides a framework for implementing that recommendation and begins to answer many of the questions the raised by the recommendation. Most importantly, this report indicates that phasing out many industrial uses of chlorine is practical, feasible, necessary and should be accomplished by the U.S. and Canada.

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