Chlorine. The word evokes pleasant images of swimming pools and clear blue water sparkling in the summer sun. For most people, in fact, the familiar smell of the chemical is linked with the reassurance that the water we use every day has been rendered pure.

But critics have brought forth another image of chlorine and chlorinated compounds that are used in many products and industrial processes, including ubiquitous polyvinyl chloride plastics. For them, chlorine is inextricably accompanied by the dark shadows of dioxins and PCBs—polychlorinated biphenyls. They blame chlorine and chlorine chemistry for unleashing some of the most serious threats to human health and the environment.

A year ago, at an off-the-record forum on sustainability sponsored by Chemical & Engineering News, the discussion shifted to chlorine. The vigorous and provocative debate that followed surprised even those of...

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us on the magazine staff who follow controversy as a matter of course in our reporting. We decided to identify two of the best experts on chlorine chemistry and sustainability in order to bring this debate to our readers. Our experts for this Point-Counterpoint on chlorine make it clear that time has erased none of the passion for this topic.

Writing in support of chlorine and related industries is C. T. (Kip) Howlett Jr., executive director of the Chlorine Chemistry Council and vice president of the American Chemistry Council. His writings about chlorine have appeared in scholarly texts, and he has addressed the United Nations regarding chlorine and its positive contributions to global human health.

Terrence Collins, Thomas Lord Professor of Chemistry at Carnegie Mellon University and director of the Institute for Green Oxidation Chemistry there, is a member of C&EN's advisory board. He contends that the dangers of chlorine chemistry are not adequately addressed by either academe or industry and that alternatives to chlorine and chlorine processes must be pursued.

COLLINS POINT

I teach students that the chlorine industry has made foundational contributions to modern civilization, including much safer drinking water, inexpensive bleached paper for education's biggest-ever growth burst, and solvents and reagents for synthesizing life-improving medicines. However, many serious pollution episodes are attributable to chlorine products and processes. This information also belongs in chemistry courses to help avoid related mistakes. Examples include dioxin-contaminated 2,4,5-T, extensively used as a peacetime herbicide and as a component of the Vietnam War's agent orange; chlorofluorocarbons (CFCs); polychlorinated biphenyls (PCBs); the pesticides aldrin, chlordane, dieldrin, DDT, endrin, heptachlor, hexachlorobenzene, lindane, mirex, and toxaphene; pentachlorophenol for wood preservation; and dioxins-producing wood pulp bleaching with elemental chlorine. Regulations have partially resolved these problems. Still, the properties of leading chlorine products call for more change before the chlorine industry can be compatible with a sustainable civilization.

Global chlorine production exceeds 40 million tons annually. Approximately one-third goes into manufacturing polyvinyl chloride. PVC's low cost, adaptability, and high technical performance seem impressive. But beneath the attractive veneer, PVC is extremely hazardous for multiple reasons. Space permits me to consider only the dioxins hazard associated with PVC combustion.

According to the National Academies, the most toxic of the
dioxins, tetrachloro-p-dibenzodioxin (TCDD, often called dioxin), elicits a diverse spectrum of cancer and noncancer effects. The noncancer disorders are far more troubling than cancer itself. Cancer destroys lives. But a broad base of evidence indicates not only that childhood intake of dioxins impairs development at infinitesimal body burdens (parts per trillion), but also that dioxins lie in wait in the tissues of parentsto-be, threatening children with a diminished humanity before their conception even occurs.

Dioxins are implicated in birth defects, impaired neurological development and related cognitive or behavioral deficits, immune suppression leading to increased susceptibility to infectious disease, cardiovascular disease, diabetes, and other effects on or injury to the liver, thymus, spleen, teeth, bone and bone marrow, and skin. Female reproductive disorders include decreased fertility, inability to maintain pregnancy, ovarian dysfunction, endometriosis, hormonal changes, and problems in breast development. Male reproductive disorders include reduced sperm count, testicular atrophy, abnormal testis structure, reduced size of the genital organs, reduced testosterone levels, changes in sexual behavior, and fewer male babies.

With this in mind, consider all the windows, siding, flooring, automobile components, packaging, and innumerable other PVC products where accidental or inadvertent fires could (and do) contaminate neighborhoods with bioaccumulative dioxins, putting children and people of reproductive age at risk of exposure. Some people discard plastic food wraps and containers on their barbeques while cooking. This practice could lead to dioxins-contaminated food when the plastics contain organochlorines such as PVC. Saran, polyvinylidene dichloride, also produces dioxins upon pyrolysis. Thus, it is heartening that S. C. Johnson & Son has recently removed Saran from Saran Wrap in its "initiative to look for more sustainable and environmentally acceptable plastic."

On a related matter, chlorine industry supporters too often argue that concern over anthropogenic dioxins is overstated because a very small amount can be generated naturally. This non sequitur is like conjecturing that it is okay to add, say, arsenic to the water supply because a trace is often present naturally.

The U.S. chlorine industry claims, via the Environmental Protection Agency’s Toxics Release Inventory, to be reducing releases of dioxins from industry facilities. Releases from incinerators have also been falling in some parts of the world. As wider prohibitions are imposed on backyard incineration, this major dioxins source will diminish. And the
Centers for Disease Control & Prevention has reported that body levels of TCDD have been dropping significantly in most of the U.S. population. These are encouraging trends, to be sure. But there are more than 1 million accidental fires each year in the U.S. alone. As more PVC accumulates in our civilization, it is hard to believe that children are not being compromised in increasing numbers by dioxins from chance PVC combustion.

Some chlorine companies (or alliances or spin-offs) are developing new genuinely "green" products. Let me highlight two of my personal favorites. In contrast with PVC, Dow Bioproduct's WoodStalk building material is both safe and technically superb. This alternative to wood-based products is composed of renewable wheat straw fiber, an agricultural discard, bound with a formaldehyde-free polyurethane resin. It is light, strong, moisture-resistant, cost-effective, and available in hardware stores. Also, Cargill-Dow has moved assertively into polylactic acid, which it makes from biomass for use in industrial packaging and biocompatible/bioabsorbable medical devices. These inventive uses of renewable feedstocks are helping to build the technological dimension of a sustainable civilization.

Perhaps the chlorine industry will one day find a way to reformulate PVC to eliminate dioxins formation upon combustion. Until then, I believe PVC should be restricted to those uses where uncontrolled combustion cannot occur; for example, in buried piping. In a sustainable civilization, the fetus and the child in every nation will be fully protected from all anthropogenic compounds where there is proven causation or reasonable suspicion of developmental impairment.


HOWLETT POINT

Chlorine chemistry is firmly supported by all three legs of sustainable development: environment, society, and economy. Chlorine chemistry--coproducts chlorine and sodium hydroxide--provide thousands of affordable, often lifesaving services critical to humankind: health, safety, security, shelter, nourishment, mobility, and communication. (See http://c3.org/chlorines_everyday_uses/chlorine.pdf for a graphic overview of how chlorine's unique properties enable it to be used in numerous, varied ways.)

Chlorine is a reliable, affordable water disinfectant in a time when more than 1 billion people around the world lack access to safe drinking water. It is critical to the long-lived, inert pipe that transports that water. Its chemistry makes soldiers' and police officers' helmets and flak jackets bulletproof in a time of terrorist threat. It is a chemical reagent...
critical to the synthesis of 85% of our pharmaceuticals—including the antibiotics that treat anthrax—in a time when millions of people suffer from incurable chronic diseases and face the new reality of biological warfare.

In Peru, in the early 1990s, public health officials responded to an antichlorine campaign by stopping proper chlorination of their drinking water. The results were predictable and horrific. Within months, a cholera epidemic swept through the country, eventually causing 1.3 million cases of illness and 13,000 deaths.

An outright ban of chlorine is a simple-minded, theoretical approach aimed at improving environmental policy, where appropriate stewardship and management of a necessary chemical tool have demonstrated excellent results for 100 years. Through technology, the sharing of best practices, and government regulation, the chlorine chemistry industry has a successful environmental management story to tell. It is one that considers risks, benefits, and trade-offs; makes significant strides in reducing emissions; and still provides humanity with thousands of critical products—many of which require chlorine-containing reagents for synthesis, but contain no chlorine in the final output.

According to the World Health Organization, 1.1 billion people lack access to safe drinking water and 2.2 million people, mostly children, die every year from diseases associated with a lack of safe drinking water and inadequate sanitation. Chlorine, as hypochlorite or chlorinated isocyanurates, provides an affordable solution for those in the developing world. The chemicals are fundamental to the top goal set at the 2002 World Summit on Sustainable Development in Johannesburg, South Africa: to halve by 2015 the proportion of people without access to safe drinking water and basic sanitation. Polyvinyl chloride pipe—made of chlorine-based vinyl—lasts up to 100 years, is more cost-effective than metal or concrete, and requires virtually no maintenance. Most important, PVC pipe helps keep disinfected drinking water protected because it resists biofilm formation better than metal or concrete. Chlorine is the only disinfecting agent that provides residual disinfectant action, continuing to protect the water during storage or distribution through pipes and taps that may be contaminated.

Due to the affordability of chlorine, experts estimate that a family of four in the developing world, where average household incomes are as low as $1.00 per day, can disinfect their drinking water with point-of-use chlorination for less than 10 cents per day.

Products and services that result in 45% of the U.S. gross domestic product are rooted in chlorine chemistry. In addition to water disinfectants and pharmaceuticals, chlorine is critical to 25% of all medical plastics, 70% of all disposable medical applications, and 95% of

http://pubs.acs.org.proxy.libraries.rutgers.edu/cen/ncw2004/8242chlorine.html
crop protection chemicals; it also plays a significant role in the production of soaps and detergents, aluminum, and pulp and paper.

The chlor-alkali sector is a solid job producer in the U.S., with a payroll of more than $360 million and more than 37,000 jobs.

The goal of the chlorine chemistry industry is to continually lessen its environmental impact while providing vital services--and it is succeeding. The largest source of dioxins today is backyard trash burning. According to the 2002 Environmental Protection Agency Toxics Release Inventory (TRI) of chemical emissions to air and water, releases from the chlorine sector (10.4 grams toxic equivalents) represent less than 1% of the total 2002/2004 EPA-projected dioxins emissions from quantified sources. The 2002 TRI also shows that the chlorine chemistry industry has reduced already low dioxins figures by 68% over emissions in 2000. The agency's data show that emissions of dioxins from U.S. quantified sources declined 77% between 1987 and 1995 and project that, as of this year, emissions will be 92% lower than 1987 levels.5

Reduction in mercury emissions from chlor-alkali plants is another environmental goal with a record of achievement. Mercury-cell technology is steadily being replaced by membrane-cell technology. In the U.S., only 10% of chlorine production capacity uses mercury-cell technology.

Sustainable development, when practiced successfully, is achieved from the integrated consideration of all three elements discussed above, not by any one in isolation from the others. With efforts that ultimately will promote and sustain social progress, economic prosperity, and environmental protection, today's chlorine chemistry industry proceeds forward on the path of sustainability.


COLLINS RESPONSE

If anyone has proposed an outright ban on chlorine, this makes no sense to me. Among all technological advances, water disinfection with chlorine probably holds the record for saving human lives--it consumes about 1% of manufactured chlorine. But the Peru tragedy Mr. Howlett refers to is unlikely to be repeated elsewhere. His point is primarily a smoke screen to obscure pollution, especially dioxins released from a myriad of uncontrollable combustion incidents involving chlorine industry products.
Chlorine Chemistry Council (CCC) stratagems may yet make the U.S. record on handling dioxins toxicity as abysmal as its performance on lead toxicity. In their recent book "Deceit and Denial," Gerald Markowitz and David Rosner analyze voluminous confidential papers that the lead and PVC-related trade associations were obliged to disclose under legal discovery. Counterproductive tactics of industrialists, trade association leaders, and supporting academics are revealed therein.

For example, a relatively small group of such persons worked assiduously to forestall U.S. restrictions on leaded paint; the 1977 U.S. near-ban took almost seven decades longer to enact than bans elsewhere. Arguably, these individuals hold significant responsibility for the deaths of thousands of children from lead poisoning and for impairing millions of U.S. citizens. Their antics were also decisive in making lead poisoning one of the most common U.S. pediatric problems, affecting approximately 890,000 children nationwide at any given time. Most dioxins are vastly more toxic than lead. Once again, developing humans are much more vulnerable than adults.

The CCC public relations initiatives that gloss over toxicity misinform people and erode public trust in chemistry. I will teach its recommended website's "Chlorine Tree" as it nicely explains the marketplace fate of manufactured chlorine. But I will also teach that the tree exemplifies disconcerting public relations.

By listing together perfectly safe and questionable products without distinction, accompanied by prose that only glorifies chlorine technologies, CCC hides toxicity information that the public has a right to know and that CCC should rightfully explain. For example, an explanatory warning should be on that brochure against burning chlorinated plastics, especially around food. Mr. Howlett claims that the chlorine industry "is firmly supported by all three legs of sustainable development." But the society and environment legs are withered by unacceptable organochlorine uses and by his diversionary posture toward toxicity. Considering that the stout economy leg has been constructed from any and all sales, his veneration of this simply underscores the imbalance in his assertion.

A National Academies committee that was charged recently with recommending policy options to reduce dietary dioxins intake highlighted that "a great deal of uncertainty still surrounds their potential for toxicity and the implications for human health." I take this seriously but measure it against animal and human studies that indicate dioxins could be damaging fetuses and children at low-parts-per-trillion (ppt) body burdens. The committee also emphasized that "most actions taken now to reduce [dioxins] in the food supply will have a long-term effect on human health because [dioxins] are persistent and widespread in the food supply." Among other things, it advised government to "make it easier for [girls and young women prior to pregnancy] to drink low-fat or skim milk instead of whole milk and eat foods lower in animal
fat," while more data are being collected. But no strategy for protecting children from dioxins ingestion can beat eliminating anthropogenic dioxins. Governments should also regulate dioxins sources now and relax regulations later if today's justifiable concerns ever prove to be baseless.

I should elaborate on barbeques because they are, of course, innate dioxins sources. But a barbeque is no place to serve up an arsenic non sequitur. Adding chlorinated plastics fuels risk of dioxins. Animal studies have shown that TCDD in a pregnant mother's blood (low-ppt levels) can severely impair her offspring--plastics burned on barbeques could deliver bursts of dioxins to the blood of pregnant women.

With governments intimidated by prospects of economic disruption, the marketplace is stepping in to corral chlorinated plastics. Manufacturer S. C. Johnson & Son is removing chlorine from Saran Wrap. Health care provider Kaiser Permanente is restricting PVC-containing materials in hospitals over concern for the full gamut of toxicity problems. Consumers may pay more to avoid PVC--but not much more. Concern over combustion by-products led Carnegie Mellon University to restrict PVC in its new undergraduate chemistry laboratories--the $100,000 extra cost represented 0.36% of the total budget for the undergraduate chemistry labs. Frank Ackerman and Rachel Massey of Global Development & Environment Institute at Tufts University, Somerville, Mass., have analyzed the economics of phasing out PVC (http://www.ase.tufts.edu/gdae).

Society cannot accommodate anthropogenic dioxins and hope to build a sustainable civilization. Governments should regulate sources of dioxins while helping industry to respond. Publicly sponsored projects to transfer water from water-rich to water-poor regions via buried PVC pipes might be helpful in North America.

As chemists tackle the challenges of sustainability, dioxins remind us to rigorously isolate persistent, environmentally mobile compounds and their precursors from dispersive technologies. Too often, the combination has been accompanied by over-the-horizon health and environmental catastrophes.


HOWLETT RESPONSE

Dr. Collins concludes that the "chlorine industry has made foundational contributions to modern civilization" and that safe, clean drinking water and lifesaving pharmaceuticals are necessary and available due to chlorine chemistry. I agree.

I also agree that chlorine chemistry has legacy issues. These have been, or are being, addressed by restrictions, phaseouts, and bans--as well as
by industry's use of best available technology. My organization, the Chlorine Chemistry Council, and others are working to have the Stockholm Convention on Persistent Organic Pollutants (POPs) implemented in the U.S. This would extend our industry's successful policy regarding management of those materials to the rest of the world.

Even our legacy issues are not clear-cut, black or white considerations. A sustainability framework demands a comparative risk approach that acknowledges the gray areas and assesses potential risk. For example, the National Academy of Sciences evaluated PCB sediment contamination and endorsed a risk-management strategy for remediation which acknowledges the option of leaving the PCBs in place.8

The pesticide DDT saved millions of people from death due to malaria and is still the least expensive, most effective, and--when used judiciously and not sprayed indiscriminately--environmentally sensible mosquitocide. Malaria causes more than 2.7 million deaths per year--mainly among children under five years--in Africa, Asia, and South America where the prior use of DDT had caused the virtual eradication of this disease. Even the United Nations Environment Programme permits the judicious use of DDT until there are better alternatives.

Dr. Collins concedes that dioxins emissions from facilities are declining and, according to EPA's Toxics Release Inventory, are nearly eliminated. Our industry is proud of its record of continuous improvement.

Dr. Collins focuses on accidental fires. If what he and others say about the generation and longevity of polychlorinated dibenzo-p-dioxins and -furans from PVC combustion in house fires is correct, then these materials should show up in the environmental record. But the environmental record shows that emissions of dioxins and body burdens have declined over 90% since 1970, whereas PVC manufacture has tripled--and most of that manufacture goes to building and construction. In fact, the residential pipe, siding, window, fence, deck, and rail markets for PVC, which now take up nearly 50% of PVC use, didn't come into common use until after the early 1970s. How can there be a correlation, as Dr. Collins asserts, between dioxins in the environment and these building products?

Dr. Collins supports the use of PVC in "buried piping." It is important to note that nearly 34% of PVC goes into pipe, much of it to large-diameter water and sewer pipe. Six billion gal of treated water in the U.S. each day is lost to leakage and unmetered use. Much of that leakage is due to old, corroded, broken pipes made of metal or concrete. PVC pipe is considerably more sustainable. Studies show that PVC develops between 10 and 100 times fewer leaks than competitive traditional materials, saving water and additional purification chemical costs.

Our industry certainly supports innovation--that's how we have grown. We have always felt secure stating that if there are better products at a
better price, then people should buy them. Dow's WoodStalk, mentioned by Dr. Collins, is based on a polyurethane--and the isocyanate from which it is derived is yet another product of chlorine chemistry. Polylactic acid may turn out to be marvelous for packaging and medical devices. Until the U.S. Food & Drug Administration approves its use in medical applications, chlorine chemistry's products, with a proven track record, will remain on the front lines of modern medicine, making possible devices such as blood bags, X-ray film, heart monitors, and more.

Dr. Collins has forgotten that sodium hydroxide, the coproduct of chlorine manufacture, is necessary in its own right and would require other chemical or mining processes to replace. Sodium hydroxide is needed for thousands of products from detergents and rayon to nylon and rocket propellants.

In a sustainability framework, the issue is not the chemistry--the issue is technology and its application. With the increasing use of sustainable technologies and practices, chlorine chemistry's environmental record has vastly improved and continues moving in the right direction. The chemistry has not changed; technology has, and it works. The employment of new combustion technology accounts for the biggest reductions in dioxins emissions. The chloride composition of the wastes does not affect these emissions.

Dr. Collins focuses on "environmental" concerns, yet he practically ignores the social and economic aspects of the "triple bottom line" of sustainability performance. Success comes from the positive integration of all three legs of sustainability. These are the three areas where industry impacts quality of life.

The chlorine chemistry industry realizes people have questions about the manufacture and use of our products, which places a burden on us to be responsible manufacturers. We have been diligently striving and successfully meeting our stewardship responsibilities. Frankly, we appreciate people like Dr. Collins who push us and make certain we do so. Our industry is better for it.
