The Benefits of Chlorine Chemistry in Bleaches and Disinfectants

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Consumers benefit from chlorine chemistry in their use of bleaches and disinfectants by having access to low cost products that satisfy their needs in a wide variety of applications. Alternatives to chlorine-based products and processes are available in all these applications, but consumers overwhelmingly prefer the chlorine-based ones where they are available. The extent to which consumers benefit from access to these products and processes can be quantified by determining the additional costs that they would have to bear if the chlorine-based ones they now use were no longer available.

Essentially all bleached pulp mills in the United States and Canada have converted to elemental chlorine free (ECF) bleaching cycles that reduce dioxins and adsorbable organic halides (AOXs) to well below regulatory limits. Re-converting them for totally chlorine free (TCF) cycles is costly unless other efficiency or productivity improvements can be made. We estimate that industry wide conversion to TCF technology would require capital outlays of about $3.4 billion, and result in an increased substitution cost of about $340 million per year. In other bleaching and disinfectant applications, substitutes such as ozone, hydrogen peroxide, other peroxy compounds, and other materials and processes can substitute for hypochlorites and other chlorine-containing ones, but at much higher cost. While only about 1% of the chlorine consumed in all bleaching and disinfection applications is used specifically for disinfection, the benefits that its use provides in terms of avoided health care costs are very large. We estimate that substitution of other chemicals or processes in these applications alone would require investments of more than $150 million and cost consumers over $200 million per year.

We estimate that the total economic benefits of chlorine chemistry to consumers of their access to bleaches and disinfectants are about $1.9 billion per year, and the availability of chlorine-containing products eliminates the need to commit about $4.7 billion in capital to produce the substitutes.

Introduction

Bleaches and disinfectants typically are chemical compounds that are strong oxidizing agents used in myriad applications in industrial and commercial processes as well as directly in the home by consumers. Chlorine and chlorine-containing compounds are widely used as bleaches and disinfectants, providing consumers with more vivid whites from their laundry, cleaner swimming pools and spas, and brighter pulps for the high grade paper they use. In addition, these products are used to disinfect and sanitize food and household surfaces, disinfect hard surfaces and medical instruments in health care settings, and provide the public with safe drinking water. Consumers prefer them in many applications where chlorine-free materials or processes are available because of their performance and cost advantages.
In the following sections, we describe the uses of chlorine and chlorine-containing compounds as bleaches and disinfectants, the ways in which chlorine-free materials and processes can be substituted for them, and the benefits that consumers enjoy through access to chlorine chemistry in these applications.

**Chlorine Chemistry and its Substitutes in Bleaching and Disinfection**

The bleaching of wood pulps accounts for almost two-thirds of the chlorine consumed as either a bleaching or disinfection agent in the United States and Canada. Household, commercial, and other applications account for another 12%. These latter applications include pool and spa sanitizing; bleaching; and surface disinfection in food processing and preparation facilities, restaurants and healthcare settings. Treatment of drinking water supplies and waste water streams accounts for the balance of chlorine consumption in this application. The applications of chlorine and chlorine-containing compounds, and their possible substitutes are described below for all applications except water treatment, which has been addressed in a separate report.1

![Chlorine Consumed in Bleaching and Disinfection in the US and Canada](image)

**Figure 1. Chlorine Consumed in Bleaching and Disinfection in the US and Canada**


**The Bleaching of Wood Pulps**: The production of paper and paper products from woods is a complex, capital intensive and costly process, with many variations possible depending on the types of woods used as the raw materials and the types of paper

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products being produced. Both mechanical and chemical processes are used to produce pulps, but chemical processing based on the Kraft alkaline sulfate process is most common, being used to produce about 85% of the pulp produced in the United States and Canada. The process “digests” debarked wood chips in a solution that selectively decomposes the constituents of the raw wood, separating the desired cellulosic material from hemicellulose, lignin, and other resins and oils. The Kraft process produces pulps that are dark in color and more difficult to bleach than mechanical or semi-chemical pulps, but also produces fibers with the best mechanical properties. The chemicals used in the Kraft process are readily recovered, and all operations in the mill are integrated to reduce cost and energy consumption while minimizing environmental releases.2

Mechanical and unbleached chemical pulps are used for the production of products such as newspapers, paper bags, and building paper. The production of higher quality products such as printing and writing papers requires that the pulps be bleached prior to the papermaking process. The bleaching process brightens the pulp by oxidizing and dissipating the residual lignins and other polymeric materials that were not removed in the pulping process. Bleaching is usually carried out in stages, with conditions in each stage controlled to maximize the brightness achieved while minimizing the consumption of bleach as well as the degradation of the mechanical properties of the pulp. Historically, elemental chlorine was the bleaching agent of choice in almost all pulp mills. Plants that co-produced chlorine and sodium hydroxide by the electrolysis of brines were sometimes located in the vicinity of the mills, which consumed both products in roughly the amounts at which they were produced. Most of the caustic went into the digestion process and the chlorine was used for bleaching.

This type of bleaching, based on the use of elemental chlorine, produced high quality bleached pulps but also removed some of the polymeric impurities by converting them into complex, soluble chlorine-containing organic compounds, such as polychlorinated phenols, dioxins, and furans. These compounds, collectively known as adsorbable organic halides (AOXs), were not removed completely in the mills’ wastewater treatment systems and a fraction of them were discharged in the plant effluent where they constituted a large percentage of the wastes’ total organic chloride content. The continued release of such compounds into public waterways was a source of environmental concern. Allowable discharge rates are now regulated, requiring that dioxins be reduced to non-detectable levels and AOX concentrations be kept low. These concerns led the pulp and paper industry to seek cost effective alternative bleaching technologies to greatly reduce or eliminate the formation of AOXs. Three different types of bleaching cycles that meet the AOX discharge limitations have been developed and used: (1) use of oxygen-assisted delignification and substitution of chlorine dioxide for a portion of the elemental chlorine used in bleaching; (2) use of more oxygen or ozone in delignification and use of only chlorine dioxide in bleaching; or (3) use of extended oxygen or oxygen-ozone delignification with bleaching accomplished by oxygen and hydrogen peroxide.

Existing mills that aimed to reduce the discharge of AOXs would choose the first option, which is lowest in cost and easiest to implement, where possible. The chlorine dioxide could be generated on-site in small “packaged” plants, and substituting chlorine dioxide for more than two-thirds of the chlorine would produce effluents that would meet discharge requirements. This option was adopted by most existing mills in the 1990s as an interim approach to reducing the discharge of hazardous compounds. A newly constructed mill might opt for more efficient, better integrated digestion and bleaching cycles that continued to use some combination of oxygen, ozone, and chlorine dioxide, while making numerous other improvements that would improve productivity and reduce costs as compared to the older process.

The second alternative described above is known as elemental chlorine free (ECF) bleaching. Retrofitting existing plants for the ECF option is somewhat more difficult and costly than partial substitution for elemental chlorine but this approach has been designated as “Best Available Technology” (BAT) under the US EPA’s cluster rule for pulp mills. The Canadian provinces have adopted similar requirements, with somewhat different discharge limits. ECF technology has been adopted by more than 99% of the pulp mills in the United States and Canada, and about 85% of the mills in the developed world. The better performing mills are capable of achieving discharge levels as low as 10% of the NSPS limits, with greatly reduced biochemical oxygen demand (BOD), total suspended solids (TSS), and color in their plant effluents as well. Mills that retrofit to this technology often modify both the digestion and bleaching steps, as well as make productivity and energy savings investments. As a result, many such conversion projects have relatively short payback time.

The third option described above is known as totally chlorine free (TCF) bleaching. It was developed and commercialized in Europe where it has found acceptance in the production of specialty products sold into markets that require chlorine-free materials. The technology is being used both in new mills and mills that have been retrofitted from older technologies, but is currently used to produce only about 5% of bleached pulps. Furthermore, there have been few capacity additions using TCF technologies in the past ten years. While also considered BAT under EPA’s regulations, retrofit costs for a TCF plant typically are higher than for an ECF plant and, in the absence of investments made to improve productivity or energy efficiency, the TCF process does not offer significant manufacturing cost advantages. While plant effluents are totally free of chlorinated compounds, they do contain a range of potentially harmful oxygenated compounds such as organic aldehydes, acids, ketones, and alcohols, albeit at low levels. This process is currently used in only a few mills in North America which produce about 10% of the world’s TCF pulp.

**Other Bleaches and Disinfectants:** While other oxidizing agents can be used as bleaches or disinfectants, chlorine-containing materials command the largest share in consumer, commercial, and industrial applications. The largest volume materials in use

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are sodium and calcium hypochlorites, whose consumption in the United States and Canada amounted to more than 400,000 metric tons of chlorine equivalent in 2005.\(^5\) Much smaller amounts of lithium and potassium hypochlorites are used in specialty applications, and approximately 100,000 metric tons of chlorine equivalent products are consumed in other compounds such as chlorinated isocyanurates and hydantoins that are used in applications where their desirable properties justify their higher prices. Consumers are perhaps most familiar with these materials when they are consumed as household laundry bleaches, which usually contain about 6% sodium hypochlorite, or as disinfectants and sanitizers for swimming pools, spas, and hot tubs. They are also used in other household products such as liquid automatic dishwasher detergents, mold and mildew removers, bowl and drain cleaners, disinfectants, and disinfectant wipes and sprays.

Hypochlorite solutions at higher concentrations find widespread use as disinfectants and hard surface cleaners in commercial laundries, municipal swimming pools, hospitals, laboratories, restaurants, and food processing and preparation facilities. In the latter application they protect consumers from the farm-to-market transmission of bacteria, such as *E.coli*, *Salmonella*, *Listeria*, and *Staphylococcus*. In addition, these products can destroy such protozoa as *Cryptosporidium*, *Giardia*, and *Cyclospora* under suitable conditions.\(^6\) Chlorine-containing disinfectants are effective in the destruction of most viruses and other, hard-to-kill pathogens like the hospital super-bug *Clostridium difficile*. In hospitals and laboratories they are used to destroy pathogens on work surfaces and in medical wastes. The U.S. Centers for Disease Control and Prevention and Food and Drug Administration have published guidelines for their effective use in these environments.\(^7\) Hypochlorites are also consumed in the manufacture of other chemicals and manufacturing processes as bleaches or selective oxidants, facilitating the production of materials that may not themselves contain chlorine.

In some applications, the major alternatives to hypochlorite-based bleaches and disinfectants are other chlorine-containing materials. For example, chlorinated isocyanurates and hydantoins compete with sodium and calcium hypochlorites as pool sanitizers, all of which are based on chlorine chemistry. Consumer choice is often based on convenience of use and extended stability. Chlorine-free pool sanitizers include such materials as polyhexamethylene biguanide, which is quite costly, and compounds based on bromine. Bromine is produced from bromine-rich brines using chlorine. In other applications, chlorine-free alternatives include oxidizing agents such as ozone, hydrogen peroxide, peroxyacetic acid, percarbonates and perborates. The latter have been used as household bleaching agents when suitably formulated, but they usually require that laundry practices be changed to obtain results that are comparable to those obtained with hypochlorite bleaches.

Other materials, such as concentrated acids or bases like acetic acid, caustic soda, or lime, or reactive chemicals such as gluteraldehyde can be used to sanitize surfaces and destroy

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\(^5\) Whitfield & Associates estimate, based on industry reports.


pathogens. Alternative non-chemical treatment options include sterilization with steam or hot water and UV or ionizing radiation. While any of these materials or processes might be technically acceptable substitutes for chlorine-based bleaches and disinfectants in a particular application, none are likely to be as generally useful or as cost effective as the chlorine-containing products consumers prefer today. All require either the use of more costly chemical agents or more intensive labor inputs to obtain equivalent disinfection performance, or both.

The Benefits of Chlorine Chemistry in Bleaches and Disinfectants

Consumers benefit from chlorine chemistry in their use of bleaches and disinfectants by having access to low cost products that satisfy their needs in a wide variety of applications. Alternatives to chlorine-based products and processes are available in all these applications, but consumers overwhelmingly prefer the chlorine-based ones where they are available. The extent to which consumers benefit from access to these products and processes can be quantified by determining the additional costs that they would have to bear if the chlorine-based ones they now use were no longer available.

If chlorine-based products were no longer available, all mills in the United States and Canada now using ECF bleaching cycles would be required to convert to TCF cycles for the production of about 45 million tones of bleached pulps. For the most part, this would require retrofitting a new technology into mills that had been retrofit with ECF technology within the last ten years. Some mills might elect to undertake other investments at the same time to improve productivity and efficiency, but the costs and any benefits of doing so would not be attributed to the costs of implementing chlorine-free technology. Other producers might elect to construct new brownfield or greenfield mills\(^8\) based on TCF technology, but only the incremental costs of a TCF mill versus an ECF mill would be relevant to this analysis. Based on the costs that have been reported for new TCF mills and for conversions from ECF to TCF bleaching in existing mills, we estimate that industry wide conversion would require capital outlays of about $3.4 billion, as shown in Table 1. We estimate that the increased operating costs and the returns to capital that the mills would require to justify the necessary investments would be about $340 million per year.

<table>
<thead>
<tr>
<th>Application</th>
<th>Additional Capital Expenditure ($ MM)</th>
<th>Substitution Cost ($ MM per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp bleaching</td>
<td>3,400</td>
<td>340</td>
</tr>
<tr>
<td>Disinfection</td>
<td>150</td>
<td>205</td>
</tr>
<tr>
<td>All other</td>
<td>1,150</td>
<td>1,370</td>
</tr>
<tr>
<td>Total</td>
<td>$4,700</td>
<td>$1,915</td>
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</tbody>
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\(^8\) A brownfield site is land previously used for industrial purposes that may be contaminated by low concentrations of hazardous waste and has the potential to be reused once it is cleaned up; a greenfield site is used to describe a piece of undeveloped land.
Consumption of sodium and calcium hypochlorites for disinfection purposes is relatively small, amounting to about 35,000 metric tons per year of chlorine equivalent. Despite the modest volumes, the health care benefits derived from their use are large since they are instrumental in preventing the transmission of a wide variety of diseases in the food service and processing industries and in health care settings. Quite simply, they are inexpensive, easy to apply, and very effective destroying pathogens that, if left unchecked, can quickly infect many people at and beyond the initial points of infection. While substitutes are available, they either involve the application of harsh chemicals or the use of more elaborate equipment or processes to obtain the same results. We estimate that additional investments of more than $150 million would be required to produce the substitutes required for disinfection, and that the increased costs for the materials and labor to apply them would be more than $200 million per year.

More than half of the chlorine-containing materials consumed as bleaches and disinfectants are used as household and municipal pool sanitizers, and over 70% of them are the relatively low-cost hypochlorites. They, and the more expensive chlorinated cyanurates and hydantoins, would have to be substituted with higher cost materials such as biguanide, or by much more elaborate disinfection systems such as ones based on the generation of dissolved ionic silver. About 25% of these chlorine-containing materials are used as laundry bleaches in household and commercial applications. They could be replaced by various peroxy compounds that now claim a 20% share of this market, but consumers would be forced to use higher temperature wash cycles to obtain equivalent performance from these more costly materials. A variety of other oxidizing agents, mainly ozone and hydrogen peroxide, would be used in all other applications currently served by sodium and calcium hypochlorites.

Not only are these materials generally more expensive per unit weight of oxidizing potential than the chlorine-based ones they would replace, but since many are now produced in relatively small volumes, manufacturers would be forced to construct new capacity to meet the increased demand. We estimate that investments of more than $1.1 billion would be required to supply the substitutes, and that they would cost consumers almost an additional $1.4 billion per year to use them.

In summary, we estimate that the total economic benefits of chlorine chemistry to consumers of their access to bleaches and disinfectants are about $1.9 billion per year, and the continued availability of chlorine-containing products eliminates the need to commit about $4.7 billion in capital to produce the substitutes.
Chlorine: Effective Disinfectant for Influenza

In May 1997, a three-year-old boy in Hong Kong contracted an influenza-like illness, was treated with salicylates, and died 12 days later. The cause was thought to be viral pneumonia, but was identified as H5N1 avian influenza three months later. Meanwhile, avian flu went on to kill six people and sicken 18 in Hong Kong until a comprehensive cull of the city’s poultry in December of that year. In March 2003, a Chinese-American businessman died in Vietnam from a severe flu-like illness. Soon after, reports of a new disease made headlines around the world. Panic struck the international community. Little was known about the disease: nobody knew where the disease came from or what caused it. The disease was spreading rapidly, and it was deadly. It was severe acute respiratory syndrome (SARS). Within months, SARS swept across the world, leaving approximately 8,400 suspected or confirmed cases and nearly 1,000 deaths in 30 countries.

Although both avian influenza and SARS are now under control, there is still a lack of effective vaccines for these diseases. Even with the introduction of a new influenza vaccine, Tamiflu®, which is recommended as a preventive measure, there is no clear evidence that Tamiflu® would be effective against the bird flu in humans. Vaccines to guard against the SAR-CoV virus are still being researched and developed. One reason it is difficult to develop vaccines for diseases like SARS is because some viruses are believed to mutate constantly. If a virus changes quickly, a vaccine might be suitable for a while but not forever. As such, efficient disinfecting and decontaminating play an important role in containing and controlling outbreaks like avian influenza and SARS.

Chlorine solutions and compounds are valuable disinfectants because they inactivate all bacteria, viruses, fungi, parasites, and some spores. They are fast-acting, very effective, inexpensive, and readily available. They are extremely useful for decontaminating soiled surgical instruments, gloves and other items, as well as large surfaces like examination tables. A 2003 study tested the efficacy of various disinfectants on avian influenza virus. Peroxygen and chlorine compounds were found to be the most effective. For the peroxygen compound to work as well as the chlorine compound, however, much higher concentrations are needed (6% versus 0.1%). More recently, another report in the Emerging Infectious Disease Journal studied the effect of chlorination on highly pathogenic avian flu virus and reiterated the effectiveness of chlorine at inactivating the virus. As such, chlorine is the disinfectant and decontaminant recommended for use in most hospitals. It is also used as a spray on meat and poultry trucks, especially in areas where avian influenza is a threat.