AN IHS ECONOMICS REPORT

The Economic Benefits of Chlorine Chemistry in Bleaches and Disinfectants in the United States and Canada

April 2016

PREPARED FOR THE AMERICAN CHEMISTRY COUNCIL

Ron Whitfield
Vice President, Applied Economics

Fran Brown
Senior Consultant

Lisa Wood
Senior Consultant

American Chemistry Council

IHS

This report offers an independent assessment of the economic benefits of chlorine chemistry. This research was supported by the American Chemistry Council. IHS is exclusively responsible for this report and all of the analysis and content contained herein. The analysis and metrics developed during the course of this research represent the independent views of IHS and are intended to contribute to scientific discourse and education of the general public.

For more information, contact:
Ron Whitfield
Vice President, IHS, Applied Economics
ron.whitfield@ihs.com

ihs.com

Contents

Executive summary

The chlorine chemistry used in bleaches and disinfectants benefits consumers by providing low cost products that satisfy their needs in a wide variety of applications. Alternatives to chlorine-based products and processes are available in each of the applications, and there is consumer interest in “greener,” “chlorine-free” sanitizers and disinfectants. Many consumers still prefer chlorine-based products, however, and chlorine-based manufacturing processes remain significant. 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 products 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 an industry wide conversion to TCF technology would require capital outlays of about $1.7 billion, and would result in an increased substitution cost of about $320 million per year. In other bleaching and disinfectant applications, substitutes such as ozone, hydrogen peroxide, other peroxy compounds, and other materials can substitute for hypochlorites and other chlorine-containing products, but at a much higher cost. While a very small percentage 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 $700 million and cost consumers close to $300 million per year.

We estimate that the total economic benefit of chlorine chemistry to consumers in the US and Canada due to their access to bleaches and disinfectants is about $5.5 billion per year. The economic benefit for consumers in the US amounts to $5.2 billion and for Canadian consumers $0.3 billion. Furthermore, the continued availability of chlorine-containing products eliminates the need to commit $4.3 billion in capital to produce the substitutes. The avoided capital spending in the US amounts to $3.3 billion and in Canada to $1.0 billion.

Introduction

Bleaches and disinfectants typically are chemical compounds that are strong oxidizing agents. They are used in a myriad of 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 health care surfaces and medical instruments, 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

Nearly 40% of chlorine used for bleaching and disinfection goes into the treatment of drinking water and wastewater streams and almost 60% is used in household, commercial, and other applications in the United States and Canada. A small amount is consumed in wood pulp bleaching. In the household and commercial segment, applications include pool and spa sanitizing; laundry bleaching; and surface disinfection in food processing and preparation facilities, restaurants, and healthcare settings. 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]

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 type of wood used as a raw material and the types of paper 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 90% of pulp in the United States and Canada. This process is based in caustic soda chemistry. Caustic soda, also known as “caustic” or sodium hydroxide, is a co-product of chlorine manufacturing. As shown below, the first step of the Kraft process is the “digestion” of 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 to make products such as newspapers, paper bags, and building paper. Mechanical pulp production in the United States and Canada is not increasing, partially because of the availability of stronger chemical pulp at only slightly higher prices. This has resulted in the closure of several Canadian chemi-thermomechanical pulp (CTMP) and bleached chemi-thermomechanical pulp (BCTMP) mills.

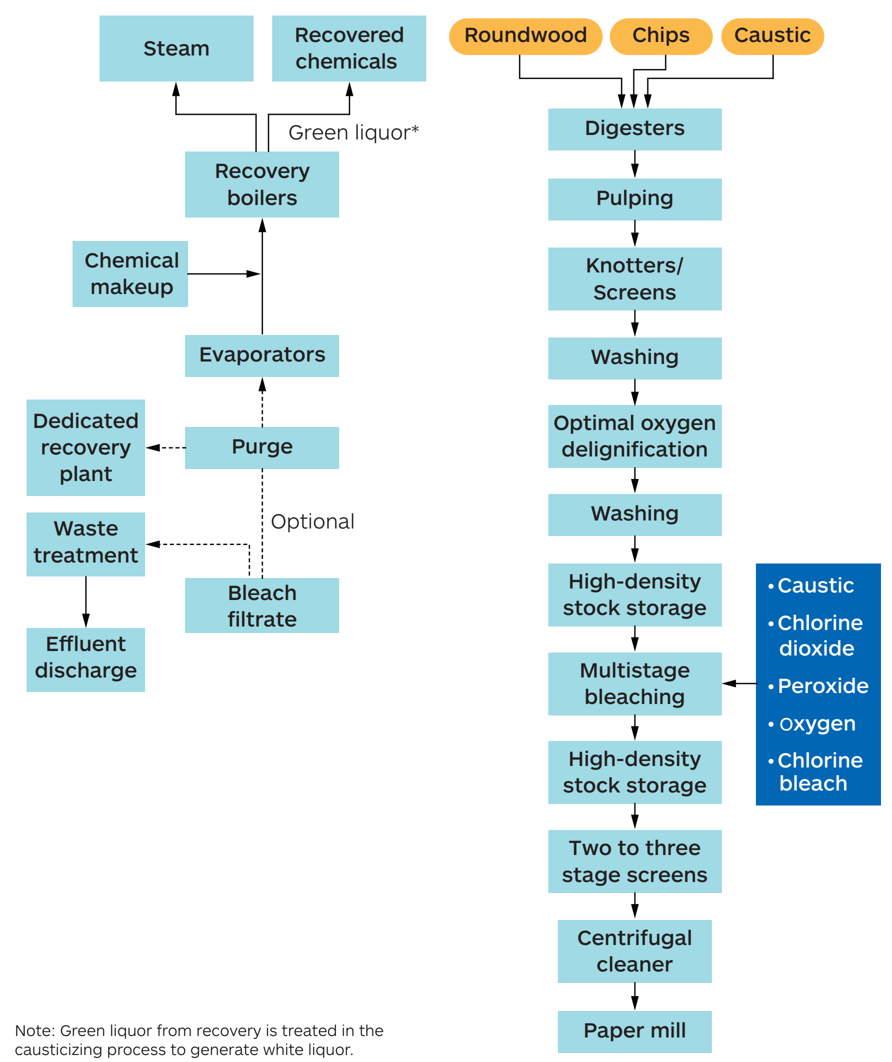
The production of higher quality products such as printing and writing papers requires that the pulps be bleached prior to the papermaking process. The bleaching process brightens the pulp by oxidizing and dissolving the residual lignins and other polymeric materials that were not removed in the pulping process. Bleaching is usually carried out in stages, with conditions in each stage controlled to maximize the brightness while minimizing the consumption of bleach as well as the degradation of the mechanical properties of the

1 “The Benefits of Chlorine Chemistry in Water Treatment,” IHS, January 2016.

2 “Profile of the Pulp and Paper Industry,” Second Edition, U.S. Environmental Protection Agency, Office of Compliance, 2002.

pulp. Historically, elemental chlorine was the bleaching agent of choice in almost all pulp mills. Plants that co-produce chlorine and sodium hydroxide by electrolyzing brine are sometimes located in the vicinity of pulp mills, which consume roughly the same amounts of each product that are produced. Most of the caustic was used in the digestion process, while the chlorine was used for bleaching.

Kraft pulping process



Note: Green liquor from recovery is treated in the causticizing process to generate white liquor.
Source: IHS

The use of elemental chlorine produced high quality bleached pulps, while removing some of the polymeric impurities by converting them into soluble, complex, 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 implemented: (1) oxygen-assisted delignification, with chlorine dioxide substituted for a portion of the elemental chlorine in the bleaching steps; (2) delignification with oxygen or ozone and bleaching with only chlorine dioxide; or (3) extended oxygen or oxygen-ozone delignification, with oxygen and hydrogen peroxide used for bleaching.

Where possible, existing mills seeking to reduce the discharge of AOXs would choose the first option, which is the lowest in cost and easiest to implement. 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 over 90% of the bleached chemical pulp worldwide is produced with ECF technology.[3] The better performing mills are capable of achieving discharge levels as low as 10% of the New Source Performance Standard limits, with greatly reduced biochemical oxygen demand, total suspended solids, 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, and some mills that have adopted this technology have found it possible to eliminate the use of chlorine dioxide as a bleaching agent for certain pulp grades that are produced in the mill on a campaign basis.[4]

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 existing mills that have been retrofitted from older technologies, but it is currently used to produce less than 5% of bleached pulps globally. Furthermore, there have been few capacity additions using TCF technologies in the past twenty 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 may not offer significant manufacturing cost advantages. While plant effluents are totally free of chlorinated compounds, they do contain a range of oxygenated compounds such as organic aldehydes, acids, ketones, and alcohols, albeit at low levels.[5] The first TCF mill in the US, Louisiana-Pacific (later Evergreen Pulp), began chlorine-free operations in 1993, but since its closure in 2010, the remaining TCF-produced pulp in North America is negligible.[6]

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 are sodium and calcium hypochlorites, whose consumption in the United States and Canada amounted to more than 700,000 metric tons of chlorine equivalent in 2014.[7] Around 90% of the lithium hypochlorite consumed annually in North America is used in swimming pool sanitation, while smaller quantities of potassium hypochlorite, chlorinated isocyanurates, and hydantoins are used in applications where their desirable properties justify their higher prices.[8]

Consumers are perhaps most familiar with these materials when they are consumed as household laundry bleaches, which usually contain either about 5.25 – 6% (regular strength) sodium hypochlorite or 8.25% (concentrated) sodium hypochlorite, or as sanitizers for municipal, YMCA/YMWA and backyard swimming pools, spas, and hot tubs. They are also used in other household products such as liquid automatic dishwater detergents, mold and mildew removers, bowl and drain cleaners, disinfectants, and disinfectant wipes and sprays.

Bleach producers also supply concentrated hypochlorite solutions that have found widespread use as disinfectants and hard surface cleaners in commercial laundries, municipal swimming pools, hospitals,

3 https://www.akzonobel.com/eka/services/pulp_bleach/ecf_tcf/

4 In a process industry such as pulp and paper, production is more efficient when resources can be dedicated to the entire manufacturing process for a certain period of time. This is often referred to as a campaign basis.

5 See EPA Office of Compliance Sector Notebook Project, "Profile of the Pulp and Paper Industry, 2nd Edition," U.S. Environmental Protection Agency, November 2002.

6 http://lostcoastoutpost.com/2014/feb/11/pulp-mill/

7 IHS, Chemical Economics Handbook, "Hypochlorite Bleaches," November 2015.

8 *Ibid.*

laboratories, restaurants, and food processing and preparation facilities. The more highly concentrated solution provides customers with the same disinfecting power of chlorine chemistry in a smaller container, reducing transport cost and packaging waste. In food processing and preparation facilities, hypochlorite solutions protect consumers from the "the farm-to-the fork," as chlorine-based disinfectants are used to prevent the transmission of bacteria all the way to home kitchens and restaurants. They are effective again bacteria, such as *E. coli, Salmonella, Listeria,* and *Staphylococcus*. In addition, these products can destroy such protozoa as *Cryptosporidum, Giardia,* and *Cyclospora* under suitable conditions.[9] Chlorine-containing disinfectants are effective in the destruction of most viruses and other hard-to-kill pathogens, like the hospital superbug *Clostridium difficile*, and have seen recent usage growth in response to outbreaks of Ebola, Severe Acute Respiratory Syndrome (SARS), avian influenza (bird flu), and influenza H1N1 (swine flu). In hospitals and laboratories, these disinfectants are used to destroy pathogens on work surfaces and in medical wastes. The US Centers for Disease Control and Prevention and the US Food and Drug Administration have published guidelines for their effective use in these environments.[10]

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. Additionally, industrial sodium hypochlorite solution is consumed in leather tanning processes and used at oil drilling sites for downhole disinfection. Calcium hypochlorite has applications in a number of industries, including agriculture, where it is used on seeds to control bacterial attack; aquaculture, where it can quickly sterilize ponds by oxidizing biological matter for removal; and even electronics manufacturing, where it is used to prepare components such as circuit boards for cleaning with very-high-purity water.[11]

In some applications, the major alternatives to hypochlorite-based bleaches, sanitizers, 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 compounds based on bromine and polyhexamethylene biguanide (PHMB). It should be noted that the most common process to produce bromine uses chlorine to extract the bromine from brines so brine-based pool sanitizers are not considered chlorine-free. PHMB, a non-halogen product that is incompatible with oxidizing agents like chlorinated isocyanurates and hypochlorites, has gained a small share of the North American market despite its higher costs. 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, including concentrated acids or bases such as acetic acid, caustic soda, or lime, and reactive chemicals such as glutaraldehyde, can be used to sanitize surfaces and destroy pathogens. Consumer interest in "greener" sanitizers and disinfectants has prompted some companies to formulate products with "chlorine-free" active ingredients such as L-lactic acid, hydrogen peroxide and citric acid. 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 costlier chemical agents or more intensive labor inputs to obtain equivalent disinfection performance, or both.

9 "Safer Salads," J. Fonseca and S. Ravishankar, *American Scientist*, 95, No 6, 494 (2007).

10 "Preventing Healthcare Associated Infections: The Role of Chlorine Products in Risk Reduction," B. Soule, *Water Quality and Health, 2006*.

11 IHS, Chemical Economics Handbook, *op. cit.*

The benefits of chlorine chemistry in bleaches and disinfectants

Consumers benefit from chlorine chemistry in 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 applications, but many consumers still prefer chlorine-based products where they are available. The extent to which consumers benefit from access to chlorine-based 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.

Economic benefits of bleaching and disinfection, 2014

Application	Additional capital expenditure ($MM)	Substitution cost ($MM per year)
Pulp bleaching	1,700	320
Sanitization and disinfection applications	2,600	5,140
Total	**4,300**	**5,460**

Source: IHS © 2016 ACC

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 to maintain production of about 18 million tons of bleached pulps. For the most part, this would require retrofitting new technology into mills that had been retrofit with ECF technology within the last twenty years. Some mills might elect to undertake other investments at the same time to also 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 based on TCF technology, but only the incremental costs of a TCF mill versus an ECF mill is relevant to this analysis.[12] 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 $1.7 billion, as shown in the table below. 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 $320 million per year.

Consumption of sodium and calcium hypochlorites for disinfection purposes is relatively small, amounting to less than 10% of chlorine equivalent. Despite the modest volumes, the public health 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 the health care industry. Quite simply, they are inexpensive, easy to apply, and very effective in destroying pathogens that, if left unchecked, could quickly infect many people at and beyond the initial points of infection. While substitutes are available, they either involve the application of other chemicals or the use of more elaborate equipment or processes to obtain the same results.

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 isocyanurates and hydantoins, would have to be substituted with higher cost materials such as PHMB, or by much more elaborate disinfection systems such as ones based on the generation of dissolved ionic silver. Approximately 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 over 20% of the market share, but consumers would be required to use higher temperature wash cycles to obtain equivalent performance from these costlier 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 required to construct new capacity to meet the increased demand. We estimate that investments

12 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.

of more than $2.6 billion would be required to supply the substitutes for sanitization and disinfection applications, and that they would cost consumers an additional nearly $5.5 billion per year to use them.

In summary, we estimate that the total economic benefit of chlorine chemistry to consumers in the US and Canada of their access to bleaches and disinfectants is roughly $5.5 billion per year. The economic benefit for consumers in the US amounts to $5.2 billion and for Canadian consumers $0.3 billion. Furthermore, the continued availability of chlorine-containing products eliminates the need to commit $4.3 billion in capital to produce the substitutes. The avoided capital spending in the US amounts to $3.3 billion and in Canada to $1.0 billion.

Chlorine: An effective disinfectant for Ebola

In 2014, the deadliest outbreak of the Ebola virus on record sparked fears that the killer virus could spread from West Africa to other regions and continents. The outbreak began when a 2-year-old boy in the town of Gueckedou, Guinea came down with an unidentified form of the disease. As virus spread to other countries in West Africa, including Sierra Leone, Liberia, and Nigeria, its death toll rose rapidly and included many health care workers.

The World Health Organization (WHO) called for drastic action to contain the disease, warning that previously undetected chains of transmission could boost the numbers of the sick and increase the chances that the disease would spread from Africa to other regions of the world. “This epidemic is without precedent,” said Bart Janssens, director of operations for Médecins Sans Frontières, also known as Doctors Without Borders. “It’s absolutely not under control, and the situation keeps worsening...There are many places where people are infected but we don’t know about it.” Because it takes between 2 and 21 days before Ebola symptoms are evident, there is little that health officials can do to stop an asymptomatic person from flying to another country, hastening the spread of the epidemic.

In Liberia, all schools were closed, flights were cancelled, and the President closed most of the country’s borders with its neighbors. Similar steps were taken in Sierra Leone. The US announced that it was removing its 340 Peace Corps volunteers from Liberia, Sierra Leone, and Guinea due to the outbreak. The epidemic caused at least 11,000 deaths in West Africa, though the WHO believes that this count substantially understates the magnitude of the outbreak due to the challenges of collecting accurate data. The average Ebola survival rate is about 50%, but it can vary greatly, in part because of the different medical resources available to treat different patients. In past outbreaks, all of which have been in Africa, fatality rates ranged from 25% to 90%.

Chlorine and chlorine-based compounds are the weapon of choice in stopping this deadly epidemic. According to the WHO, “The Ebola virus can be eliminated relatively easily from surfaces using heat, alcohol-based products, and sodium hypochlorite (bleach) or calcium hypochlorite (bleaching powder) at appropriate concentrations.” Because the Ebola virus can live on inanimate surfaces, especially those that are soiled with blood or other body fluids from infected people, chlorine solutions and compounds are valuable disinfectants because they inactivate the virus. Additionally, they are fast-acting, very effective, inexpensive, and readily available. Chlorine is the disinfectant and decontaminant recommended for use in most hospitals, where it is used to decontaminate soiled surgical instruments, gloves and other items, as well as large surfaces like examination tables.

Even outside of medical centers, the benefits of chlorine solutions in combating the spread of Ebola were widely understood. As Deborah Lindholm, the founder of a group devoted to collecting donations of bleach for the region, observed in 2014, “There are buckets of bleach all over the streets in Liberia, and the people in Liberia and in the surrounding areas that have been affected by Ebola understand that if they keep their hands clean they can kill off the virus.”

Sources: http://www.waterandhealth.org/chlorine-bleach-trusted-ally-battle-ebola/#sthash.4RxcSlum.dpuf; http://www.cnn.com/2014/03/27/world/ebola-virus-explainer/; http://www.bbc.com/news/world-africa-28755033