Questioning the Impact of Triclosan on our Future

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Gabriel Lawrence

Spring, 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Bryn E. Seabrook, Department of Engineering and Society

Introduction:

This STS research paper looks at the use of Triclosan and its first- and second-order effects and intended and unintended consequences as a sociotechnical system using actor-network theory.

What are the sociotechnical impacts of Triclosan as an actor in the environmental network?

Since the 1870s, in western societies, the treatment and avoidance of disease defines the world of medicine. One way of preventing disease is through the disinfection of surfaces. (*Antibiotic Resistance*, n.d.; Fisher et al., 2022) When doctors, patients, and cleaning staff overuse antiseptics and other disinfection agents, they lose their ability to protect because the harmful microorganisms that survive and thrive are those that are resistant to the treatments designed to prevent their spread. (*CDC's Core Infection Prevention and Control Practices for Safe Healthcare Delivery in All Settings | Infection Control | CDC*, 2022)

"Should antimicrobial products be used to fight infection, when doing so sacrifices the future for the present?" After the COVID-19 pandemic, this question has become more prominent. Institutions are using methods that sacrifice future effectiveness to fight a present threat, and the overuse of disinfecting products is threatening the future's health and safety. Will the evolution of disease uproot our world again? (Tauanov et al., 2023)

Numerous stakeholders, including regulators, consumers, doctors, environmental activists, and medical organizations, continue to shape the discussion over Triclosan. These groups have roles and obligations that shape their viewpoints, objectives, and connections. One example of these relationships is between consumers and the Food and Drug Administration (FDA). To the consumer, Triclosan prevented infection with few apparent downsides. However, according to the FDA, Triclosan causes antibiotic resistance while disrupting human hormonal development.(Commissioner, 2020a; *Synergistic and Antagonistic Interactions of Triclosan with Various Antibiotics in Bacteria: Journal of Environmental Science and Health, Part C: Vol 38, No 3*, n.d.; C.-F. Wang & Tian, 2015) Using the language of Actor-Network theory, this constructive behavior shows that Triclosan is a Quasi-Object with complexity that stimulates interactions that are the basis of conflict between distinct groups.

Triclosan is ubiquitous in medicine and consumer products to kill germs on or in people, surfaces, mouthwash, toothpaste, and food storage. An example of triclosan's usage comes from a study named: "Guidelines for the control and prevention of methicillin-resistant Staphylococcus aureus (MRSA) in healthcare facilities," which recommended the usage of triclosan as a method of reducing the inappropriate or unnecessary use of antibiotics as a method of removing antibiotic resistant bacteria from patients.[1] Additional example of how ubiquitous triclosan is in western societies is the CDC's urine samples for Triclosan, which they determined that "Triclosan was in the urine of almost 75% of the people tested."[2]

However, as the world begins to assess the effects of triclosan, its relationship with Triclosan is evolving. People are now considering the potential long-term effects of its extensive use. In the United States, an example of this shifting relationship is the banning of Triclosan from over-the-counter antibacterial soap, as the FDA declared that antibacterial soap with triclosan had no benefit over regular soap. (Commissioner, 2020a) Some of these long-term effects are antibiotic resistance, hormone disruption, environmental toxicity, and other unknown long-term effects. [3]

---

[1] (Guidelines for the Control and Prevention of Methicillin-Resistant Staphylococcus Aureus (MRSA) in Healthcare Facilities - ScienceDirect, n.d.)
[2] (Triclosan Factsheet | National Biomonitoring Program | CDC, 2021)
[3] (Government of Canada, 2016; Olaniyan et al., 2016; Yueh & Tukey, 2016)

Another factor in triclosan's impact on the world is that it is a persistent pollutant, which means that it does not break down to harmless products in the environment, instead it turns into a variety of different, harmful byproducts through solar radiation and influencing ecosystems negatively. (Yueh & Tukey, 2016a) According to Yueh and Tukey, when Triclosan breaks down it generates PCDDs which "Notably, PCDDs are generally highly persistent in the environment, and some are associated with carcinogenic activities." Another direct impact of triclosan on the environment is that it is a hormone disruptor, which according to Wang and Tian presents as "it [triclosan] is very likely to be harmful to humans, which urges further studies on its adverse effects on human, especially on vulnerable populations." (Wang & Tian, 2015)

This Paper's Method for Analysis

What are the sociotechnical impacts of Triclosan as an actor in the environmental network?

This research paper demonstrates the effects and impacts of Triclosan using the following methodology and in-order outline: an literature-informed comparison between Triclosan and its alternatives, a literature review of the environmental effects of Triclosan, a case study analyzing Triclosan's effects on environmental and human health, a policy analysis of North American and European Union regulatory responses to the threat of Triclosan, a discussion of limitations of this research, and then final conclusions based on this paper's findings. The literature review used the following key words: triclosan degradation, 2,8-Dichlorodibenzo-p-dioxin, photochemical conversion, antibiotic resistance, bioaccumulation, environmental risk assessment, and byproducts of Triclosan.

This Paper in the Socio-Technical Literary Environment

This paper fits in the subfield of environmental studies in science and technology studies (STS), as it discusses the intersection of science, technology, and society and the natural environment. As such, the proper framework is one that corresponds to the dynamic, ever shifting environment of both human and non-human actors in an interconnected system. One such framework is the Actor-Network theory.

Actor-Network theory (ANT) is a sociological perspective that views social interactions as a network of actors or entities that interconnect and have agency. According to ANT, human (actors) and non-human actors (actants), such as technology and institutions, are equal participants in shaping social order (network). (Latour, 2007) This paper's definition of ANT is based on Latour's discussion of ANT in reassembling the social, and the literature review builds on this foundation.

Literature Review of the Environment and Actor Network Theory

This paper's literature review found no papers directly related to STS studies and triclosan, thus, this paper will discuss this STS framework section using Latour's definitions, and a paper that is loosely related to triclosan, Swatiprava Rath and et al's "Exploring the Reality of Waste." (Rath & Swain, 2022) In Rath's paper, he identifies the actors as: "social actors such as scientists, industrialists, politicians, journalists and environmental activists" who socially construct the issue of waste as an environmental issue, while supplementing ANT with political ecology, which the paper never gives a formal definition. Unlike our paper, Rath takes the approach that the actors are the main source of activity and interactions in the network, which is at odds with Latour's and by extension, this paper's definition of Actor-Network theory, as it uses Law's definition mixed with Latour's, which compete over the role of actants in the system.

However, this paper and Rath both agree on the role of transformation in defining meaning for systems and actants, as both papers have the same source for that aspect of Actor-Network theory.

This paper uses a more limited set of Law's definitions and tools for Actor-Network theory as Law defines ANT as a "material-semiotic" method that maps the relations between things and concepts and assumes that nothing exists outside those relations in "Notes on the Theory of the Actor-Network: Ordering, Strategy and Heterogeneity." And this paper only uses his concepts of translation and transformation while relying on Latour more than Law. (Law, 1992)

Applying Actor-Network Theory to Triclosan

According to Latour, one of these tools for examining group dynamics is the concept of translation. Translation refers to how actants and actors interact to form meaning. An actant furthers to an object that acts within a network. An actor is a person or institution that influences the use or perception of an actant. (Latour, 2007)

Another element of ANT according to Latour is reflexivity. Reflexivity refers to circular relationships between cause and effect. In Triclosan's case, society's negative consequences from Triclosan result from reflexivity. An example of reflexivity is that when society uses Triclosan more, it becomes less effective at removing pathogens. This loss of effectiveness makes consumers need more Triclosan for the same protection. And this long-term loss of effectiveness worsens its long-term penalties at the cost of short-term gain. Using ANT allows the paper to pursue the second-order consequences of this event. For example, the opportunity cost of focusing on Triclosan over developing new antimicrobials.

Latour argues that ANT enables the analysis of group dynamics in unstable conditions. Triclosan is both a "chemical" and a "cleaning agent," causing instability in its meaning. In Western popular culture, chemicals have the perception of being harmful or scary, despite often having little evidence to support that claim. In contrast, cleaning chemicals, such as Triclosan, are for cleaning in the same culture which often have harmful effects, but customers, because of the cleaning products' main effect of decontamination, praise cleaning agents for their effects on the constructed environment. And Triclosan, like other cleaning agents, has a purpose of making the environment clean, an aspiration in Western cultures. Thus, Triclosan is the path for "cleanliness is next to godliness" and a diabolic entity in the same mind. (Rollini et al., 2022) Therefore, ANT furthers the understanding of Triclosan, and its relationship to traditional closure.

Results and Discussion:

Triclosan is an actor that exhibits long-term toxicity while promoting short-term health.

Triclosan has constructed a network based on its unique traits of low price, effectiveness at antimicrobial action, and non-existent acute toxicity in humans. These factors make an attractive chemical for producers/manufacturers to avoid and reduce liabilities for bacterial contamination and the long-term consequences of Triclosan, as it is difficult to legally prove beyond a reasonable doubt that a single chemical was a direct cause of cancer or another harm. Triclosan's properties make it valuable in preventing infections immediately with few quickly observable side effects and that Triclosan had a low complexity of administration, addressed the needs of the medical community for an antiseptic. Additionally, doctors appear to have deprioritized the long-term effects of Triclosan, not out of malice for the environment or their patients, but Triclosan's negative influence on health and the environment is subtle and complex.

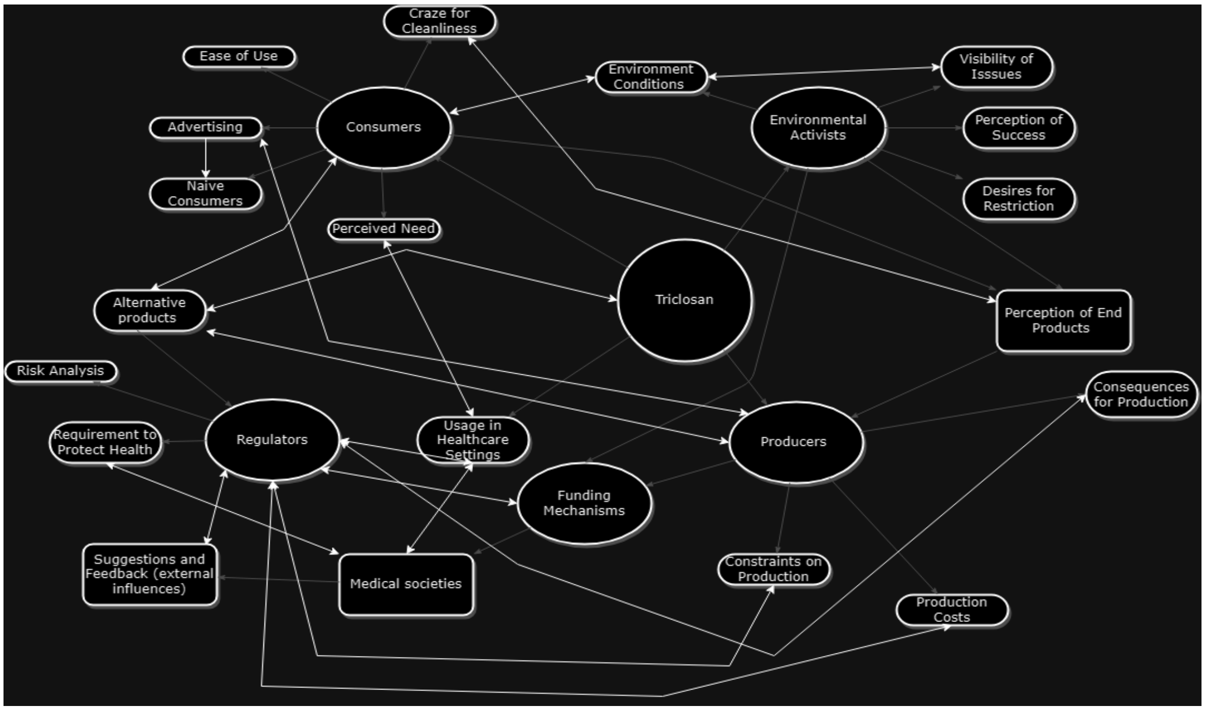

Figure 1: Overview of the Actor-Network Model of Triclosan

Through these factors, Triclosan exhibits the following traits: translation, reflexivity, interpretive flexibility, and lack of closure, which makes the research question answerable using actor-network theory. Using the lens of actor-network theory, Triclosan rose as an actant during the craze for cleanliness in the 1970s in medical and consumer fields as it solved a perceived problem of dirtiness. (News ·, 2019) After it gained prominence in products from toothpaste to athletic clothing, Triclosan began to interact with environmental activists such as the Sierra Club, which pushed for regulation, invoking another actant, the regulatory agencies in the United States, which led to further study and questioning the risk-benefit balance of Triclosan in its ubiquitous role. (*Regulations.Gov*, n.d.) These interactions built the environmental-political-sociotechnical system Triclosan acts upon (figure 1, Overview) and explains the impacts discussed earlier.

What is Unique about Triclosan?

In this section, this paper compares Triclosan over other chemicals of similar effectiveness against a broad-spectrum of biological threats: benzalkonium chloride, chloroxylenol, and chlorhexidine. The rationale for this comparison aims to expand on Actor-Network Theory's idea of translation, aiming to help examine Triclosan's role in the environmental network. Moreover, another reason for this analysis is to determine Triclosan's replaceability. A method of determining replaceability is a comparison of a Quasi-Object with its alternatives. If a Quasi-Object, like Triclosan, has replaceability, it limits its influence and power. Through the lens of translation, this analysis demonstrates how Triclosan, and its sociopolitical impacts are unique among antimicrobial agents. And the comparison helps to explain the context of the research on Triclosan, such as the papers in the literature review.

The chart in Figure 2 (below) compares Triclosan with its replacement antiseptics and preservatives and how they differentiate themselves from Triclosan in Environmental Persistence, Price, Environmental Toxicity, Human Health, and Antibiotic resistance.

Lower is better in Ranking	Triclosan	Benzalkonium Chloride	Chloroxylenol	Chlorhexidine
Bio-persistence	[4] – Known Persistent, Resistant chemical, readily accumulates in sediments and living things.	[3] – Low if any biodegradability; bioaccumulation and persistence is an element of its toxicity.	[1] – (Specifically: Fuschman, 2022) indicates that there is no evidence for bio-persistence for Chloroxylenol.	[2] – Bioaccumulation exists in Diatoms and persists throughout the food chain with minimal change to the chemical.
Environmental Toxicity	[4] – Dosages in water greater than 0.47 nanograms/L causes extensive toxicity.	[3] - Comparable to Triclosan in C. *elegans*, and low-dosage [45 nanograms/l] for plants in chronic levels.	[1] - Low Toxicity in the Environment [lowest acute toxicity is 1,000 nanograms/l], no chronic toxicity	**[2!]** -Limited information about its environmental impact, despite its extensive usage in Europe and North America.
Post-Degradation (via UVA/UVB)	[4] – When Triclosan Degrades, it becomes a dioxin, one of the most dangerous categories of	[3] – Primary degradation product is Chloroform, a chemical with limited bio-persistence, but	[1]- Becomes a Nitrogen source after degradation, which if in copious quantities causes eutrophication, destroying	[2]- When exposed to considerable amounts of UV Light, Heat and Shaking, tiny amounts of p-chloroaniline (a

	persistent organic chemicals.	linked with increase rates of cancer. (EPA Extremely Hazardous Substance)	waterways indirectly.	chemical that is very environmentally toxic) generated from Chlorhexidine, otherwise Chlorhexidine is stable.
Chronic Human Health Effects	[4] – Strong Evidence of Causing Birth Defects, Thyroid Issues, and Cancer.	[1] – Toxicity limited to Corneal effects in placed in Eyeball at large doses.	[3] – Genotoxicity shows in four of the studies in the references below, along with support for Neurotoxicity and development harm.	[2] - Extremely low level of tissue toxicity, liver damage if ingested in copious amounts.
Cost per Kilogram [Average Prices on Alibaba, 2023-2024]	[2] $1.00 for extra-large orders (10,000 kg), $12.00 for small orders (1 kg)	[3] - $5.00 kg for large orders (2,000 kg), and $15.00 for small orders	[4] - $8.00 per kilogram, available large orders only	[1] $5.00 kg for small and large orders/stable pricing
Antibiotic Resistance	[3] – Contradictory Evidence, and Bacteria	[4] - Moderate Evidence of cross-resistance in	[2] Unknown – Mixed Results, cross-resistance not	[1] – Limited Resistance in specific bacterial

	Dependent	general	discussed in literature.	species, mostly to itself.
Acute Human Health Effects	[1] Little to no observed acute human health effects.	[2] – Same as chronic health impacts.	[2] – Severe irritation of the skin, eyes, and nose, along with sensitization.	[3] – In extremely extreme amounts, causes liver damage and failure.

Figure 2: Summary-Ranking Table of Triclosan and its Possible Replacements

The rationale for these categories is one, the studies found in the literature review for the construction of this chart focused on these traits when comparing antiseptics, and two, these categories relate to how Triclosan acts in the environmental system in constructed and natural environments. [4]

As Figure 2 shows, there is no best answer for what to replace Triclosan with, as each replacement interacts with the environmental network in different ways; some substitutes appear to have less of an ecological impact, and the lack of research into their interactions makes it problematic to determine if they would be an improvement or Triclosan. Additionally, each of these choices for Triclosan's substitutes in the health care and consumer settings comes with unique drawbacks, either cost in industrial quantities or a lack of research for two reasons: lack of interest in switching from Triclosan because the opportunity cost of validating replacement chemicals as safer than Triclosan is prohibitive, and the extensive contamination of the

[4] (Fuchsman et al., 2022; Huang et al., 2017; Lear et al., 2006; Moazeni et al., 2023; Pereira-Maróstica et al., 2023; Rundle et al., 2019; Sreevidya et al., 2018; Sun et al., 2019; Tan et al., 2021; Wang et al., 2023; Yu et al., 2021; Zhang et al., 2022)

environment with Triclosan makes it problematic to determine a valid comparison between a novel chemical and Triclosan.

Triclosan's environmental impacts primarily come from its degradation into 2,8-Dichlorodibenzo-p-dioxin, a persistent organic pollutant that tends to cause developmental issues in fish and wildlife through its genotoxic effects leading to increases in cancers, local destruction of keystone species and food chains, while being bio-accumulative and immune to further degradation in the environment. (Olaniyan et al., 2016) Additionally, Triclosan and its by-products tend to accumulate in diatoms and other plant species either leading to their direct demise (reducing the number of primary producers in the ecosystem), reduced growth and function (leading to the ecosystem becoming unbalanced), or the transmission of Triclosan from the plants through the food chain causing the same effects in animals. (Yueh & Tukey, 2016b) And because Triclosan and its 2,8-Dichlorodibenzo-p-dioxin does not become inert in the environment, this cycle continues indefinitely until the environment collapses or until humans remove Triclosan from the environment, which is expensive and destructive. Therefore, Triclosan serves as a signifier of humanity's power over the environment and the responsibilities that humanity has in solving environmental issues, or the issues will start to affect our constructed environment.

What does Triclosan do in Humans?

One of the strange facts about Triclosan as discussed in Part I is that "Triclosan was in the urine of almost 75% of the people tested," in a study of Americans by the CDC.(*Triclosan Factsheet | National Biomonitoring Program | CDC*, 2021) And this fact extended to every part of the body, from breast milk to blood, with some studies in China, Australia and other regions showing presence of Triclosan (TCS) in 96% of the blood samples, showing that Triclosan is extensively present in humans, despite what populations they test. Triclosan appears to have a variety of different biological impacts on human populations, some of which are: cancer, autoimmune diseases, developmental abnormalities, and thyroid issues.(Government of Canada, 2016; Jones et al., 2000; Prichystalova et al., 2017; Yueh & Tukey, 2016b) From the part 1 of this paper: According to Yueh and Tukey, when Triclosan breaks down it generates PCDDs which "Notably, PCDDs are generally highly persistent in the environment, and some are associated with carcinogenic activities." As this paper established the introduction, through Wang and Tian's study, Triclosan is a hormone disruptor of the endocrine system and the reproductive system of humans, animals, and plants exerting a variety of effects from inappropriate feminization and masculinization to cardiovascular failure. Using these quotes, Triclosan is a clear and apparent threat to human health, and the variety of biological impacts of Triclosan should be a cause to regulate it or even prohibit it generally, as on a population scale, the Yueh's and Wang's studies show that the increase in cancer rates throughout the Western World is linked to an evaluated exposure to Triclosan. Thus, Triclosan has a myriad of negative effects that researchers are finding out more about daily.

Considering these effects, this context prompts the question "why do consumers still use Triclosan?" Generally, consumers do not get a choice in what chemicals products use, either they lack sufficient knowledge to make an informed choice, or they do not have enough power to change corporate policy, as that is primarily decided using profit and risk rather than consumer demands.(Hartmann & Klaschka, 2017; Rollini et al., 2022) Additionally, Triclosan appears to be still effective against infectious diseases of fungal and bacterial origin, which is one of the reasons for its continuous usage in industrialized countries, as avoiding illness through doing something is felt to be easier than improving conditions to avoid the need for action. Additionally, the regulatory response to Triclosan, at least in the United States has only confused consumers, as they instruct them to check the products for Triclosan while the FDA states that they banned it in specific applications, which gives the illusion of safety while providing none. Therefore, the reason for the continuous popularity of Triclosan is not that people actively enjoy eating, wearing, and drinking something that lined with cancer or thyroid issues, it is that switching away from Triclosan would cause short-term discomfort with subtle long-term benefits, which is not particularly enthralling to the western public.

How have governments reacted to Triclosan's consequences?

Finally, this policy analysis looks at regulations made by authorities in the United States and European Union. It also considers the feedback from the public, industry, and environmental activist groups. This paper will focus on specific policies and responses related to Triclosan. And this demonstrates Triclosan's interpretive flexibility and lack of closure. These include the FDA's rule on the Safety and Effectiveness of Consumer Antiseptics (2017) with comments from various organizations, and the European Union's Assessment Report for Triclosan.[5]

The FDA's rule is often represented as a "ban" on Triclosan, despite that being an inaccurate description of the policy's effects, as the FDA rule focused on removing Triclosan from hand soaps and sanitizers, as the FDA considered those sources as the most common exposures, which based on the CDC study from 2021, the FDA's rule did not impact the contamination of Triclosan in the environment. The reasons for the FDA's rule are the following: one, there was pressure from Environmental Groups to regulate or do something about Triclosan,

---

[5] (Commissioner, 2020a, 2020b; *Regulations.Gov*, n.d.; *Safety and Effectiveness of Consumer Antiseptics; Topical Antimicrobial Drug Products for Over-the-Counter Human Use*, 2016)

and two, the manufacturers and implementors of Triclosan did not desire additional regulation, as seen by their objections to the original rule on Triclosan at Regulations.gov. This conflict over Triclosan's value shows the conflict that Triclosan creates through its interpretive flexibility, and the weakness of the FDA's approach to Triclosan, as their solution based on the conflicting group's average did not resolve the problems with Triclosan nor satisfy the manufacturers. Additionally, there is little evidence to suggest that there is additional research into alternatives, as Triclosan is still readily available and used without plans for a major phase out of Triclosan. Thus, the American response to Triclosan's threat was a half-measure that only led to dissatisfaction while not stopping the spread and impacts on Triclosan on human and environmental health.

In comparison, the European Union response to Triclosan is well-defined, as the European Union regulates Triclosan as a biocide rather than with limited restrictions for its usage. For the European Union, a biocide is a chemical that acts against biological agents, while Biocides regulation 528 restricts the usage of biocides to reduce their environmental and health risks while maintaining the unrestricted transportation and restricted usage of these chemicals. In fact, most of the studies that this paper examined were funded through the European Union or through organizations (environmental groups and companies) that contributed to the restrictions of Triclosan in the European Union.(Team, n.d.) However, the European Union has also been slow to act against Triclosan, as it only has a "partial ban" on Triclosan, because industry still demands a transition period away from it, as discussed in Beauty Forum, a beauty industry marketing magazine, as they also argue that the partial ban does not prevent the exposure of people from Triclosan, and also discuss the fact that there is No-Observed-Adverse-Effect-Level

(NOAEL), and claims that "This is why a final threshold value has not yet been established."[6] Thus, despite the progress that the European Regulators made in reducing the harms of Triclosan, they too have been unable to stop the widespread exposure to Triclosan in the environment and in humans, and this is a problem that will only get worse with time.

Unanswered Questions and Missing Data

Further research on possible or current replacements for Triclosan is necessary to understand why Triclosan is not fully replaceable due to a severe lack of studies and evidence in this area. Additionally, a historical sociopolitical analysis of why industrialized societies selected Triclosan as the primary antiseptic for over 50 years would be beneficial. Furthermore, more case studies on the effects of Triclosan on the environment would benefit the research area, as literature currently lacks narratives in this specific field of inquiry. The rationale for this suggestion is that this research paper, despite its attempts to do otherwise, has limitations in its recommendations and comparisons for replacing Triclosan. Another limitation is that Triclosan's consequences are still vague with contradictions and a baseline error from its ubiquity, limiting our ability to see the full extent of Triclosan's damage to the environment.

The Legacy of Triclosan:

Manufacturers and Customers still use Triclosan in a wide variety of medicine and consumer products to kill germs on people, surfaces, and food storage. However, Triclosan is destroying environments while negatively affecting human health through the mechanisms that made it valuable in the first place. Triclosan represents the value that Western societies (through their usage and approach toward Triclosan) place on convenience over the long-term consequences of technology. It does so because despite Triclosan's devasting impacts on

---

[6] (*Triclosan - Partial Ban, Widely Used - Ingredients*, n.d.).

environmental health - Triclosan is still ubiquitous globally. Our findings indicate that Triclosan, as an actor in the network, needs replacement with more modern and safer alternatives, as Triclosan does not and cannot provide more benefits than its costs. Moreover, Triclosan is the actor in a network of dysfunction enforced and constructed through institutional inertia rather than practicability, merit, or a lack of alternatives. Thus, Triclosan endures as an essential part of healthcare systems, clothing, and toothpaste not because it is better than the other options, it is that it is good enough for the short-term despite its long-term consequences being broad and destructive.

References

Antibiotic resistance. (n.d.). Retrieved October 10, 2023, from https://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance.

CDC's Core Infection Prevention and Control Practices for Safe Healthcare Delivery in All Settings | Infection Control | CDC. (2022, November 29). https://www.cdc.gov/infectioncontrol/guidelines/core-practices/index.html

Commissioner, O. of the. (2020a). Antibacterial Soap? You Can Skip It, Use Plain Soap and Water. *FDA*. https://www.fda.gov/consumers/consumer-updates/antibacterial-soap-you-can-skip-it-use-plain-soap-and-water

Commissioner, O. of the. (2020b, March 24). *FDA issues final rule on safety and effectiveness of antibacterial soaps*. FDA; FDA. https://www.fda.gov/news-events/press-announcements/fda-issues-final-rule-safety-and-effectiveness-antibacterial-soaps

Fisher, M. C., Alastruey-Izquierdo, A., Berman, J., Bicanic, T., Bignell, E. M., Bowyer, P., Bromley, M., Brüggemann, R., Garber, G., Cornely, O. A., Gurr, S. J., Harrison, T. S., Kuijper, E., Rhodes, J., Sheppard, D. C., Warris, A., White, P. L., Xu, J., Zwaan, B., & Verweij, P. E. (2022). Tackling the emerging threat of antifungal resistance to human health. *Nature Reviews Microbiology*, *20*(9), Article 9. https://doi.org/10.1038/s41579-022-00720-1

Fuchsman, P., Fetters, K., O'Connor, A., Bock, M., Henning, M., Brown, L., Mrdjen, I., & Stanton, K. (2022). Ecological Risk Analysis for Benzalkonium Chloride, Benzethonium Chloride, and Chloroxylenol in US Disinfecting and Sanitizing Products. *Environmental Toxicology and Chemistry*, *41*(12), 3095–3115. https://doi.org/10.1002/etc.5484

Government of Canada, E. and C. C. C. (2016, August 9). *Environment and Climate Change Canada—Risk Management Approach for Phenol, 5-chloro-2-(2,4-dichlorophenoxy)—Triclosan*. https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=371A2F3C-1

Hartmann, S., & Klaschka, U. (2017). Interested in consumers' awareness of harmful chemicals in everyday products. *Environmental Sciences Europe*, *29*(1), 29. https://doi.org/10.1186/s12302-017-0127-8

Huang, N., Wang, T., Wang, W.-L., Wu, Q.-Y., Li, A., & Hu, H.-Y. (2017). UV/chlorine as an advanced oxidation process for the degradation of benzalkonium chloride: Synergistic effect, transformation products and toxicity evaluation. *Water Research*, *114*, 246–253. https://doi.org/10.1016/j.watres.2017.02.015

Jones, R. D., Jampani, H. B., Newman, J. L., & Lee, A. S. (2000). Triclosan: A review of effectiveness and safety in health care settings. *American Journal of Infection Control*, *28*(2), 184–196. https://doi.org/10.1067/mic.2000.102378

Latour, B. (2007). *Reassembling Social: An Introduction to Actor-Network-Theory* (First Edition). Oxford University Press.

Law, J. (1992). Notes on the theory of the actor-network: Ordering, strategy, and heterogeneity. *Systems Practice*, *5*(4), 379–393. https://doi.org/10.1007/BF01059830

Lear, J. C., Maillard, J.-Y., Dettmar, P. W., Goddard, P. A., & Russell, A. D. (2006). Chloroxylenol- and triclosan-tolerant bacteria from industrial sources—Susceptibility to antibiotics and other biocides. *International Biodeterioration & Biodegradation*, *57*(1), 51–56. https://doi.org/10.1016/j.ibiod.2005.11.002

Moazeni, M., Ebrahimpour, K., Mohammadi, F., Heidari, Z., & Ebrahimi, A. (2023). Human health risk assessment of Triclosan in water: Spatial analysis of a drinking water system.

Environmental Monitoring and Assessment, *195*(10), 1171. https://doi.org/10.1007/s10661-023-11789-3

News ·, K. C. C. (2019, April 20). *What happened to triclosan? A lingering legacy of the hyper-hygiene era | CBC News*. CBC. https://www.cbc.ca/news/health/triclosan-hand-sanitizer-antibacterial-health-canada-fda-toxic-environment-1.5104614

Pereira-Maróstica, H. V., Ames-Sibin, A. P., Pateis, V. de O., de Souza, G. H., Silva, B. P., Bracht, L., Comar, J. F., Peralta, R. M., Bracht, A., & Sá-Nakanishi, A. B. (2023). Harmful effects of chlorhexidine on hepatic metabolism. *Environmental Toxicology and Pharmacology*, *102*, 104217. https://doi.org/10.1016/j.etap.2023.104217

Prichystalova, R., Fini, J.-B., Trasande, L., Bellanger, M., Demeneix, B., & Maxim, L. (2017). Comparison of methods for calculating the health costs of endocrine disrupters: A case study on triclosan. *Environmental Health*, *16*(1), 55. https://doi.org/10.1186/s12940-017-0265-x

Rath, S., & Swain, P. K. (2022). The Interface between Political Ecology and Actor–Network Theory: Exploring the Reality of Waste. *Review of Development and Change*, *27*(2), 264–278. https://doi.org/10.1177/09722661221122553

Regulations.gov. (n.d.). Retrieved October 6, 2023, from https://www.regulations.gov/comment/FDA-2015-N-0101-1279.

Rollini, R., Falciola, L., & Tortorella, S. (2022). Chemophobia: A systematic review. *Tetrahedron*, *113*, 132758. https://doi.org/10.1016/j.tet.2022.132758

Rundle, C. W., Hu, S., Presley, C. L., & Dunnick, C. A. (2019). Triclosen and Its Alternatives in Antibacterial Soaps. *Dermatitis: Contact, Atopic, Occupational, Drug*, *30*(6), 352–357. https://doi.org/10.1097/DER.0000000000000519

Safety and Effectiveness of Consumer Antiseptics; Topical Antimicrobial Drug Products for Over-the-Counter Human Use. (2016, September 6). Federal Register. https://www.federalregister.gov/documents/2016/09/06/2016-21337/safety-and-effectiveness-of-consumer-antiseptics-topical-antimicrobial-drug-products-for

Sreevidya, V. S., Lenz, K. A., Svoboda, K. R., & Ma, H. (2018). Benzalkonium chloride, benzethonium chloride, and chloroxylenol—Three replacement antimicrobials are more toxic than triclosan and triclocarban in two model organisms. *Environmental Pollution*, *235*, 814–824. https://doi.org/10.1016/j.envpol.2017.12.108

Synergistic and antagonistic interactions of triclosan with various antibiotics in bacteria: Journal of Environmental Science and Health, Part C: Vol 38, No 3. (n.d.). Retrieved October 3, 2023, from https://www.tandfonline.com/doi/abs/10.1080/26896583.2020.1781494.

Tan, J., Kuang, H., Wang, C., Liu, J., Pang, Q., Xie, Q., & Fan, R. (2021). Human exposure and health risk assessment of an increasingly used antibacterial alternative in personal care products: Chloroxylenol. *Science of The Total Environment*, *786*, 147524. https://doi.org/10.1016/j.scitotenv.2021.147524

Tauanov, Z., Zakiruly, O., Baimenova, Z., Baimenov, A., Akimbekov, N. S., & Berillo, D. (2023). Antimicrobial and Antiviral Properties of Triclosan-Containing Polymer Composite: Aging Effects of pH, UV, and Sunlight Exposure. *Polymers*, *15*(5), 1236. https://doi.org/10.3390/polym15051236

Team, C. (n.d.). *Regulation (EC) No 1223/2009 on Cosmetic Products*. ChemLinked. Retrieved March 24, 2024, from http://cosmetic.chemlinked.com/database/view/1377.

Triclosan Factsheet | National Biomonitoring Program | CDC. (2021, September 2). https://www.cdc.gov/biomonitoring/Triclosan_FactSheet.html

Triclosan—Partial ban, widely used—Ingredients. (n.d.). Retrieved March 24, 2024, from https://dermaviduals.de/english/publications/ingredients/triclosan-partial-ban-widely-used.html.

Wang, C.-F., & Tian, Y. (2015). Reproductive endocrine-disrupting effects of triclosan: Population exposure, present evidence and potential mechanisms. *Environmental Pollution*, *206*, 195–201. https://doi.org/10.1016/j.envpol.2015.07.001

Wang, J., Shan, S., Li, D., Zhang, Z., & Ma, Q. (2023). Long-term influence of chloroxylenol on anaerobic microbial community: Performance, microbial interaction, and antibiotic resistance gene behaviors. *Science of The Total Environment*, *897*, 165330. https://doi.org/10.1016/j.scitotenv.2023.165330

Yueh, M.-F., & Tukey, R. H. (2016a). Triclosan: A Widespread Environmental Toxicant with Many Biological Effects. *Annual Review of Pharmacology and Toxicology*, *56*(1), 251–272. https://doi.org/10.1146/annurev-pharmtox-010715-103417

Yueh, M.-F., & Tukey, R. H. (2016b). Triclosan: A Widespread Environmental Toxicant with Many Biological Effects. *Annual Review of Pharmacology and Toxicology*, *56*(1), 251–272. https://doi.org/10.1146/annurev-pharmtox-010715-103417

Zhang, H., Li, J., An, Y., Wang, D., Zhao, J., Zhan, M., Xu, W., Lu, L., & Gao, Y. (2022). Concentrations of bisphenols, benzophenone-type ultraviolet filters, triclosan, and triclocarban in the paired urine and blood samples from young adults: Partitioning between urine and blood. *Chemosphere*, *288*, 132563. https://doi.org/10.1016/j.chemosphere.2021.132563