APPENDIX B1

The Cigarette Filter: A Review of Utility, Environmental Impacts, and Policy Solutions

Laila Hamzai MPH,[1] Thomas E. Novotny MD MPH,[1*] Liz Hendrix, MPP,[2]
Rebecca Williams, DrPH MPH[2]

[1] School of Public Health, San Diego State University
[2] California Tobacco Control Program, California Department of Public Health
*Corresponding author

Introduction

The California Tobacco Control Program (CTCP) of the California Department of Public Health (CDPH) commissioned this review to address the environmental impacts and health issues related to the cellulose acetate cigarette 'filter'. Although this document will continue to use the term 'filter' throughout the following discussion, it is clear that it does not truthfully describe the function of this commercial cigarette additive. This product additive was attached to 99.8% of the 202.9 billion commercial cigarettes sold by major manufacturers in the United States in 2019.[1] According to *The Tax Burden on Tobacco,*[2] there were 12.46 billion filtered cigarette sold in California in 2019. A substantial proportion of the butts from these cigarettes may end up as tobacco product waste (TPW) in the California environment, whether improperly discarded by smokers or dumped from waste bins into landfills.[3]

Cigarette butts, mainly the cellulose acetate filter, have been the most commonly picked up item on International Coastal cleanups worldwide for almost all of the last 30 years.[4] In addition, urban litter audits have identified cigarette butts as 10-20% of small item litter in multiple cities.[5-7] In 2020, nearly a million were picked up on the International Coastal Cleanup, held each September, but this was far less than the more than five million picked up globally in 2019 (likely a result of the COVID-19 pandemic, with widespread reduction in group activities, non-essential travel, and socialization).[4] Cleanup activities call attention to the problem of filter-related TPW, but unless they are conducted with scientific rigor, they do not represent a valid surveillance system for monitoring this type of waste. In fact, during 2020, the US Federal Trade Commission reported the first increase in cigarette sales in 20 years.[8] Although some

smokers were concerned that smoking increased risks for COVID-19 transmission, there are reports of increased cigarette smoking associated with the stresses induced by the pandemic.[9]

This review will provide a foundation for possible policy interventions related to the cellulose acetate filter and its contribution to TPW. Several important reasons underlie the need for this review. First, because cigarette butts have been such a significant item of trash picked up on beach and urban cleanups in California and globally for most of the last three decades, and because laboratory and field studies have shown the potential for this waste through improper disposal to leach toxic chemicals into waterways, landfills, and the environment,[10] environmental and tobacco control advocates have suggested enacting more specific regulations to alleviate this environmental risk.[11] Second, in order to develop policies to reduce TPW and its environment footprint, it is important to establish the scientific evidence surrounding the lack of utility for the cellulose acetate filter in terms of protecting the health of smokers, its potential environmental toxicity, and possible policy options to mitigate the environmental or health impacts of the cellulose acetate filter as TPW. There is widespread misunderstanding about the value of the filter itself in terms of reducing the adverse impacts of smoking. However, it is clear that the filter has not reduced the harms of smoking since it became an essential part of the commercial cigarette over the last sixty years.[12] Third, there is an additional public health concern that discarded butts may be a significant source of microplastic and chemical pollution of California's natural aquatic environments, both in coastal and inland areas.[13,14] Discarded butts may be

considered a public environmental nuisance and a non-point source of toxic waste that may be subjected to new environmental regulation.[15,16]

Fourth, and most importantly, CTCP can use the information from this review to engage more expansive and integrative educational interventions and partnerships in order to reduce the potential impact of tobacco product waste on human health and the environment.

This paper will first review the history of the cigarette filter, including how it has been designed, marketed, and relied upon to sell cigarettes. This discussion will address the health concerns related to the growth of the filtered cigarette market over the last 60 years. Next, it will discuss the anatomy of the filter, its chemistry, ecotoxicity, and design features such as ventilation, flavorings, coloring, and other components. This will include the issues of biodegradability and recycling schemes as well as various additions and modifications such as charcoal and flavorings. Third, it will review studies on knowledge, attitudes, and beliefs about filters by smokers and the public, including a discussion on tobacco industry efforts to influence public opinion or policy regarding filters and their environmental concerns. Finally, this review will discuss past and future policy approaches related to the filter through product regulation, design changes, or sales restrictions.

Methods

Searches were conducted in PubMed and Scopus using key phrases including "cigarette filter," "cellulose acetate filter," "filter ecotoxicity," etc. Tobacco industry documents were accessed from the *Truth Tobacco Industry Documents* database at the University of California, San Francisco.[17] Robert N. Proctor's *Golden Holocaust*, specifically Chapter 19 entitled, "Filter Flimflam," provided several important reference materials .[18] Lastly, court cases, news media, and various industry and public health websites regarding filters were reviewed.

A Brief History of the Filtered Cigarette

Filters were first used, dating back to the 1860s, to keep loose tobacco out of smokers' mouths.[19] In the 1930s and 1940s, they were marketed to protect smokers from 'poisons', such as nicotine, and were typically composed of paper, wool, or cotton. Subsequently, other porous and fibrous materials were tested, including silica gel crystal, cellulose, and porous clay porcelain.[18] In 1936, Brown and Williamson commercialized the first American cigarette with a filter, calling it *Viceroy*. Although they were a popular novelty at first, filtered cigarettes did not affect unfiltered cigarette sales during the early 20th Century. [18]

The 'Health Scare' and Filters

As the first concerns about the adverse health effects of smoking became evident in the 1940s and 50s, applied research on cigarette filters rapidly increased. By the mid-1950s, scientific evidence implicated cigarettes as a contributor to the reported

increase in lung cancer cases.[20] In 1955, Sir Richard Doll identified multiple carcinogens in cigarettes including arsenic, 3,4-benzpyrene, and radioactive potassium.[21] Around this time, tobacco companies' research units were also identifying carcinogens in tobacco and tobacco smoke. A 1952 internal document from the Brown and Williamson Tobacco Corporation revealed that their research team had detected a carcinogenic compound, benzopyrene, in tobacco smoke.[22] Alan Rodgman, director of fundamental research at RJ Reynolds Tobacco Corporation, sent a letter to a colleague confirming the presence of carcinogenic polycyclic hydrocarbons such as 3,4-benzpyrene in tobacco smoke.[23] He also concluded that, 'it is in the best interest of consumers for these compounds to be eliminated from tobacco smoke'.[23] Helmut Wakeham, vice-president for Philip Morris' science and technology department, reported a partial list of 40 carcinogens in tobacco smoke. He recommended a program aimed at reducing the levels of these cancer-causing compounds so that cigarettes would be 'medically acceptable'.[24] As tobacco companies focused on ways to eliminate carcinogens from their product, the research on filters increased in intensity.[18] However, these internal efforts to identify carcinogens in tobacco were not reported because the industry refused to publicly acknowledge their presence in cigarettes.

Marketing of Filtered Cigarettes

In response to both internal and external research about the potential and real health consequences of smoking, cigarette companies expanded marketing efforts to suggest implicitly and explicitly that cigarettes could be safer with the addition of filters.[18] In 1951, only 1% of cigarettes on the market had a filter. However, by 1958, almost half

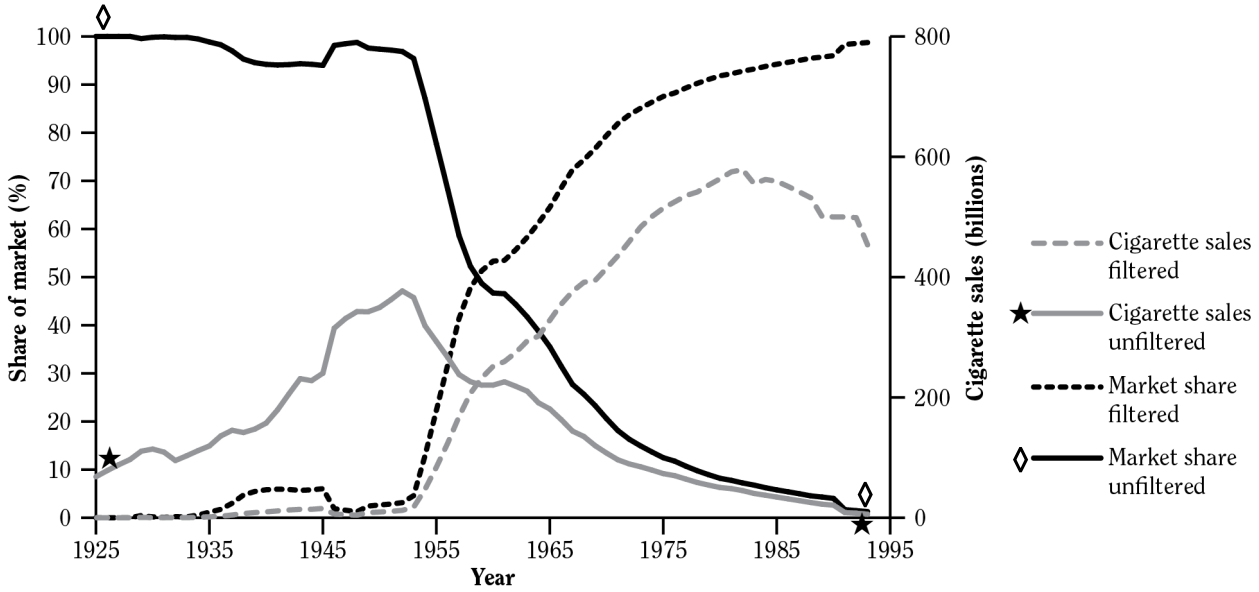
of the cigarettes on the market included filters, [11] and the Brown and Williamson Tobacco Corporation was selling tens of billions of Viceroys. Other companies joined in commercializing filtered cigarettes, with Lorillard's Kent cigarette becoming a market leader.[18] From 1952 to 1956, Lorillard sold Kent cigarettes with an asbestos filter (the 'Micronite Filter'), knowing that pieces of asbestos could break off and expose smokers to this known carcinogen.[18,25] Despite concerns voiced by other tobacco companies and academic researchers, asbestos-containing filtered cigarettes that remained in stores were sold to the public even after Lorillard decided to stop making them.[18] Although the American Tobacco Company was a major cigarette manufacturer, it did not include filters in their cigarettes until the 1960s, which resulted in it losing significant market share.[18]

The industry's overall shift to filtered cigarettes continued into the 1960s because of two important historical events. First, in 1962, the United Kingdom's Royal College of Physicians published a report (*Smoking and Health)* highlighting the link between smoking and lung cancer, other lung diseases, heart disease, and gastrointestinal problems.[26] It called for public health measures to reduce cigarette smoking and urged doctors to advise patients to quit in order to prevent illnesses caused and exacerbated by smoking. Second, the United States (US) Surgeon General's Advisory Committee on Smoking and Health published the first *Report on the Health Consequences of Smoking* in 1964. Based on evidence from more than 7,000 articles relating to smoking and disease, the Committee concluded that cigarette smoking is a cause of lung cancer and laryngeal cancer in men, a probable cause of lung cancer in women, and the most important cause of chronic bronchitis.[27] The report also provided suggestive evidence

that smoking caused other illnesses such as emphysema, cardiovascular disease, and various other types of cancer. These reports resulted in enormous press attention and in subsequent actions to advise the public about the health consequences of smoking. These reports likely fueled the shift in tobacco industry marketing to emphasize the value of smoking filtered cigarettes.

The US Federal Trade Commission (FTC) reported in its first congressionally mandated report in 1963 that filtered cigarettes were 58% of the market. By 1993, almost all manufactured cigarettes consumed in the United States were filtered (Figure 1). According to the 2020 FTC Cigarette Report, the market share for filtered cigarettes across all major manufacturers was 99.8%.[28]

Figure 1. Market share and total annual cigarette sales of filtered and unfiltered cigarettes in the United States, 1925–1993



Source: US DHHS 2014. *The health consequences of smoking—50 years of progress: a report of the Surgeon General.* Chapter 6, *Cancer*

The Filter Fraud

The tobacco industry documented early on the inability of filters to reduce exposure to harmful chemicals in smoke without damaging the cigarette's marketability. In 1932, the research director of the American Tobacco Company wrote to the company's vice president that the filter was not selective in filtering out harmful chemicals. He concluded that attempts to reduce delivery of harmful compounds in smoke would ultimately result in an unsatisfying cigarette.[29] Similarly, according to an internal 1958 company memo, Philip Morris scientists recognized that selective filtration of harmful compounds was "a thermodynamic impossibility".[30] Further, in a 1961 presentation with his industry collogues, Philip Morris' Wakeham explained that available filters "did not permit selective filtration" of harmful chemicals. He went on to emphasize that there were carcinogens in almost every class of compounds produced by smoking.[31] As for the cellulose acetate filter, industry researchers evaluated these in 1932 and determined that there was very little difference in nicotine content delivered between regular and filtered cigarettes.[32] In 1962, Fred G. Bock and colleagues from Roswell Park Memorial Institute published a laboratory study showing that cigarettes with filters caused cancer in mice, just as with previous studies of animal exposure to unfiltered cigarette smoking. After publishing these findings, the tobacco industry ceased to fund further studies by Dr. Bock.[33] The tobacco industry never shared with the public or researchers outside of the industry that filtered cigarettes were just as potentially harmful as unfiltered cigarettes.[18]

In 1957, US Congressman John A. Blatnik led an investigation on 'false and misleading' advertisements by tobacco companies on the implied benefits of cigarette filters. The Congressional committee concluded that the tobacco companies did in fact

deceive the public regarding the safety of their products.[18] Filters were then a powerful yet fraudulent industry marketing tool even before the publicity surrounding the Royal College of Physicians' and US Surgeon General's reports.

In the *Golden Holocaust* Chapter entitled, 'Filter Flimflam',[18] Proctor summarized the three reasons why filters were part of almost all commercial cigarettes. These are: 1) to lower the cost of manufacturing (cellulose acetate is cheaper than tobacco leaf); 2) to keep tobacco bits from entering the mouths of smokers (probably the principal reason people had used cigarette holders in the past); and 3) to convince people into thinking that filtered brands were somehow 'safer' than unfiltered brands.

It is clear that the cigarette companies' achieved marketing success in the 1950s and 60s through strategic advertising and efforts to ease increasing concerns over health risks associated with smoking. They were assisted at that time by free advertising in widely read sources such as *Reader's Digest* and with advertising touting filters' efficacy in reducing 'tar and nicotine' in academic journals such as *Journal of the American Medical Association.*[34] Lower machine-measured tar and nicotine yields were thought by smokers to reduce cancer risks; "light," "low tar," and "mild" became key advertising messages despite growing evidence of increased risks for lung cancer and other diseases even with these efforts at lowering tar and nicotine yields.[35] These fraudulent terms are now prohibited from use in the United States by the 2009 Family Smoking Prevention and Tobacco Control Act, unless authorized by the US Food and Drug Administration for Modified Risk Tobacco Products.[36]

Other Problems with Filters

Aside from the ‘health scare’, tobacco companies became aware of other problems with not only the Kent Micronite product. According to an internal memo, the president of Philip Morris was aware of concerns related to inhaling fibers from the cellulose acetate filter as early as 1957.[37] By 1961, Philip Morris began testing the extent of fiber breakage and fallout.[38] In the early 1960s, the director of research at Philip Morris communicated to the chief executive officer of the company that all cigarette filters release fibers, as well as other cigarette components, that will likely deposit into the lungs of consumers.[39,40] Nancy Ryan, an employee at Philip Morris who performed numerous tests related to cigarette filter particles, later received instructions to destroy records regarding her findings. A confidential disposal notice signed by Ryan confirmed that she successfully destroyed company records related to her projects.[41] Subsequently, there has been careful evaluation of tobacco industry documentation, patent applications, and other scientific reports that have confirmed the problem of ‘filter fallout’ from today’s filtered cigarettes.[40]

An additional refinement to the filter that would effectively lower the tar and nicotine levels measured by machine smoking was the ventilation of filters. This means providing small holes in the filter that allow the dilution of the smoke with air when the cigarette is puffed (Figure 2). Because smokers need to extract sufficient nicotine to maintain their addiction to this powerful drug, they are able to obstruct the vents, (so-called compensatory smoking) and puff more deeply, thereby obviating any reduced delivery of toxins or nicotine to the smoker. The addition of ventilated filters has clearly changed the pattern of smoking, including more intense puffing, and this has changed the pattern of lung cancer incidence in particular.[35]

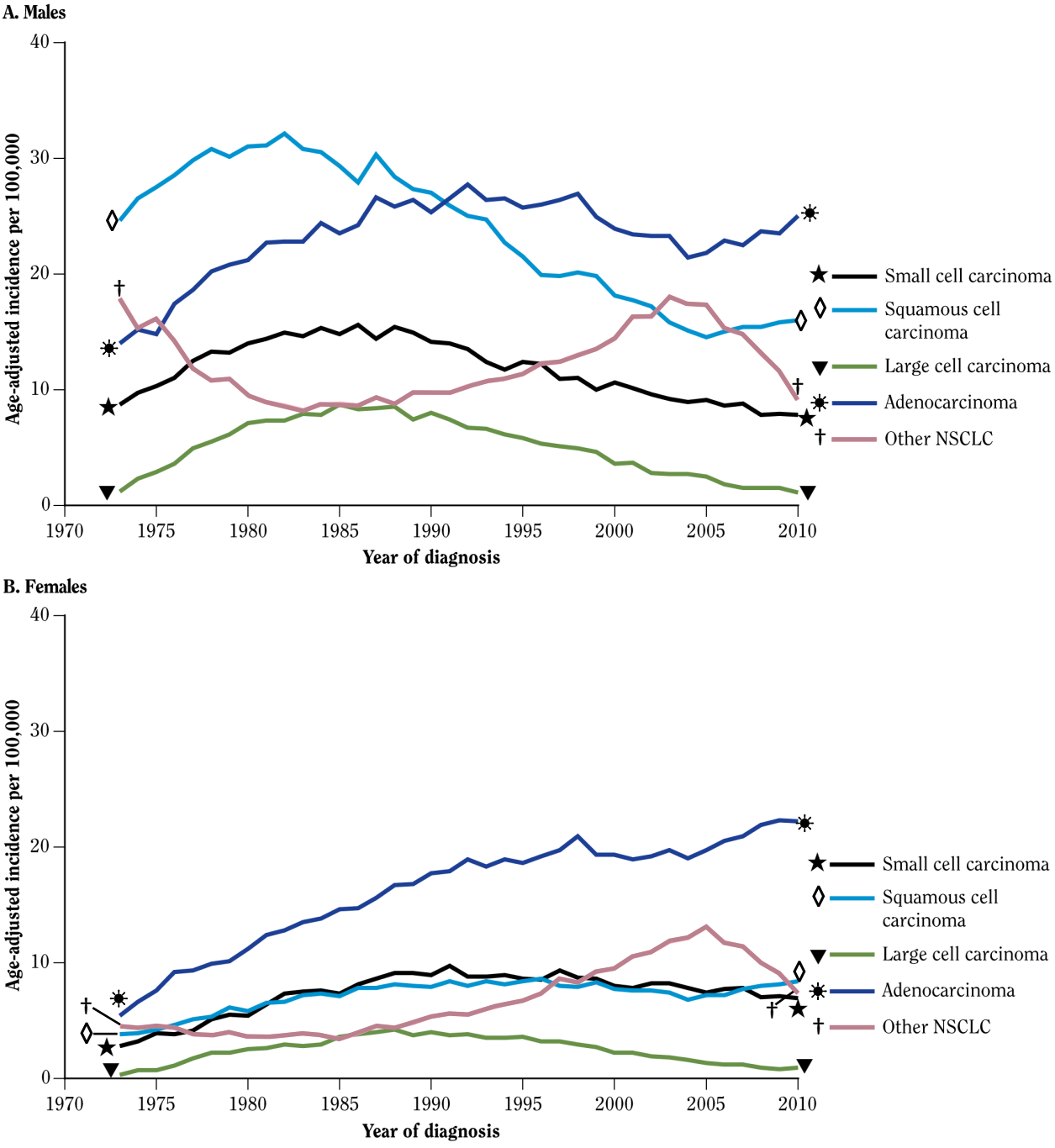
Figure 2. The Ventilated Filter.

Photo by Bill King.

In 2001, the US National Cancer Institute (NCI) Monograph 13[42] asserted that changes in machine-measured tar and nicotine yields in cigarette smoke (with the so-called 'FTC Method'[43]) did not reduce smokers' actual exposure to tobacco toxicants. Chapter 6 (on 'Cancer') in the 2014 *US Surgeon General's Report,*[20] extensively reviewed the way changes in cigarette design, mainly the filter and its ventilation, have changed lung cancer incidence. The evidence demonstrated that the risk of lung cancer associated with smoking has increased over time, and in particular, the incidence of the more aggressive cell type of adenocarcinoma (Figure 3). The incidence of other cell types (small cell, in particular) declined due to widespread smoking cessation. The evidence was sufficient to conclude that the increased risk of lung adenocarcinoma among smokers results from changes in the design and composition of cigarettes since the 1950s; however, the Report did not specify which

changes these were. Nonetheless, there was suggestive evidence that ventilated filters and increased levels of tobacco-specific nitrosamines in modern cigarettes are the reason for this increase in risk,[20] particularly among women.

Figure 3. Standardized incidence of lung cancer, by gender and histology (age adjusted to 2000 U.S. population), 1973–2010. (Source: USDHHS 2014)



Despite the accumulating evidence regarding the inability of 'filters' to eliminate toxic tobacco chemicals and the increase in lung adenocarcinoma that is likely attributable to the design changes in commercial cigarettes over the last 50 years,[44] there still seems to be uncertainty among the public [45] and some scientists about the health value of 'filters'. One recent study concluded that smoking unfiltered cigarettes was "more harmful than smoking filtered cigarettes."[46] The researchers found that, "After adjustment, unfiltered cigarette smokers were nearly 40% (hazard ratio, 1.37; 95% CI, 1.10-1.17) more likely to develop lung cancer and nearly twice (hazard ratio, 1.96; 95% CI, 1.46-2.64) as likely to die of lung cancer compared with those who smoked filtered cigarettes." However, it is critically important to recognize that this was a secondary analysis of data from a cohort study set up to assess the efficacy of tomographic screening in detecting lung cancer among high-risk smokers and not to assess the population-based risks of smoking unfiltered cigarettes.[47] The limitations of this study need elucidation. These include: 1) the population included in the study was extremely high risk (men and women age 55-74 with $\geq$30 pack year [heavy smoking] history or quit within last 15 years); 2) there was limited adjustment for socioeconomic status (even though some variables such as education were available in the data set); and 3) the reported prevalence of unfiltered cigarette use in the study population was 11.4% (this indicates the lack of population representation---less than 1% of cigarette sales in the United States are of unfiltered cigarettes). Hence, this research letter does not provide population-based evidence that smoking unfiltered cigarettes increases the risks for lung cancer; instead, it suggests that there are multiple confounding factors among those at the highest risk for lung cancer that determine lung cancer mortality.

Conducting a study to directly measure the health effects of filtered vs unfiltered cigarettes would involve a clinical trial comparing exposures and incidence among those randomly selected to smoke filtered vs unfiltered cigarettes. To date, only a small pilot, proof-of-concept study has attempted such a controlled trial to assess perceptions, changes in topography, and changes in exposure to nicotine and some carcinogens.[48] Preliminary data from this trial suggest that committed smokers, when switched to unfiltered cigarettes, smoke fewer cigarettes per day and experience less satisfaction from their smoking.[49] They do not differ with respect to urinary cotinine (the main metabolite of nicotine).

Anatomy of the Cigarette Filter

Almost all commercial cigarette 'filters' are now made of cellulose acetate fibers (a plant-based plastic), paper, plasticizers, and sometimes activated charcoal. In 2011, Harris described the development and construction of the cellulose acetate filter in a Supplement to the journal *Tobacco Control* [50]:

> *"Cellulose acetate fibers are produced by treating raw cellulose, usually obtained from wood pulp, with acetic anhydride (a common acid reagent) in the presence of a catalyst. Cellulose acetate flake precipitates out of the reaction, which is then dissolved in acetone to yield a viscose solution. This solution is spun rapidly and allowed to extrude through small spinnerets into an area of warmed air where the acetone rapidly evaporates. Multiple solid, uniform strands of cellulose acetate filament are left behind. These filaments are combined into a 'tow': a ribbon*

consisting of many cellulose acetate strands. The tow is packaged and shipped to cigarette manufacturers where it is machined into a continuous tube of cellulose acetate foam the diameter of a cigarette and cut into segments before being treated and affixed to the cigarette, an elaborate mechanical process that took years to perfect. Celanese Corporation and Eastman Kodak were two of the leading innovators in this area of filter research and development."

By the 1950s, cellulose acetate was the most commonly used filter component. Chemical companies, primarily Hoechst Celanese and Tennessee Eastman,[51] in cooperation with the tobacco industry, manufactured these filters. Over a period of two years, the production of cellulose acetate for filters increased from three million tons in 1953 to 22 million tons in 1955.[51] Cellulose acetate filters are now attached to more than 99% of commercial cigarettes sold in the United States. Despite calls for their elimination based on environmental grounds, and the scientific evidence that they do not reduce harm to smokers, tobacco industry commentators assert that they are unlikely to be banned.[52] Interestingly, the tobacco industry recognized that, by incorporating a filter into a cigarette, less tobacco was required to maintain cigarette length. This actually made the cost of manufacturing less than if there was only tobacco in the finished product. The filters cost less than the tobacco.[19]

Other components: flavorings, colorings, carbon

There are other marketing gimmicks that have been incorporated into filters, including flavorings, colorings, and carbon. Capsules can be included in the filter

additive and crushed by the smoker to release flavor; these are most popular among young adult ages 18 to 24 years old.[53] Capsules have historically been menthol flavored, but the flavors have expanded to be attractive specifically to even younger consumers. Flavored threads have also been incorporated into the filter itself to increase appeal and to differentiate brands of cigarettes.[53,54]

As for colors, Claude Teague, lead scientist for RJ Reynolds Tobacco Corporation, summarized another important perception that was key to marketing filtered cigarettes:

> *The cigarette smoking public attaches great significance to visual examination of the filter material in filter tip cigarettes after smoking the cigarettes. A before and after smoking visual comparison is usually made and if the filter tip material, after smoking, is darkened, the tip is automatically judged to be effective. While the use of such colour change material would probably have little or no effect on the actual efficiency of the filter tip material, the advertising and sales advantages are obvious.*[55]

Activated charcoal has been included in the cigarette filter additive as an attempt to reduce volatile compounds in mainstream smoke. Hearn et al. (2010) found that under standard machine smoking conditions, charcoal-containing filter additives were able to remove some phenols, tobacco-specific nitrosamines (TSNAs), and lower molecular weight PAHs. However, the more dangerous, higher molecular weight PAHs such as benzo(a)pyrene, were not removed by the charcoal.[56] Polzin et al. (2008) found that the charcoal additive can reduce some compounds (e.g., tar, nicotine, carbon

monoxide, volatile organic compounds) from machine-generated smoke under standard conditions. However, the effectiveness of these reductions depends on the amount of charcoal included and the topography of human smoking. Ultimately, under more intense and realistic smoking conditions, the charcoal can become saturated, break off, and is no longer more effective for removing harmful compounds than the cellulose acetate filter alone.[57] Nonetheless, smokers may perceive that charcoal filtered cigarettes are less risky than cellulose acetate filters alone, largely because of industry marketing efforts.[58] A 1997 publication reported on a study of a popular brand of cigarettes (Lark) with a charcoal-containing filter.[59] Charcoal granules were observed on the filter surface and were released from the filter when the cigarettes were smoked. During smoking, the toxin-containing charcoal granules were inhaled or ingested, and these contained toxic filtrates of tobacco smoke.

Talhout et al. (2018) described the effects of cigarette design features on smoke emissions, product appeal, and smoking behaviors as three factors that may determine a smoker's exposure to toxins and related health risks (Table 1).[54] This review paper is informative regarding smoker behavior, especially its conclusion that cigarette design characteristics greatly affect consumer perception, behavior, and exposure to toxins in cigarette smoke. Extensive evidence regarding ventilation and porosity of the filter was also an important consideration. These design features appear to enhance product appeal by suggesting that they reduce the health risks of smoking, thus making it easier for young people to initiate smoking and reassuring smokers by enhancing the perception of a safer product. It is important to note that the *elasticity* of smoking topography (how the cigarette design allows smokers to obtain their desired amount of

nicotine regardless of machine-smoked measurements) is established through ventilation. This elasticity negates the implication that low-tar, low-nicotine yielding cigarettes are in any way safer than unfiltered cigarettes.[35] The previously cited report of a small randomized clinical trial of unfiltered cigarettes [49] confirmed that those who smoked unfiltered cigarettes during the trial had greater nicotine effects and less desirable sensory effects than when they smoked filtered cigarettes.

Table 1. Summary of the Effects of Non-tobacco, Physical Design Characteristics on Smoke Emissions, Product Appeal, and Smoking Behavior*

	Effects on		
Design Characteristic	**Smoke Emissions**	**Product Appeal**	**Smoking Behaviors**
Increased Filter ventilation and paper porosity	• Reduced per cigarette machine-generated emissions • Less complete combustion	• Perceptions of relative safety and lighter taste • Modification of sensory cues: less 'impact', 'mouth feel', 'throat hit' reduced perception of draw	• Compensatory smoking behavior: more intense smoking behavior resulting in similar or higher exposures to toxic and carcinogenic emissions
Filter Additives such as charcoal	• Reduced emissions of selected but not all smoke components	• Perceptions of relative safety. • Modification of sensory cues.	• Compensatory smoking behavior
Filter Flavor Capsules and flavor threads	• (Some evidence for) increased emissions of several gas phase smoke components	• Perceptions of relative safety and novelty, brand differentiation, more appeal (particularly for young people)	• Unknown.
Reduced circumference 'Slim Cigarettes'	• Reduced emissions of selected but not all smoke components	• Perceptions of relative safety and high quality, more appeal (particularly for women)	• Some evidence for compensatory smoking behavior

*Adapted from: Talhout R, Richter PA, Stepanov I, et al. Cigarette Design Features: Effects on Emission Levels, User Perception, and Behavior. *Tob Regul Sci* 2018;4(1):592-604. **DOI**: https://doi.org/10.18001/TRS.4.1.6

Based on the history and anatomy of the filter, it now seems appropriate to consider defining this marketing tool differently. According to Google's *Oxford Languages* online dictionary (https://languages.oup.com/), the definition of 'filter' is: "a

porous device for removing impurities or solid particles from a liquid or gas passed through it". Given this specification for how filters should function, it may be better to consider cigarette filters as *product additives.* It is clear that although filters may change the machine-smoked measures of nicotine and other toxic chemicals as well as reduce some of the particulates produced when smoking cigarettes, they have not prevented exposure to tobacco smoke components that cause severe illnesses. If these additives had effectively functioned as 'filters' (i.e., removing impurities or solid particles from cigarette smoke), there would be scientific evidence that the risks of smoking-attributable diseases have declined since filtered cigarettes became normalized and market dominant. This is clearly not the case.[60] The filter ultimately has become nothing more than a fraudulent marketing tool designed mainly to reassure smokers and young initiators that they are doing *something* to reduce their risks.[40]

Chemicals and ecotoxicity of filters

The negative impacts of cigarette filters on ecosystems and the organisms inhabiting them is now a growing field of research. Most research reviewed here involves laboratory studies, and these include studies of microorganisms, insects, aquatic invertebrates and vertebrates, and birds.

Filters as a source of microplastics

Of growing concern are the microplastics derived from cigarette filters discarded into the environment.[61] According to a report from the San Francisco Estuary Institute, cellulose acetate was one of the dominant fiber polymers identified in San Francisco

Bay Area urban runoff, and cigarette butts are likely the main source of these fibers. Belzagui et al (2021) estimated that roughly 0.3 million tons of cellulose acetate filters are disposed of annually worldwide.[14] This estimate translates to approximately 1748.7 tons of cellulose acetate filters dropped into the California environment in 2019, which may eventually end up as microfibers.[62] However, current methods of polymer identification do not clearly distinguish between cellulose acetate fibers and other cellulosic fibers such as cotton. Therefore, definitive attribution of cigarette butts to the findings of cellulose acetate fibers in aquatic environments requires additional research. Nonetheless, laboratory studies provide significant evidence of potential concern for microfibers derived from cellulose acetate cigarette filters.

A cigarette filter has 12,000-15,000 cellulose acetate strands, and when cigarette butts are discarded into aquatic or terrestrial environments, the fibers can detach and disperse into various aquatic ecosystems. Belzagui et al. (2021) modeled this process in a laboratory setting and estimated that a typical filter releases approximately 100 microfibers per day, most of which are less than 0.2 mm in size.[14] These researchers further assessed the ecotoxicity of the microfibers from smoked cigarette butts by performing an immobilization test with *Daphnia magna* (the water flea). The researchers measured the concentration of smoked filter *leachate* that immobilized the organisms. (*Leachate* is a term used in environmental sciences that refers to a liquid containing dissolved or incorporated harmful substances that may enter the environment). They found that a lower concentration of cigarette butt leachate *with* microfibers (0.620 smoked filters per liter of water) was needed to immobilize the daphnids, compared to the concentration of leachate without microfibers (0.888 smoked

filters per liter of water). Daphnid Immobilization is common laboratory method to assess sub lethal toxic effects of chemicals. This indicates that the breakdown of the filter into microfibers induced more toxicity than that from the filter without microfibers; in some cases, the presence of microfibers increased the toxicity of cigarette leachate four-fold.[14]

Microbial communities residing on coastal marine sediments are also vulnerable to alterations from exposure to cigarette filters. Quemeneur et al. (2021) demonstrated that discarded cellulose acetate filters can change the diversity of microbial communities by depleting some microbes and enriching others.[63]

The effects of exposure to leachates of smoked cellulose acetate filters on invertebrates has been studied using various mollusks, mussels, and flatworms. In one study, exposure to a concentration of five smoked cigarette butts (with cellulose acetate filters) per liter of water resulted in 60% to 100% mortality of multiple mollusk species and flatworms within five days.[64] Lower concentrations of the leachate showed reduction in activity among these organisms.[64] Green et al. (2021) tested the impact of cigarette butt leachate with two different filters (cellulose acetate and biodegradable cellulose) on mussels. Those mussels exposed to leachates from cellulose acetate filters had lower clearance rates (a measure of filtering capacity used in ecotoxicity testing as a sensitive and ecologically relevant sub-lethal endpoint) compared to mussels exposed to the other type of filter.[65]

Experiments with marine worms have shown that exposure to even low concentrations of cellulose acetate filter fibers and toxicants leached from them can have harmful impacts. Wright et al. (2015) demonstrated that marine worms exposed to

microfiber concentrations 60 times lower than those observed in urban run-off are at risk for negative behavioral and physiological changes, including longer burrowing time and significant weight loss. DNA damage was also twice that for exposed worms compared with unexposed worms.[66]

Lawal and Ologundudo found that mortality among frogs increased with exposure to leachate from filtered cigarettes.[67] Their study found that smoked cigarette filter leachates are six and a half times more lethal to frogs and fishes compared to unsmoked filter leachates.[67] Additional studies with fresh and saltwater fish have confirmed that smoked cigarette filter leachates are toxic, but even unsmoked filter leachates demonstrate toxicity at higher concentration levels.[16] It has been shown that exposure is also associated with negative growth as well as physiological and behavioral changes.[16,68]

Chemical constituents were investigated in the leachate of smoked cigarettes using novel non-targeted analyses. [69,70] Approximately 800 chemical constituents were detected in the fresh and saltwater leachates; nicotine was the most abundant, followed by diacetin and triacetin. Some alkaloids were bioaccumulative in rainbow trout exposed to the fresh water leachate; these included nicotine, myosmine, nicotyrine, and 2,2'-bipyridine.[70] Thirty-eight compounds found in the saltwater leachate were identified in exposed mussels, including 2-furanmethanol, benzyl alcohol, cotinine, 4,4'-bipyridine, 2,3'-dipyridyl, ethyl pyrazine, 1-pyrrolidine carboxyaldehyde, 1-acethyl pyrrolidine, 2-hydroxy-3-methylethanone, and N-acetylpyrrolidone.[69] The leachates of smoked cigarettes produced positive *in vitro* responses in these organisms for genotoxicity (increased activation of the aryl hydrocarbon receptor [AhR, a transcription factor that

regulates gene expression]) and cytotoxicity (on the Estrogen Receptor-p53 loop). This suggests a potential risk to human health through consumption of exposed biota.[71]

There are very limited studies of terrestrial animals regarding exposure to discarded filters, but there are reports of cigarette butt consumption by pets, birds, and other wild animals (Figure 4).[72] One notable study reported that certain birds used cellulose fibers from smoked cigarette butts to line their nests. While this can have short-term benefits by repelling ectoparasites (due to the remaining nicotine), further research reported negative long-term impacts. Suarez-Rodriguez and Macias-Garcia (2014) found genotoxic damage among the finches that was positively associated with higher proportions of cellulose acetate, along with the adsorbed toxins in the filters, in the nests.[73]

Figure 4. Black Skimmer feeding its chick a cigarette butt. (Photo: Karen Mason, *Audubon Magazine*, August 1, 2019)

Novotny et al. (2011) reviewed human and animal poison control center data for reports of accidental ingestion of tobacco products, including filters.[72] The authors

found that cigarette butt consumption by small children and animals is a frequent source of concern due to indiscriminate eating behavior. Veterinary reports of nicotine poisoning are uncommon, but domestic animals may consume butts and show serious gastrointestinal, central nervous system, and cardiovascular signs.

Plant growth and development are also susceptible to negative impacts associated with exposure to cellulose acetate filters. In a greenhouse study with perennial ryegrass and white clover, Green et al. (2019) found that plants exposed to smoked filters, unsmoked filters, or smoked filters with tobacco residue had significantly reduced germination success and initial growth. Alterations in chlorophyll content were also observed.[74] In a later aquatic study, Green et al. (2021) observed lower chlorophyll content in mesocosms (experimental systems that examine the natural environment under controlled conditions) with exposure to cigarette butts with the cellulose acetate filter.[65]

Biodegradability

Cigarette butts persist in the environment because the filter, although moderately photodegradable, is not readily biodegradable.[75] The tobacco industry was aware of environmental concerns about the poor biodegradability of cellulose acetate filters for several decades; industry representatives disingenuously claimed that butts were not a litter problem because 'practically all the materials we use have a degree of biodegradability'.[76] In 2000, a report was submitted to the Cooperation Centre for Scientific Research Relative to Tobacco (CORESTA) by the Cigarette Butt Biodegradability Task Force, which included members from Philip Morris and R.J.

Reynolds tobacco companies.[77] The task force came to no definitive conclusions on methods to predict biodegradability of the cigarette filter, and their report cited technical difficulties and inconsistencies across laboratories as potential reasons for this. In one experiment, up to 26% of degradation occurred over the course of a year in outdoor environments; however, these results were not reproduced across multiple laboratories, and the reports were not published in peer reviewed journals.[77]

Bonanomi et al. (2015) published one of the few peer-reviewed scientific studies on the biodegradability of cigarette butts.[78] The researchers measured the degradation of smoked cigarette butts across various natural conditions in both laboratory and field conditions (e.g., sand dunes, grasslands, etc.). Wood sticks were included in the degradation experiments as a slow decomposing standard. After two years of biodegradation, the average mass loss of cigarette butts was only 37.8% of its starting mass. Furthermore, the most biodegradation occurred in the first month, with an average 15.2% mass loss occurring in the first 30 days. The researchers attributed the low degradability of the cigarette butt to the cellulose acetate filter being resistant to microbial activity due to its high degree of acetylation.

The biodegradability of the cellulose acetate component of cigarette butts was recently assessed in laboratory studies by Belzagui et al. (2021). The researchers did not observe chemical decomposition of the filters under UV light over the course of a month in laboratory-created seawater conditions. No signs of chemical decomposition in the filters were observed after a year and a half of differing freshwater and sunlight conditions.[14] These findings are consistent with Bonanomi et al.'s (2015) conclusions that the filter itself is responsible for the low biodegradability of cigarette butts overall.[78]

Greenbutts, a research and development company in California, developed a filter, made of fibers including hemp, cotton flock, wood pulp and abaca (Manilla hemp), that would reportedly degrade in about one week.[79] The stated corporate goal of *Greenbutts* is to address the pollution caused by discarded cellulose acetate filters. Another company in India has developed a filter for roll-your-own cigarettes that contains plant seeds.[80] These discarded filters ostensibly will result in seedlings that grow into plants. The company also advertises its product as having absorbent properties for 'taking up excess tar and nicotine', again implying health benefits of these filters. There are no reports evaluating the ecotoxicity of these products, but it is likely that any filter material will leach out the same chemicals as detected in leachates of cellulose acetate filters.

Smith and Novotny (2011) reviewed tobacco industry documents regarding biodegradable filters. British American Tobacco (BAT) suggested that biodegradable filters would offer 'outdoor convenience' by 'eliminating' litter.[81] Brown & Williamson concluded that the 'perceived benefit' of a biodegradable filter was 'the ability to litter without guilt'.[82,83] Tobacco companies continue to investigate how to create and market biodegradable filters.[64] However, even if these efforts are successful, the environmental harms of discarded filters will persist, as toxic chemicals will continue to be leached from whatever type of biodegradable filter that is marketed.[12]

Recycling schemes

Marinello et al. (2020) reviewed recycling schemes for cigarette butts.[75] The researchers identified 37 publications describing butt recycling into re-usable products,

categorized according to output products. The categorizations were: infrastructure/ buildings, energy storage, environmental engineering, chemical and medical industries, insecticides, metallurgical industry, and paper industry. *Infrastructure* was the category with most reported recycled butt products, with 31% of the studies describing recycling cigarette butts into building materials. Other products were for energy storage devices (19% overall), insecticides (17% overall), or environmental engineering products (14% overall). The remaining 19% of the studies reported cigarette butt recycling into materials that could be used in the metallurgical, paper, medical, or chemical analysis industries. Marinello et al. noted that there were no large-scale evaluations or experimental applications of these products.

Several of the reviewed studies reported the possibility of recycling cigarette butts into construction products, including bricks, with up to 10% of brick weight being recycled cigarette butts in one report.[75] This results in bricks with lower density, and so the compressive strength of the brick may be inadequate. The use of recycled cigarette butts in asphalt and concrete has also been reported as well as in oil-absorbing materials for use in environmental cleanups. Cigarette butts have also been used as pesticides (due to the nicotine in them) in both their original form and after being transformed into a liquid solution or ‘tobacco dust’.

Although multiple studies have reported on the processing of cigarette butts such that they may be used in various consumer products, implementing these recycling schemes may not be feasible outside of the laboratory setting. Marinello et al. (2020) highlights the fact that collection of cigarette butts for commercial recycling purposes will require large-scale logistical systems for collection and transportation. The operational

requirements and monetary costs of recycling cigarette butts are not likely to be feasible or attractive to waste management companies or local jurisdictions. A more important consideration is the toxicity of both the cigarette butt substrate and the potential toxicity of the output products and/or byproducts of manufacturing. Smoked cigarette butts contain toxic compounds, and recycling them will not necessarily remove toxicity. Marinello et al. (2020) also cited a lack of information on toxicity and energy costs as disadvantages of a majority of the cigarette butt recycling strategies.[75]

Terracycle is New Jersey-based company that started recycling plastic bottles and other more difficult to recycle plastic trash in 2001. It collaborated in 2012 with tobacco companies, including Imperial Tobacco (Canada) and Reynolds American's Santa Fe Natural Tobacco brand, to establish a volunteer-based cigarette butt collection program.[84] Claiming to develop a new technology to reduce the toxicity of the end products (plastic pellets that could be molded into commercial products such as pallets and building materials), Terracycle continues to partner with tobacco companies as well as several local jurisdictions. These jurisdictions and volunteer 'Cigarette Waste Brigades' send the collected butts 'using sturdy plastic containers or bags' to the corporate offices. There they are decontaminated, separated from non-plastic components, and processed into plastic pellets.[85] The safety profile of the transport and recycling processes is unknown as is whether there is a viable commercial market for plastic pellets made from recycled cellulose acetate filters. Additional regulatory concerns arise concerning the transport of cigarette butts across the country and for the costs that may be borne by communities in order to collect the butts for processing. The company provides funds to *Keep America Beautiful,* a non-profit organization also

subsidized by Philip Morris and Santa Fe Natural Tobacco, as part of its ecological corporate strategy.[86]

Knowledge, attitudes, and beliefs

Public knowledge of filters and attitude towards policies.

Using a population-based sample of 2,979 adult non-smokers, former smokers, and current smokers, Patel et al. (2021) studied knowledge and beliefs around cigarette filters and how these factors are associated with support for policies aimed at reducing the environmental impact of discarded plastic filters.[45] Only about a quarter of the participants (28.9%) thought that cigarette filters contained plastic. Despite this gap in knowledge, 72.4% indicated they support a litter fee, and approximately half (48.9%) of the participants indicated that they support banning sales of cigarettes with filters altogether. The participants in this study who believed cigarette butts are not biodegradable and can harm the environment were more likely to support a litter fee incorporated into the price of cigarettes and/or banning filters altogether. Findings from this study also suggest that beliefs about filters making cigarettes less harmful endure. Stratified by smoking status, 33.2% of smokers compared with 21.3% of non-smokers believed that filters reduce the harmful effects of smoking ($p<0.001$).

Another study (Epperson et al. 2020) sought to assess knowledge, attitudes, and beliefs about the environmental impact of filters among a sample of young adults.[87] Most respondents (89%) agreed that filters are harmful to the environment and not biodegradable, but only 43% knew that filters are made of plastic. Those who believed

that filters are harmful to the environment were more supportive of bans on sales of cigarettes as an environmental intervention.

Using data from a 2019 representative household survey of the German population aged 14 years and over, Kotz and Kastaun (2021) reported that the majority of both smokers and non-smokers did not know that cigarette filters were made of synthetic materials.[88]

The previously cited Smith and Novotny study (2011) reported on focus groups with smokers conducted by the tobacco industry on knowledge and opinions about cigarette butt waste.[76] Most smokers knew that cigarette butts were not degradable, and found them 'smelly and dirty.' Smokers were loath to manage them as personal litter and cited conflicting reasons for discarding them improperly. For some, it was a conscientious behavior to stomp out a flicked butt on the sidewalk, and for others it was an act of rebellion. Interestingly, for some, flicking was done to minimize contact with a reminder of their nicotine addiction.

Smokers' awareness of filter ventilation.

King et al. (2021) analyzed survey data from 11,844 participants who were daily smokers, non-daily smokers, and recent quitters across four countries (Australia, United States, Canada, and United Kingdom).[89] Approximately 40% of the participants reported being aware of filter ventilation; however, knowledge of filter ventilation was lowest among the daily smokers group. Among the 7,541 daily smokers, the subset of American participants (n=1604) had the lowest filter ventilation awareness, at 34%. Those participants who knew their product had a ventilated filter were 2.4 times more

likely to believe their cigarettes were less harmful. King et al. (2021), along with other researchers who have studied cigarette filters, call for banning of cigarette filters given that they create a false illusion of harm reduction.

Policy Options

The environmental concerns regarding TPW have increased with the recognition that the cellulose acetate filter, attached to almost all commercially marketed cigarettes, is a single-use plastic product that is the main component of TPW collected on cleanup campaigns throughout the world.[4] This waste is of interest in particular to local agencies, communities, and organizations concerned with plastic pollution, hazardous waste management, and ecological protection.[61] These concerns are then inevitably linked to public health efforts to reduce tobacco use overall, with a growing focus on the 'Tobacco End Game'.[90] This broad goal has created momentum to engage innovative approaches involving local communities and more aggressive tobacco control policies, including tobacco-product sales restrictions such as those in Beverly Hills and Manhattan Beach, California, which eliminate the sale of almost all tobacco products in these communities.[91] Linking environmental advocacy surrounding the single use plastic and ecotoxicity issues of cigarette filters with tobacco control behavioral objectives may yield promising changes in terms of environmental protection and reduction of cigarette smoking in California.

There remains widespread misunderstanding about the protective value of the cellulose acetate filter as well as knowledge gaps about the lack of degradability of this cigarette additive. Studies cited above suggest that further public education is

necessary regarding the fact that the filter on almost all commercial cigarettes is poorly biodegradable plastic and that it has no health benefit. There is sufficient information, based on reviews by the US National Cancer Institute and the US Surgeon General, to dispel beliefs that the filter provides protection from cancers or other health consequences of smoking. Furthermore, changes in the cigarette design over the last 50-60 years have yielded an increase in the incidence of lung adenocarcinoma. This is despite reductions in overall cancer incidence among US smokers following widespread smoking cessation. A recent pilot study among committed smokers suggested that there was no change in nicotine exposure and that smokers experienced worse taste, less satisfaction, less enjoyment, more aversion, more harshness, and negative reinforcement after switching to unfiltered cigarettes.[49] Measurement of biomarkers for carcinogens are still pending for this study, but such studies can add evidence and understanding about the role of the filter in sustaining smoking while not protecting against the harms of tobacco use. To answer the question about any changes in health risks if users only smoked unfiltered cigarettes, a large, longitudinal study comparing filtered and unfiltered cigarette smoking would be necessary. This is neither practically nor ethically possible.

There is a growing body of evidence citing the ecotoxicity, poor biodegradability, and ubiquity of the filter as trash and even as a hazardous waste product.[10] There is also a growing concern that cellulose acetate filter waste contributes to microfibers and microplastics in the California aquatic environment.[14,61] These ecological concerns can lead to regulatory efforts by communities to address TPW as hazardous or plastic waste through existing or new regulations. Further, on January 12, 2016, the California EPA

approved the State Water Resources Control Board's Amendments to the California Clean Water Act, directing that for oceans: "Trash shall not be present in ocean waters, along shorelines or adjacent areas in amounts that adversely affect beneficial uses or cause nuisance." And for the inland waters: "Trash shall not be present in inland surface waters, enclosed bays, estuaries, and along shorelines or adjacent areas in amounts that adversely affect beneficial uses or cause nuisance." [92] These Amendments will require local communities (as 'Permittees') to prevent trash greater than 5 mm from entering aquatic environments through storm drainage systems by 2030. This requires either full capture infrastructure or source reduction. This size requirement would apparently apply to cigarette filters, which are 20-30 mm long.

Hill et al. have reviewed various policy approaches to address TPW in general as an environmental hazard.[93] These include *upstream policies* (shifting consumption, sales, and use patterns, thereby reducing the number of products sold, used, and then discarded); *midstream policies* (imposing additional costs or regulatory requirements on the consumption of the products); and *downstream policies* (mitigating, managing, or paying for the costs for cleanup imposed on the public by TPW). A few of the policy options described by Hill et al., (2022) are briefly presented here.

Upstream Policies

Banning the sale of filtered cigarettes is an upstream environmental solution to mitigate the microplastic and chemical pollution caused by discarded cigarette butts. This may be thought of in environmental science as 'source reduction.' This would not require new recycling structures, hazardous waste management systems, or collection

schemes. FDA regulatory authority expressly allows such sales restrictions at state or local levels.[94] There have been a few attempts at state levels in California (and New York state) to ban the sale of filtered cigarettes on environmental grounds. In 2014, AB 48, submitted by an environmental leader in the California Assembly, Mark Stone, sought to ban the sale of single-use filters in California. The bill intended to substantially reduce the burden of cigarette butt cleanup for communities, protect beaches and wildlife, and reduce urban blight.[95] Stone reintroduced the bill in 2018. Tobacco industry resistance and front groups caused these bills not to survive Assembly committee processes. In 2019, Senator Hannah-Beth Jackson introduced SB 424, which would have prohibited selling, giving, or furnishing to another person of any age in the state a cigarette utilizing a single-use filter made of any material, an attachable and single-use plastic device meant to facilitate manual manipulation or filtration of a tobacco product, and a single-use electronic cigarette or vaporizer device. This bill passed the California Senate but was again relegated to committee processes in the Assembly where it was withdrawn by the author.[96] Current efforts to ban the sale and provision of single-use plastic products, including those targeting specific products such as plastic bags and straws, could be applied to cellulose acetate cigarette filters and other tobacco product-related plastic waste. Banning the sale of filtered cigarettes may not reduce smoking prevalence or all tobacco waste. What is certain is that this type of policy will decrease the plastic and toxic pollution from cigarette butt waste, whether due to reduced consumption or gradual changing normative cigarette product use. California Assembly members have again introduced legislation to ban the sale of single

use filters and other single use tobacco products (AB1690), and this legislation is currently pending in the Assembly Health Committee.[3]

Banning smoking in outdoor public spaces (such as beaches, outdoor restaurants, walkways, etc.) should help reduce the quantities of TPW discarded in these environments. Research from New York City indicates significant changes in observed smoking behavior resulting from a city-wide smoking ban in parks and beaches,[97] and such restrictions are very consistent with California state and local goals to reduce exposure to secondhand smoke outdoors.[98] In 2020, SB 8 was signed into law in California, which banned smoking in State parks and beaches, except on paved roadways or parking facilities, and prohibited the disposal of cigar and cigarette waste at parks and beaches unless in a waste receptacle Violation of this law is subject to a $25 fine. In addition, signage is required to support this law for all 280 state parks and 340 miles of coastline, but according to local sources, such signage has not been placed. Without signage, this law is unenforceable. Evaluation studies of such interventions are scarce, but increasingly communities are embracing such bans to reduce the public nuisance due to TPW and health risks of public outdoor smoking.[99]

Midstream Policies

Because the costs associated with cleanup and prevention of TPW may be significant for communities, voluntary groups, individuals, or businesses, application of litter fees to tobacco product sales is a policy option to reverse the negative economic externalities of these costs. Annual TPW cleanup costs have been estimated ranging

[3] See: https://legiscan.com/CA/bill/AB1690/2021

from $4.2 million in San Francisco to $19.7 million in Los Angeles.[100] In 2009, San Francisco successfully applied and defended (against tobacco industry lawsuits) a $0.20 litter fee that would fund public education, enforcement, cleanup costs, and administration of a tobacco waste mitigation program for the city.[101] This fee has increased substantially since then, and additional research is now underway to develop econometric models to accurately estimate both direct costs (such as cleanup and prevention costs due to TPW) as well as secondary costs (such as those that result from ecological damage, loss of pristine environments, and urban community degradation due to TPW).

Downstream Policies

Downstream policies include cleanup campaigns, installation of outdoor butt depositories, public education campaigns, recycling programs, marketing of 'biodegradable' filters, and litigation to recover costs of TPW damage to the environment. Cleanup campaigns serve an important purpose in terms of calling attention to the problem of TPW, but as pointed out, such cleanups, including those that collect butts for recycling, have very minimal impact on the total TPW burden. Butt waste receptacles have been installed in public outdoor spaces, mostly by voluntary groups, but the waste collected in these must be handled and disposed of (usually in landfills), and their use by smokers is irregular at best.[102]

There is a clear need for public education campaigns, both concerning the poor biodegradability of the cellulose acetate filter and the lack of utility of this cigarette additive as a protection against the health consequences of smoking. As mentioned

above, biodegradable filters may reassure smokers that they are doing ‘something’ to prevent environmental contamination with the plastic filter waste, but in actuality, the ecotoxicity of the chemical leachates from such filters will still be a problem.

Extended producer responsibility and *product stewardship* are environmental concepts applied to the management of common waste elements such as unused paints, recyclable electronic products, mattresses, automobile tires, etc. These may in theory be applied to TPW and the cellulose acetate filter.[103] Recycling schemes paid for by manufactures, advanced recycling fees, and other environmental policies have been employed to manage other toxic waste streams. These concepts could assign accountability for TPW to manufacturers, distributors, and consumers of tobacco products. However, unlike other consumer products that might be managed with downstream approaches, it is not practical to completely collect and dispose of all toxic cigarette butts in the environment. Instead, filter-related TPW mitigation could involve upstream, midstream, and downstream policies, including litigation to address the public nuisance of TPW and the costs involved in prevention and abatement.[15]

Conclusions

1. The cellulose acetate filter, as a primary, poorly degradable component of TPW, has no benefit in preventing the adverse health effects of smoking. It has been a fraud in terms of its implied health protections to smokers, while succeeding as an important marketing tool for the tobacco industry in its efforts to sustain cigarette smoking and deceive smokers since the 1950s.

2. The filter is likely a source of microplastics in the environment and may be a significant source of ecotoxicity as part of discarded tobacco product waste, even without attached tobacco remnants.
3. There are policy options available now to communities and the State that could reduce the environmental burden of discarded cellulose acetate filters and further denormalize smoking. These outcomes would jointly serve California's near term environmental and public health goals.
4. In order to implement effective environmental and tobacco control options regarding cellulose acetate filters and TPW, additional public information and advocacy is needed to address misconceptions about the composition and health risks of cellulose acetate or other types of cigarette filters.

References

1. US Federal Trade Commission. *Cigarette Report for 2019.* Issued 2021.
2. Centers for Disease Control and Prevention. Chronic Disease and Health Promotion Indicators. The Tax Burden on Tobacco. https://chronicdata.cdc.gov/Policy/The-Tax-Burden-on-Tobacco-1970-2019/7nwe-3aj9/data.
3. Rath JM, Rubenstein RA, Curry LE, Shank SE, Cartwright JC. Cigarette litter: smokers' attitudes and behaviors. *International journal of environmental research and public health.* 2012;9(6):2189-2203.
4. Ocean Conservancy. *International Coastal Cleanup: 2020 Report.* Ocean Conservancy https://oceanconservancy.org/wp-content/uploads/2021/09/2020-ICC-Report_Web_FINAL-0909.pdf.
5. AET Group Inc. *2020 Litter Audit Prepared for City of Toronto.* November 2020.
6. HDR. *The City of San Francisco Street Litter Re-Audit 2008.* HDR Engineering/Brown, Vence & Associates, Inc./MGM Management
7. Dillon Consulting. *City of Vancouver Street Litter Audits.* https://vancouver.ca/files/cov/street-litter-audit-survey-report-2019.pdf;2019.
8. FTC Report Finds Annual Cigarette Sales Increased for the First Time in 20 Years [press release]. October 21 2021.
9. Rigotti NA, Chang Y, Regan S, et al. Cigarette Smoking and Risk Perceptions During the COVID-19 Pandemic Reported by Recently Hospitalized Participants in a Smoking Cessation Trial. *Journal of general internal medicine.* 2021;36(12):3786-3793.
10. Beutel M, Harmon T, Novotny T, et al. A Review of Environmental Pollution from the Use and Disposal of Cigarettes and Electronic Cigarettes: Contaminants, Sources, and Impacts. *Sustainability.* 2021;13:12994.
11. Novotny TE, Lum K, Smith E, Wang V, Barnes R. Cigarettes butts and the case for an environmental policy on hazardous cigarette waste. *International journal of environmental research and public health.* 2009;6(5):1691-1705.
12. Evans-Reeves K, Lauber K, Hiscock R. The 'filter fraud' persists: the tobacco industry is still using filters to suggest lower health risks while destroying the environment. *Tobacco Control.* 2021:tobaccocontrol-2020-056245.
13. Brander SM, Hoh E, Unice KM, et al. *Microplastic Pollution in California: A Precautionary Framework and Scientific Guidance to Assess and Address Risk to the Marine Environment.* Sacramento, California, USA 2021.
14. Belzagui F, Buscio V, Gutiérrez-Bouzán C, Vilaseca M. Cigarette butts as a microfiber source with a microplastic level of concern. *Science of The Total Environment.* 2021;762:144165.
15. Witkowski J. Holding Cigarette Manufacturers and Smokers Liable for Toxic Butts: Potential Litigation-Related Causes of Action for Environmental Injuries/Harm and Waste Cleanup. *Tulane Environmental Law Journal.* 2014;28(1):1-36.
16. Slaughter E, Gersberg RM, Watanabe K, Rudolph J, Stransky C, Novotny TE. Toxicity of cigarette butts, and their chemical components, to marine and freshwater fish. *Tobacco Control.* 2011;20(Suppl 1):i25.
17. University of California San Francisco. Truth Tobacco Industry Documents. https://www.industrydocuments.ucsf.edu/tobacco/.

18. Proctor R. *Golden holocaust: origins of the cigarette catastrophe and the case for abolition.* Berkeley: Berkeley : University of California Press; 2011.
19. Tobacco Asia. The History of Filters. 2003; https://web.archive.org/web/20030824115139/http://www.tobaccoasia.com/news.asp?id=534.
20. U.S. Department of Health and Human Services. *The health consequences of smoking—50 years of progress: a report of the Surgeon General.* Atlanta 2014.
21. Doll R. Etiology of Lung Cancer. In: Greenstein JP, Haddow A, eds. *Advances in Cancer Research.* Vol 3. Academic Press; 1955:1-50.
22. Report of Progress - Technical Research Department 521224. In. Brown & Williamson Records; Minnesota Documents; Master Settlement Agreement 1952.
23. Rodgman A. The Optimum Composition of Tobacco and Its Smoke. In. RJ Reynolds Records; Minnesota Documents; Master Settlement Agreement 1959.
24. Pm Philip M, Wakeham H. Tobacco and Health - R&D Approach Presentation to R & D Committee by Dr. H. Wakeham at Meeting Held in New York Office on 611115. In. Philip Morris Records; Master Settlement Agreement 1961.
25. Parmele H. re: Cigarette Testing. In. Ness Motley Law Firm Documents 1951.
26. Royal College of Physicians. *Smoking and health.* London 1962.
27. United States Public Health Service. *Smoking and Health: Report of the Advisory Committee to the Surgeon General of the Public Health Service.* Washington, DC: US Department of Health, Education, and Welfare 1964.
28. Commission USFT. *Cigarette Report for 2020.* Issued 2021.
29. Hanmer-Hr R. -- No Title. In. American Tobacco Records; Master Settlement Agreement 1932.
30. O'Keefe AE. Selective Filtration. In. Philip Morris Records; Master Settlement Agreement 1958.
31. Wakeham H. Tobacco and Health - R&D Approach. In. Philip Morris Records; Master Settlement Agreement 1961.
32. Action Of Cellulose Filter-Pads In Cigarettes On The Nicotine Content Of The Smoke. In. American Tobacco Records; Master Settlement Agreement 1935.
33. Bock FG, Moore GE, Dowd JE, Clark PC. Carcinogenic Activity of Cigarette Smoke Condensate: Biological Activity of Refined Tar from Certain Brands of Cigarettes. In:1962:668-673.
34. Miller LMM, Monahan J. Wanted—And Available—Filter-tips that Really Filter. In. *Reader's Digest*1957:43–49.
35. Song M-A, Benowitz NL, Berman M, et al. Cigarette Filter Ventilation and its Relationship to Increasing Rates of Lung Adenocarcinoma. *JNCI: Journal of the National Cancer Institute.* 2017;109(12).
36. National Cancer Institute (NCI). *"Light" Cigarettes and Cancer Risk.* Rockville, MD Updated October 28 2008.
37. Philip Morris, Stubing AC. In. Philip Morris Records; Master Settlement Agreement 1957.
38. Wakeham H. Filter Fallout. In. Philip Morris Records; Master Settlement Agreement 1961.
39. Philip Morris, Wakeham H. Your memo of January 9, 1962 in re Coughing by Dual Tareyton Smokers. In. Ness Motley Law Firm Documents 1962.

40. Pauly JL, Mepani AB, Lesses JD, Cummings KM, Streck RJ. Cigarettes with defective filters marketed for 40 years: what Philip Morris never told smokers. *Tobacco Control.* 2002;11(suppl 1):i51.
41. Responsible Records Management Group, Ryan NR. Notice of Active Disposal. In. Philip Morris Records; Master Settlement Agreement 1994.
42. National Cancer Institute. Risks Associated with Smoking Cigarettes with Low Machine-Measured Yields of Tar and Nicotine, Smoking and Tobacco Control Monograph No 13. In: U.S. Department of Health and Human Services PHS, National Institutes of Health, National Cancer Institute, ed. Bethesda (MD)2001.
43. Peeler C. *Cigarette testing and the Federal Trade Commission: a historical overview, The FTC Cigarette Test Method for Determining Tar, Nicotine, and Carbon Monoxide Yields of US Cigarettes Report of the NCI Expert Committee.* Bethesda (MD): U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, National Cancer Institute;1996. NIH Publication No. 96-4028.
44. Thun MJ, Carter BD, Feskanich D, et al. 50-year trends in smoking-related mortality in the United States. *N Engl J Med.* 2013;368(4):351-364.
45. Patel M, Cuccia AF, Folger S, Benson AF, Vallone D, Novotny TE. Support for cigarette filter waste policies among US adults. *Tobacco Control.* 2021:tobaccocontrol-2020-056451.
46. Tanner NT, Thomas NA, Ward R, et al. Association of Cigarette Type With Lung Cancer Incidence and Mortality: Secondary Analysis of the National Lung Screening Trial. *JAMA Internal Medicine.* 2019;179(12):1710-1712.
47. Aberle DR, Berg CD, Black WC, et al. The National Lung Screening Trial: overview and study design. *Radiology.* 2011;258(1):243-253.
48. Oren E, Pulvers K, Romero DR, et al. Effects of Unfiltered Cigarettes on Smoking Behavior and Toxicant Exposure: Protocol for a Randomized Crossover Clinical Trial. *JMIR Res Protoc.* 2020;9(12):e19603-e19603.
49. Pulvers K, Tracy L, Novotny TE, et al. Switching people who smoke to unfiltered cigarettes: perceptions, addiction and behavioural effects in a cross-over randomised controlled trial. *Tob Control.* 2021:tobaccocontrol-2021-056815.
50. Harris B. The intractable cigarette 'filter problem'. *Tob Control.* 2011;20(Supplement 1):i10-i16.
51. Round, Firm, and Filtered. In. *Chemical & Engineering News*1956.
52. Breaking Up: Following the Health Establishment's Logic, Cigarette Filters Should Be Banned. In: Tobacco Reporter; 2014; April:42-46.
53. Thrasher JF, Abad-Vivero EN, Moodie C, et al. Cigarette brands with flavour capsules in the filter: trends in use and brand perceptions among smokers in the USA, Mexico and Australia, 2012–2014. *Tobacco Control.* 2016;25(3):275-283.
54. Talhout R, Richter PA, Stepanov I, Watson CV, Watson CH. Cigarette Design Features: Effects on Emission Levels, User Perception, and Behavior. *Tobacco Regulatory Science.* 2018;4(1):592-604.
55. Brandt AM. *The cigarette century : the rise, fall, and deadly persistence of the product that defined America.* New York: Basic Books; 2007.
56. Hearn BA, Ding YS, Vaughan C, et al. Semi-volatiles in mainstream smoke delivery from select charcoal-filtered cigarette brand variants. *Tobacco Control.* 2010;19(3):223-230.

57. Polzin GM, Zhang L, Hearn BA, et al. Effect of charcoal-containing cigarette filters on gas phase volatile organic compounds in mainstream cigarette smoke. *Tobacco Control.* 2008;17(Suppl 1):i10.
58. Hammond D, Parkinson C. The impact of cigarette package design on perceptions of risk. *Journal of Public Health.* 2009;31(3):345-353.
59. Pauly JL, Stegmeier SJ, Mayer AG, Lesses JD, Streck RJ. Release of carbon granules from cigarettes with charcoal filters. *Tobacco control.* 1997;6(1):33-40.
60. Institute of Medicine (US) Committee to Assess the Science Base for Tobacco Harm Reduction. *Clearing the smoke : assessing the science base for tobacco harm reduction / Kathleen Stratton [and others], editors.* Washington, D.C: National Academies Press (US); 2001.
61. Moran KM, E.; Mendez M.; Moore, S.; Gilbreath, A.; Sutton R.; Lin, D. *A Synthesis of Microplastic Sources and Pathways to Urban Runoff. SFEI Technical Report: SFEI Contribution #1049.* Richmond, CA: San Francisco Estuary Institute;2021.
62. Clean Virginia Waterways. Cigarette Butt Litter. How Many Cigarette Butts Are There? http://www.longwood.edu/cleanva/cigbutthowmany.htm.
63. Quéméneur M, Chifflet S, Akrout F, Bellaaj Zouari A, Hassen M. Impact of cigarette butts on microbial diversity and dissolved trace metals in coastal marine sediment. *Estuarine, Coastal and Shelf Science.* 2020;240:106785.
64. Green DS, Kregting L, Boots B. Smoked cigarette butt leachate impacts survival and behaviour of freshwater invertebrates. *Environmental Pollution.* 2020;266:115286.
65. Green DS, Kregting L, Boots B. Effects of cigarette butts on marine keystone species (Ulva lactuca L. and Mytilus edulis L.) and sediment microphytobenthos. *Marine Pollution Bulletin.* 2021;165:112152.
66. Wright SL, Rowe D, Reid MJ, Thomas KV, Galloway TS. Bioaccumulation and biological effects of cigarette litter in marine worms. *Scientific reports.* 2015;5:14119-14119.
67. Lawal M, Ologundudu SO. Toxicity of cigarette filter leachates on Hymenochirus curtipes and Clarias Gariepinus in Nigeria. *Journal of Environmental Extension ISSN: 1595 - 5125.* 2013;11:7-14.
68. Lee W, Lee CC. Developmental toxicity of cigarette butts – An underdeveloped issue. *Ecotoxicology and Environmental Safety.* 2015;113:362-368.
69. Wei H. *Determination of organic compounds in smoked cigarette leachate and their bioaccumulation potentials in the marine mussel, Mytilus galloprovincialis*. San Diego, CA, San Diego State University; 2018.
70. Yabes Y. *Bioaccumulation of organic compounds from cigarette litter in the freshwater rainbow trout, Oncoryhnchus mykiss*. San Diego, CA, San Diego State University; 2018.
71. Xu EG, Richardot WH, Li S, et al. Assessing Toxicity and in Vitro Bioactivity of Smoked Cigarette Leachate Using Cell-Based Assays and Chemical Analysis. *Chemical Research in Toxicology.* 2019;32(8):1670-1679.
72. Novotny TE, Hardin SN, Hovda LR, Novotny DJ, McLean MK, Khan S. Tobacco and cigarette butt consumption in humans and animals. *Tobacco Control.* 2011;20(Suppl 1):i17.
73. Suárez-Rodríguez M, Macías Garcia C. There is no such a thing as a free cigarette; lining nests with discarded butts brings short-term benefits, but causes toxic damage. *Journal of Evolutionary Biology.* 2014;27(12):2719-2726.

74. Green DS, Boots B, Da Silva Carvalho J, Starkey T. Cigarette butts have adverse effects on initial growth of perennial ryegrass (gramineae: Lolium perenne L.) and white clover (leguminosae: Trifolium repens L.). *Ecotoxicology and Environmental Safety.* 2019;182:109418.
75. Marinello S, Lolli F, Gamberini R, Rimini B. A second life for cigarette butts? A review of recycling solutions. *Journal of Hazardous Materials.* 2020;384:121245.
76. Smith EA, Novotny TE. Whose butt is it? tobacco industry research about smokers and cigarette butt waste. *Tob control.* 2011;20(Suppl 1):i2-i9.
77. Cigarette Butt Degradability Task Force. *Cigarette Butt Degradability Task Force Final Report.* Cooperation Centre for Scientific Research Relative to Tobacco (CORESTA) Scientific Commission;2000.
78. Bonanomi G, Incerti G, Cesarano G, Gaglione SA, Lanzotti V. Cigarette Butt Decomposition and Associated Chemical Changes Assessed by 13C CPMAS NMR. *PLOS ONE.* 2015;10(1):e0117393.
79. Greenbutts. Greenbutts: Dedicated to solving the global problem of cigarette butt pollution [Website]. https://www.green-butts.com/. Accessed 9/16/21.
80. Prasadam: Treeless Paper Products. Karma Filter Tips: About Karma. [Website]. http://www.karmatips.in/#floral. Accessed 9/16/21.
81. Sword Innovation Services L, McCarthy B. Letter from Brian McCarthy to RP Ferris enclosing report from the BAT Scimitar programme. In. British American Tobacco Records 1990.
82. Herironimus J. Nadir Research. In. Brown & Williamson Records; Master Settlement Agreement 1996.
83. Gelson E. Project Nadir Report. In. Brown & Williamson Records; Master Settlement Agreement 1996.
84. Terracycle Canada. Leaving no butts behind: TerraCycle launches second year of ambitious program to recycle cigarette waste. https://www.newswire.ca/news-releases/leaving-no-butts-behind-terracycle-launches-second-year-of-ambitious-program-to-recycle-cigarette-waste-512612721.html.
85. Terracycle. Cigarette Waste Recycling Program. https://www.terracycle.com/en-US/brigades/cigarette-waste-recycling.
86. Keep America Beautiful. Cigarette Litter Prevention Program. https://kab.org/programs/cigarette-litter/.
87. Epperson AE, Novotny TE, Halpern-Felsher B. Perceptions About the Impact of Cigarette Filters on the Environment and Smoking-Related Behaviors. *Journal of Adolescent Health.* 2021;68(4):823-826.
88. Kotz D, Kastaun S. Do people know that cigarette filters are mainly composed of synthetic material? A representative survey of the German population (the DEBRA study). *Tob Control.* 2021;30(3):345.
89. King B, Borland R, Le Grande M, et al. Smokers' awareness of filter ventilation, and how they believe it affects them: findings from the ITC Four Country Survey. *Tob Control.* 2021:tobaccocontrol-2020-056134.
90. McDaniel PA, Smith EA, Malone RE. The tobacco endgame: a qualitative review and synthesis. *Tob Control.* 2016;25(5):594.

91. Smith EA, McDaniel PA, Malone RE. California advocates' perspectives on challenges and risks of advancing the tobacco endgame. *J Public Health Policy.* 2020;41(3):321-333.
92. California Water Quality Control Board. *Final Staff Report for Trash Amendments.* April 7 2015.
93. Hill K WC, Kingston H, Novotny TE. *A Review of Policy Options to Address Tobacco Product Waste.* CTCP White Paper *Tobacco Product Waste In Califronia*, 2022.
94. Freiberg M. (Don't) See More Butts: Preemption and Local Regulation of Cigarette Litter. *Hamline Law Review* 2014;37:205-228. https://publichealthlawcenter.org/sites/default/files/resources/article-freiberg-cigarette-litter-hamlinelawreview-2014.pdf .
95. WBUR Here and Now. California Assemblyman Tries To Ban Filtered Cigarettes. https://www.wbur.org/hereandnow/2014/01/31/ban-filtered-cigarettes.
96. California Legislative Information. SB-424 Tobacco products: single-use and multiuse components (2019-2020). https://leginfo.legislature.ca.gov/faces/billStatusClient.xhtml?bill_id=201920200SB424.
97. Johns M, Farley SM, Rajulu DT, Kansagra SM, Juster HR. Smoke-free parks and beaches: an interrupted time-series study of behavioural impact in New York City. *Tob Control.* 2015;24(5):497.
98. Smokefree CA. California Leads The Way With Smokefree Spaces. 2021; https://tobaccofreeca.com/secondhand-smoke/california-leads-the-way-with-smokefree-spaces/.
99. Bloch M, Shopland DR. Outdoor smoking bans: more than meets the eye. *Tob Control.* 2000;9(1):99.
100. Schneider JE, Scheibling CM, Peterson NA, Stigler Granados P, Fulton L, Novotny TE. Online Simulation Model to Estimate the Total Costs of Tobacco Product Waste in Large U.S. Cities. *International Journal of Environmental Research and Public Health.* 2020;17(13):4705.
101. Schneider JE, Peterson NA, Kiss N, Ebeid O, Doyle AS. Tobacco litter costs and public policy: a framework and methodology for considering the use of fees to offset abatement costs. *Tob Control.* 2011;20(Suppl 1):i36.
102. Patel V, Thomson GW, Wilson N. Cigarette butt littering in city streets: a new methodology for studying and results. *Tob Control.* 2013;22(1):59.
103. Curtis C, Collins S, Cunningham S, Stigler P, Novotny TE. Extended Producer Responsibility and Product Stewardship for Tobacco Product Waste. *Int J Waste Resour.* 2014;4(3):157.