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Cellulose acetate cigarette filter is hazardous to human health

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ABSTRACT

The World No Tobacco Day 2022 theme emphasised tobacco's adverse environmental effects, including through agriculture, manufacturing, distribution, use and the disposal of tobacco product waste. A main concern regarding this toxic waste is the cigarette filter, which is attached to nearly all commercial cigarettes and is predominantly made from a plant-based plastic (cellulose acetate). Laboratory studies have demonstrated the chemical toxicity of discarded cigarette butts, and there is growing public concern regarding environmental plastic pollution resulting from single-use cellulose acetate filters. Important considerations are whether the filter has any protective role against the harms of smoking and whether it should be regulated as a plastic environmental pollutant. There is persistent misunderstanding among smokers and policy makers about the implied value of the cigarette filter. The cellulose acetate filter is simply a marketing tool that encourages smoking initiation and reduces intentions to quit smoking. This is because it makes smoking easier and implies added safety through the presumed filtration of inhaled smoke. The sale of filtered cigarettes should be prohibited to protect public health and the environment.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ FIltered cigarettes do not protect people who smoke against the harms of smoking, yet plastic filters continue to be attached to almost all commercial cigarettes. They are the main component of tobacco product waste, the single most picked up item of trash globally.

WHAT THIS STUDY ADDS

⇒ This study summarises the history, marketing, industry deceptions, ecotoxicity, and misunderstandings regarding cellulose acetate filters. It redefines these cigarette components as tobacco additives that are harmful to human health and the environment.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study calls for regulatory policies on cellulose acetate filters as unecessary single-use plastics. It suggests additional research is needed on the potential environmental and human harms due to toxic tobacco product waste.

INTRODUCTION

The harms of smoking have been recognised for decades, yet almost 6 trillion commercial cigarettes are sold globally each year, and an estimated 8 million people die each year due to smoking-attributable diseases. Recently, scientists and advocates have described the toxicity and potential ecological impacts resulting from the environmental deposition of trillions of cigarette butts. WHO's World No Tobacco Day 2022 addressed tobacco's life cycle impact on the environment.[1] In 2021, the California Tobacco Control Program (CTCP) of the California Department of Public Health commissioned a review of the science, tobacco industry responses and policy approaches regarding tobacco product waste.[2]

The environmental focus on tobacco's harms is not new, as the evidence for harms to non-smokers by exposure to secondhand smoke has been understood for many years.[3] In addition, recent research has described the health risks of third-hand smoke pollution (the toxic residues left behind in enclosed environments even after all smoking in these environments has ceased).[4] Increasingly, environmentalists and tobacco control advocates understand the life cycle environmental harms from tobacco growing, manufacturing, distribution and disposal.[5]

A main concern regarding this toxic waste is the cigarette filter, which is attached to nearly all commercial cigarettes and is predominantly made from a plant-based plastic (cellulose acetate).[6] Discarded cigarette butts are known to leach out toxic tobacco chemicals, are poorly degradable across a variety of environmental conditions and may be a significant source of microplastic waste in aquatic and terrestrial environments.[7] They have been the single most picked up waste item on beach and urban clean-ups for decades.[8] Because of these environmental concerns, WHO, public health researchers and environmental advocates have called for a prohibition on the sale of single-use cigarette filters, no matter their composition.[1] In New York in 2021, legislators introduced the *Tobacco Product Waste Reduction Act*, banning the sale of filtered cigarettes and single-use e-cigarettes; it is still 'In Committee'.[2] In California, lawmakers introduced the *Smoking Waste Pollution Prevention Act* in 2022, which would have, as originally drafted, banned single-use tobacco products.[2] In March 2022, the United Nations Environment Assembly established a committee to draft a treaty to address the global plastic crisis. This committee met in November 2022 to plan treaty negotiations, and tobacco control advocates participated as stakeholders in this process in order to include prohibiting the single-use plastic filter in the treaty.[9]

Because there are still widespread beliefs that the word 'filter' means that filtered cigarettes are safer

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than unfiltered cigarettes, policy makers have been reluctant to take on the tobacco industry with regard to banning cellulose acetate filters.[10] This Special Communication, based on the recently published CTCP white paper,[2] will review (1) the history of the cellulose acetate filter; (2) environmental concerns regarding cellulose acetate filters; (3) health concerns regarding the use of filtered cigarettes; and (4) the challenges in addressing the cellulose acetate filter as a health and environmental hazard.

The history of the cellulose acetate filter

Most available historical information is USA oriented, including key documents from the University of California San Francisco Truth Tobacco Industry Documents Library (https://www.industrydocuments.ucsf.edu/tobacco/). Filters were first used in the 1860s to keep loose tobacco out of smokers' mouths.[11] In the 1930s and 1940s, they were marketed to protect smokers from 'poisons', such as nicotine.[12] Although they were a popular novelty at first, filtered cigarettes did not affect unfiltered cigarette sales in the early 20th century.[12] By the mid-1950s, carcinogens such as arsenic, 3,4-benzpyrene and radioactive polonium were identified in cigarettes,[13] implicating them as a contributor to the reported increase in lung cancer incidence.[14] Internal tobacco industry documents reveal that their research units also identified carcinogens in tobacco and tobacco smoke,[15–17] but the industry did not publicly report or acknowledge these findings. As tobacco companies focused on ways to eliminate carcinogens from their product, the research on filters increased in intensity.[12] Implicit and explicit product marketing focused on the presumed 'safety' of filtered cigarettes.[12] However, according to a 1958 internal company memo, Philip Morris scientists recognised that selective filtration of harmful compounds was 'a thermodynamic impossibility'.[18] As for the cellulose acetate filter, industry researchers evaluated this in 1932 and determined that there was very little difference in nicotine content delivered between regular and filtered cigarettes.[19] There were also other problems with the filter, such as fibres disbursing and being inhaled by smokers.[20 21]

By the 1950s, cellulose acetate was the most commonly used filter material. In cooperation with tobacco companies, major chemical manufacturers (Hoechst Celanese and Tennessee Eastman) provided these filters.[22] Cellulose acetate production for filters increased from 3 million tons in 1953 to 22 million tons in 1955. In 1957, a congressional committee investigation addressed 'false and misleading' advertisements by tobacco companies on the implied benefits of cigarette filters and concluded that the tobacco companies deceived the public regarding the safety of their products.[12]

The industry's overall shift to filtered cigarettes continued into the 1960s because of two important historical events. First, in 1962, the UK's Royal College of Physicians published *Smoking and Health,* highlighting the link between smoking and lung cancer and other diseases.[23] Second, the US Surgeon General's Advisory Committee on Smoking and Health published the landmark *Report on the Health Consequences of Smoking* in 1964, concluding that cigarette smoking is a cause of lung cancer and laryngeal cancer and the most important cause of chronic bronchitis.[24] These reports resulted in enormous press attention and likely encouraged tobacco industry marketing to emphasise the value of filtered cigarettes.

Almost all commercial cigarette filters are now made of cellulose acetate fibres along with paper and plasticisers. Some filters include activated charcoal, which may remove some gas-phase chemicals but not particulates or carbon monoxide.[25 26] According to the 2020 Federal Trade Commission (FTC) Cigarette Report, the US market share for filtered cigarettes across all major manufacturers was 99.8%.[6]

In Robert Proctor's historical volume, *Golden Holocaust,* a chapter entitled 'Filter Flimflam' summarised the three reasons why filters are now 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; and (3) to convince people into thinking that filtered brands were somehow 'safer' than unfiltered brands.[12]

Environmental concerns regarding cigarette filters

Cigarette butts, mainly the cellulose acetate filter, have been the most commonly picked up item on International Coastal Cleanup, held worldwide each September, for almost all of the last 30 years.[8] In 2020, nearly a million were collected, but this was far less than the more than 5 million picked up globally in 2019 (likely a result of the COVID-19 pandemic, with widespread reduction in group activities, non-essential travel and socialisation).[8] Clean-up activities call attention to the problem of tobacco product waste, but because of the ubiquity of this waste source, they do not represent a valid surveillance system for quantifying tobacco waste or an intervention to substantially reduce it; they collect only a small proportion of the discarded tobacco waste products.

The negative impacts of cigarette filters on ecosystems and the organisms inhabiting them are now a growing field of research (table 1).[27] Recent reports mainly involve laboratory studies with microorganisms as well as with larger aquatic and terrestrial organisms. There is increasing concern about environmental microplastic contamination in general, including that derived from discarded cigarette filters.[28] A cigarette filter has 12 000–15 000 cellulose acetate strands, and if discarded into aquatic or terrestrial environments, these fibres can disperse into ecosystems. Belzagui *et al*[29] modelled this process in a laboratory setting and estimated that a typical filter releases approximately 100 microfibres per day, most of which are less than 0.2 mm in size. They estimated that roughly 0.3 million tons of cellulose acetate filters are disposed of annually worldwide. The released microfibres may harm small aquatic organisms. In fact, microplastics have been found in fish and shellfish that may become part of the human food chain. Although the human health risks of aquatic microfibre pollution are uncertain, it is clear that humans are exposed to them and to the toxins that adhere to them through aquatic contamination.[30] Toxic chemicals, pharmaceuticals and microorganisms may sorb onto microplastics disposed into the environment, providing potential risks to human health.[31]

Approximately 800 chemical constituents were detected in one laboratory study of fresh and saltwater cigarette butt leachates;[32] nicotine was the most abundant, which is a hazardous chemical previously used as a pesticide. Also found were diacetin and triacetin, which are plasticisers used in filter fabrication and attachment. Thirty-eight compounds found in the saltwater leachates were also identified in laboratory-exposed mussels.[32] These leachates appeared to produce positive in vitro responses in these organisms for genotoxicity (increased activation of the aryl hydrocarbon receptor (a transcription factor that regulates gene expression)) and cytotoxicity (on the oestrogen receptor-p53 loop). In another leachate study, some leached nicotinic alkaloids were found to bioaccumulate in exposed rainbow trout.[33] These and other laboratory studies suggest a potential

Table 1 Selected studies on ecotoxicity of cellulose acetate cigarette filter

Author (date)	Organism	Findings
Microbial		
Quéméneur *et al* (2020)[49]	Bacterial strains	Smoked cellulose acetate filters change diversity of microbial communities by depleting some microbes and enriching others.[49]
Aquatic		
Belzagui *et al* (2021)[29]	Water flea	Breakdown of cellulose acetate filter into microfibres induced more toxicity among water fleas than that from filter without microfibres, in some cases by fourfold.[29]
Green *et al* (2021)[50]	Mussel, macroalgae	Mussels exposed to leachates from whole butts with cellulose acetate filters had lower clearance rates, indicating increased toxicity compared with mussels exposed to other filters. Mesocosms exposed to cigarette butts with the cellulose acetate had lower chlorophyll content.[50]
Wright *et al* (2015)[51]	Ragworm	Marine worms exposed to microfibre concentrations 60 times lower than those observed in urban run-off had negative behavioural and physiological changes, including longer burrowing time and significant weight loss. DNA damage was also twice that for exposed worms compared with unexposed worms.[51]
Green *et al* (2020)[52]	Molluscs, flatworm	Exposure to leachates of five smoked cigarette butts (with cellulose acetate filters) per litre of water resulted in 60%–100% mortality of multiple mollusc species and flatworms within 5 days while lower concentrations showed reduction in activity among the organisms.[52]
Slaughter *et al* (2011)[53]	Fish	Unsmoked and smoked cigarette filter leachates were found to be toxic to both freshwater and marine fish.[53]
Lee and Lee (2015)[54]	Fish	Smoked cigarette filter leachates altered development of fish embryos and increased anxiety-like behaviour after hatching. At higher concentrations, both smoked and unsmoked filters increased mortality among the fish.[54]
Lawal and Ologundudu (2013)[55]	Frog, fish	Exposure to leachate from filtered cigarettes increased mortality among frogs. Exposure to smoked cigarette filter leachates was six and a half times more lethal to frogs and fishes compared with unsmoked filter leachates.[55]
Terrestrial		
Green *et al* (2019)[56]	Plants	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.[56]
Suárez-Rodríguez and Macías Garcia (2014)[57]	House finch	Finches use cellulose fibres from smoked cigarette butts to line their nests; genotoxic damage among the birds was positively associated with higher proportions of cellulose acetate, along with the adsorbed toxins in the filters, in the nests.[57]

risk to human health through consumption of cigarette butt-exposed biota.[34]

Novotny *et al*[35] reviewed human and animal poison centre data for reports of accidental ingestion of tobacco products, including filters. The authors found that cigarette butt consumption by small children was a health concern likely due to indiscriminate eating behaviours and modelling adult behaviours. Veterinary reports of nicotine poisoning suggest that domestic animals have consumed butts and suffered serious gastrointestinal, central nervous system and cardiovascular effects.

Health concerns regarding use of filtered cigarettes

In 2001, the *US National Cancer Institute (NCI) Monograph 13*[36] asserted that changes in machine-measured tar and nicotine yields in cigarette smoke due to filtration or other design changes (with the so-called 'FTC Method'[37]) did not reduce smokers' actual exposure to tobacco toxicants. Chapter 6 (on 'Cancer') in the 2014 *US Surgeon General's Report*[14] extensively reviewed the way changes in cigarette design have changed smoking-attributable lung cancer patterns. The population risks for lung cancer associated with smoking have increased over time, and for a particularly aggressive cell type of lung cancer (adenocarcinoma), incidence has increased. 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.

A refinement to the filter, intended by the tobacco industry to lower the machine-measured tar and nicotine yields, is filter ventilation. This involves providing small holes in the filter that allow the dilution of the smoke when the cigarette is puffed. Because smokers need to extract sufficient nicotine to maintain their addiction, they obstruct the vents (so-called compensatory smoking), and puff more deeply, thereby obviating any benefits from reduced toxin or nicotine delivery. 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 (ie, adenocarcinoma in particular). The elasticity of compensatory smoking negates any benefit from smoking low-tar, low-nicotine yield (filtered) cigarettes.[38]

Despite the accumulating evidence regarding the inability of 'filters' to eliminate toxic tobacco chemicals and the increase in lung adenocarcinoma incidence that is likely attributable to cigarette design changes,[39] there still seems to be uncertainty among the public[40] and some scientists about the health value of 'filters'. Notably, the 2014 *US Surgeon General's Report on the Health Consequences of Smoking*[14] and the *US NCI Monograph 13* reviewed previous longitudinal epidemiological studies showing potentially reduced risks from low-tar, low-nicotine yield cigarettes and concluded that filters and changes in design did not make cigarettes safer.[36] A more recent Research Letter concluded that smoking unfiltered cigarettes was 'more harmful than smoking filtered cigarettes'.[41] 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 important to recognise that this was a secondary analysis of data from a cohort study set up to assess the efficacy of tomographic (radiologic) screening in detecting lung cancer among high-risk smokers and not to assess the population-based risks of smoking unfiltered cigarettes.[42] The limitations of that Research Letter are: (1) the population included in the study was extremely high risk (men and women aged 55–74 with >30 pack-year history or quit within the last 15 years); (2) there was limited adjustment

for socioeconomic status; and (3) the reported prevalence of unfiltered cigarette use in the study population was 11.4% (less than 1% of cigarette sales in the USA are of unfiltered cigarettes). Hence, that recent study mainly suggests there are multiple confounding factors that determine lung cancer mortality among those at the highest risk for lung cancer.

Conducting a study to measure the health effects of filtered versus unfiltered cigarettes would involve a clinical trial comparing exposures and disease incidence among those randomly selected to smoke filtered and unfiltered cigarettes. The logistical and ethical challenges for such a study would be extraordinary. To date, only a small pilot, proof-of-concept study has attempted such a controlled trial. It assessed perceptions, changes in smoking topography (inhalation and puffing patterns) and changes in exposure to nicotine and some carcinogens comparing filtered and unfiltered cigarette smoking.[43] 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.[44] They did not differ with respect to urinary cotinine (the main metabolite of nicotine) or selected carcinogen exposure (Eyal Oren, personal communication, principal investigator).

Challenges in addressing the cellulose acetate filter as a health and environmental hazard

Many smokers and non-smokers still believe that filtered cigarettes are safer than unfiltered cigarettes, and most do not know that almost all commercial cigarettes have plastic filters. Using a population-based sample of 2979 adult non-smokers, former smokers and current smokers, Patel et al. (2021) studied knowledge and beliefs around cigarette filters. The authors evaluated how these factors might inform support for policies aimed at reducing the environmental impact of discarded plastic filters.[40] Only about a quarter of the participants (28.9%) thought that cigarette filters contained plastic. Stratified by smoking status, 33.2% of smokers compared with 21.3% of non-smokers believed that filters reduce the harmful effects of smoking ($p<0.001$). Epperson *et al* sought to assess knowledge, attitudes and beliefs about the environmental impact of filters among a sample of young adults.[45] Most respondents (89%) agreed that filters are harmful to the environment and not biodegradable, but only 43% knew that filters are made of plastic. Using data from a 2019 representative household survey of the German population aged 14 years and over, Kotz and Kastaun reported that the majority of both smokers and non-smokers did not know that cigarette filters were made of synthetic materials.[46]

Based on the history and anatomy of the filter, it now seems appropriate to consider defining this additive differently. According to Google's *Oxford Languages* online dictionary (https://languages.oup.com/google-dictionary-en/), 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 by combusted tobacco, they have not prevented the severe human harms due to smoking. If these additives had effectively functioned as 'filters' (ie, removing impurities or all solid particles from cigarette smoke), there would be evidence that the risks for smoking-attributable diseases have declined since filtered cigarette smoking became normalised over the last 50 years. This is clearly not the case.[47] The filter ultimately has become nothing more than a fraudulent marketing tool, designed specifically to mislead smokers and young initiators that they are doing *something* to reduce their risks.[21]

CONCLUSION

The consensus among health scientists is that filtered cigarettes do not reduce the health risks of smoking and that they may damage ecosystems. The challenge now is to narrow the information gap among smokers, policy makers and regulatory bodies regarding the health and environmental harms of the cellulose filter. There is extensive misunderstanding about the potential value of filters, established through decades of fraudulent product marketing that implied that filters and other gimmicks reduced risks of smoking. Moreover, there is growing concern about the chemical and microplastic environmental contamination caused by trillions of filtered cigarettes discarded globally each year. Yet the global sale of filtered cigarettes continues without regulatory intervention.

In order to implement effective environmental and tobacco control policies regarding cellulose acetate filters, they should be included for regulatory consideration as part of the planned international plastics treaty. Information and advocacy materials should address misconceptions and misinformation about the composition and health risks of cigarette filters. Package warnings and point of sale messaging might be helpful in reducing these misconceptions, but upstream policy interventions to eliminate the cellulose acetate and other filters from the tobacco market will likely be more effective in reducing the adverse effects of these product additives. Ostensibly, regulatory agencies can eliminate the sale of filtered cigarettes altogether because of environmental concerns. This action should not raise concerns about product safety because filtered cigarettes do not reduce the harms of smoking.

More importantly, the cellulose acetate filter, attached to almost all globally sold commercial cigarettes, should be considered a health hazard and labelled as such. It encourages people to smoke, it deceives them into thinking a filtered cigarette is somehow safer than an unfiltered cigarette, it encourages young people to start smoking and it has led to an increased incidence of lung adenocarcinoma. Added to these concerns are the unmeasured long-term impacts of extensive environmental contamination due to discarded cigarette butts and other tobacco product waste. Increasingly, scientists concerned with the environmental impacts of discarded cellulose acetate filters are calling for a ban on these product additives.[48] There is no evidence-based health or environmental reason to allow cellulose acetate filtered cigarettes to be sold and misrepresented as beneficial to health.

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REFERENCES

1 World no tobacco day 2022. n.d. Available: https://www.who.int/campaigns/world-no-tobacco-day/2022
2 Novotny TE, Bialous SA, Hill K, *et al*. Tobacco product waste in california: A white paper. California Tobacco Control Program, California Department of Public Health; 2022. Available: https://merg.sdsu.edu/tpwwp/
3 U.S. Department of Health and. National center for chronic disease prevention and health promotion, office on smoking and health. In: *The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Coordinating Center for Health Promotion*. 2006.
4 Protano C, Vitali M. The new danger of thirdhand smoke: why passive smoking does not stop at secondhand smoke. *Environ Health Perspect* 2011;119:A422:10.:.
5 Zafeiridou M, Hopkinson NS, Voulvoulis N. Cigarette smoking: an assessment of tobacco's global environmental footprint across its entire supply chain. *Environ Sci Technol* 2018;52:8087–94.
6 United States Federal Trade Commission. Federal trade commission cigarette report for 2020 and smokeless tobacco report for 2020. issued 2021. n.d. Available: https://www.ftc.gov/reports/federal-trade-commission-cigarette-report-2020-smokeless-tobacco-report-2020
7 Novotny TE, Slaughter E. Tobacco product waste: an environmental approach to reduce tobacco consumption. *Curr Environ Health Rep* 2014;1:208–16.
8 Ocean Conservancy. International coastal cleanup: 2020 report. n.d. Available: https://oceanconservancy.org/trash-free-seas/international-coastal-cleanup/annual-datarelease/
9 Global center for good governance in tobacco control. UN plastics treaty and negotiations. 2022. Available: https://files.ggtc.world/uploads/2022-12-19/15-37-15-693029/PT%20Negotiations_finalv6.pdf
10 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. *Tob Control* 2022;31:e80–2.
11 Tobacco Asia. The history of filters. Lockwood Trade Journal Co., Inc; 2003. Available: https://web.archive.org/web/20030824115139/http://www.tobaccoasia.com/news.asp?id=534
12 Proctor RN. *Golden holocaust: origins of the cigarette catastrophe and the case for abolition*. Berkeley: University of California Press, 2011.
13 DOLL R. Etiology of lung cancer. *Adv Cancer Res* 1955;3:1–50.
14 United States Department of Health and Human Services. The health consequences of smoking: 50 years of progress. A report of the surgeon general. atlanta, GA: U.S. department of health and human services, centers for disease control and prevention. In: *National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health*. Printed with corrections, 2014.
15 Unknown. Report of progress - technical research department 521224. brown & williamson records; minnesota documents; master settlement agreement. 1952. Available: https://www.industrydocuments.ucsf.edu/docs/ztlk0134
16 Rodgman A. The optimum composition of tobacco and its smoke. RJ reynolds records; minnesota documents; master settlement agreement. 1959. Available: https://www.industrydocuments.ucsf.edu/docs/mnfb0094
17 Philip Morris Incorporated. Tobacco and health - R & D approach: presentation to R & D committee by dr. H. wakeham at meeting held in new york office on november 15, 1961. 1961 november 15. philip morris records; master settlement agreement. n.d. Available: https://www.industrydocuments.ucsf.edu/docs/yglf0164
18 O'Keefe AE. Selective filtration. 1958 september 16. philipmorris records; master settlement agreement. 1958. Available: https://www.industrydocuments.ucsf.edu/docs/hhpb0122
19 Unknown. Action of cellulose filter-pads in cigarettes on the nicotine content of the smoke. american tobacco records; master settlement agreement. 1935. Available: https://www.industrydocuments.ucsf.edu/docs/xkbf0144
20 Wakeham H, Philip Morris Incorporated. Your memo of january 9, 1962 in re coughing by dual tareyton smokers. ness motley law firm documents. 1962. Available: https://www.industrydocuments.ucsf.edu/docs/qgpb0040
21 Pauly JL, Mepani AB, Lesses JD, *et al*. Cigarettes with defective filters marketed for 40 years: what philip morris never told smokers. *Tob Control* 2002;11 Suppl 1(Suppl 1):I51–61.
22 Chemical & Engineering News. Round, Firm, and Filtered. Philip morris records; master settlement agreement. 1956. Available: https://www.industrydocuments.ucsf.edu/docs/kjll0120
23 Royal College of Physicians of London. U.S exhibit 21,023, report, "Smoking and health. depositions and trial testimony (DATTA); RICO privilege downgrades collection. 1962. Available: https://www.industrydocuments.ucsf.edu/docs/hfwv0035
24 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. Available: https://profiles.nlm.nih.gov/101584932X202
25 Harris B. The intractable cigarette "filter problem." *Tob Control* 2011;20 Suppl 1(Suppl_1):i10–6.
26 Goel R, Bitzer ZT, Reilly SM, *et al*. Effect of charcoal in cigarette filters on free radicals in mainstream smoke. *Chem Res Toxicol* 2018;31:745–51.
27 Green DS, Tongue ADW, Boots B. The ecological impacts of discarded cigarette butts. *Trends Ecol Evol* 2022;37:183–92.
28 Moran K, Miller E, Mendez M, *et al*. A synthesis of microplastic sources and pathways to urban runoff. SFEI technical report: SFEI contribution # 1049. Richmond, CA: San Francisco Estuary Institute; 2021. Available: https://www.sfei.org/documents/synthesis-microplastic-sources-and-pathways-urban-runoff
29 Belzagui F, Buscio V, Gutiérrez-Bouzán C, *et al*. Cigarette butts as a microfiber source with a microplastic level of concern. *Sci Total Environ* 2021;762:144165.
30 United States Environmental Protection Agency. What you should know about microfiber pollution. n.d. Available: https://www.epa.gov/sites/default/files/2020-07/documents/article_2_microfibers.pdf
31 Prata JC. Microplastics in wastewater: state of the knowledge on sources, fate and solutions. *Mar Pollut Bull* 2018;129:262–5.
32 Wei H. Determination of organic compounds in smoked cigarette leachate and their bioaccumulation potentials in the marine mussel, mytilus galloprovincialis. Diego State University, San Diego, CA, San; 2018. Available: https://digitallibrary.sdsu.edu/islandora/object/sdsu%3A22658
33 Yabes Y. Bioaccumulation of organic compounds from cigarette litter in the freshwater rainbow trout, oncoryhnchus mykiss. San Diego State University, San Diego, CA; 2018. Available: https://digitallibrary.sdsu.edu/islandora/object/sdsu%3A24517
34 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. *Chem Res Toxicol* 2019;32:1670–9.
35 Novotny TE, Hardin SN, Hovda LR, *et al*. Tobacco and cigarette butt consumption in humans and animals. *Tob Control* 2011;20(Supplement 1):i17–20.
36 United States National Cancer Institute. Risks associated with smoking cigarettes with low machine-measured yields of tar and nicotine. 13. Bethesda, MD: U.S. Department of Health and Human Services, National Institutes of Health, National Cancer Institute. NIH Pub. no.02-5047;2001; *Tobacco control monograph*Available: https://www.cancercontrol.cancer.gov/brp/tcrb/monographs/monograph-13
37 United States National Cancer Institute. The FTC cigarette test method for determining tar, nicotine, and carbon monoxide yields of U.S. cigarettes. report of the NCI expert committee. 7. Bethesda, MD: U.S. Department of Health and Human Services, National Institutes of Health, National Cancer Institute. NIH Pub. no.96-4028;1996; *Tobacco control monograph*Available: https://www.cancercontrol.cancer.gov/brp/tcrb/monographs/monograph-07
38 Song M-A, Benowitz NL, Berman M, *et al*. Cigarette filter ventilation and its relationship to increasing rates of lung adenocarcinoma. *J Natl Cancer Inst* 2017;109:djx075.
39 Thun MJ, Lopez AD, Hartge P. Smoking-related mortality in the united states. *N Engl J Med* 2013;368:1753.
40 Patel M, Cuccia AF, Folger S, *et al*. Support for cigarette filter waste policies among US adults. *Tob Control* 2021;32:118–20.
41 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 Intern Med* 2019;179:1710–2.
42 Team NLSTR, Aberle DR, Berg CD. The National lung screening trial: overview and study design. *Radiology* 2011;258:243–53.
43 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:e19603.
44 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.
45 Epperson AE, Novotny TE, Halpern-Felsher B. Perceptions about the impact of cigarette filters on the environment and smoking-related behaviors. *J Adolesc Health* 2020;68:823–6.
46 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;30:345–7.
47 Stratton K, Shetty P, Wallace R, et al., eds. Eds. clearing the smoke: assessing the science base for tobacco harm reduction. In: *Institute of Medicine (US) Committee to Assess the Science Base for Tobacco Harm Reduction*. Washington (DC): National Academies Press (US), 2001.

48 Green DS, Almroth BC, Altman R, *et al*. Time to kick the butt of the most common litter item in the world: ban cigarette filters. *Sci Total Environ* 2023;865:161256.
49 Quéméneur M, Chifflet S, Akrout F, *et al*. Impact of cigarette butts on microbial diversity and dissolved trace metals in coastal marine sediment. *Estuar Coast Shelf Sci* 2020;240:106785.
50 Green DS, Kregting L, Boots B. Effects of cigarette butts on marine keystone species (ulva lactuca L. and mytilus edulis L.) and sediment microphytobenthos. *Mar Pollut Bull* 2021;165:112152.
51 Wright SL, Rowe D, Reid MJ, *et al*. Bioaccumulation and biological effects of cigarette litter in marine worms. *Sci Rep* 2015;5:14119.
52 Green DS, Kregting L, Boots B. Smoked cigarette butt leachate impacts survival and behaviour of freshwater invertebrates. *Environ Pollut* 2020;266(Pt 3):115286.
53 Slaughter E, Gersberg RM, Watanabe K, *et al*. Toxicity of cigarette butts, and their chemical components, to marine and freshwater fish [published correction appears in tob control. *Tob Control* 2011(Suppl_1):i25–9.
54 Lee W, Lee CC. Developmental toxicity of cigarette butts - an underdeveloped issue. *Ecotoxicol Environ Saf* 2015;113:362–8.
55 Lawal M, Ologundudu SO. Toxicity of cigarette filter leachates on hymenochirus curtipes and clarias gariepinus in nigeria. *J Environ Ext* 2013;11:7–14.
56 Green DS, Boots B, Da Silva Carvalho J, *et al*. Cigarette butts have adverse effects on initial growth of perennial ryegrass (gramineae: lolium perenne l.) and white clover (leguminosae: trifolium repens l.). *Ecotoxicol Environ Saf* 2019;182:109418.
57 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. *J Evol Biol* 2014;27:2719–26.