

THE PERILS OF PVC PLASTIC PIPES

April 2023



Environmental Health Sciences

BEYOND
PLASTICS



plasticpollutioncoalition

BEYOND PLASTICS / Bennington College, One College Drive, Bennington, VT 05201 / BeyondPlastics.org

ACKNOWLEDGMENTS

Meg Wilcox, an independent science writer, is the lead researcher and author of this report. **Eve Fox** provided essential project management, research, and editing. **Melissa Valliant** provided excellent copyediting.

We are immensely grateful to **Matt Kayhoe** at **Environmental Health Sciences**, **Ryan Johnson** at **Healthy Building Network**, and **Mike Schade** at **Toxic-Free Future** for their helpful guidance to Beyond Plastics with the project; to **Meg Wilcox** for her diligence in maintaining independence in reporting; to **Kat Hughes** for her skillful design; and to **Judith Enck**, whose watchful eye and deep passion for our environment and justice prompted this report.

We are especially grateful to the **Natural Resources Defense Council** (NRDC) for providing funding for this report. Please note that the information contained herein was produced solely by the authors, not by NRDC.

Plastic Pollution Coalition also provided vital support.

Design: **Kat Hughes** | **Bennington College**

TABLE OF CONTENTS

1. Foreword by Judith Enck	1
2. Introduction and Key Findings	3
3. Recommendations From Beyond Plastics, Environmental Health Sciences, and Plastic Pollution Coalition	7
4. Plastic Water Pipes 101	8
5. A Toxic Stew: Polyvinyl Chloride (PVC) and Chlorinated Polyvinyl Chloride (CPVC) Pipes	10
6. How Is Drinking Water Quality Regulated?	12
6.1. U.S. EPA Drinking Water Standards	12
6.2. Pipe Construction Standards	14
6.3. Standard Setting Process	14
6.4. Testing and Certification	15
6.5. Standard Setting by a Private Organization	17
7. Life Cycle Health Risks	19
7.1. PVC Manufacturing: An Environmental Justice Concern	20
7.2. Installation	22
7.3. Consumer Health Issues (Water Pipe Use)	24
7.3.1. Leaching	24
7.3.1.1. Summary of Relevant Research on Chemical Migration From PVC Pipes	26
7.3.1.2. Organotins	27
7.3.1.3. Phthalates	29
7.3.1.4. Vinyl Chloride	30
7.3.2. Permeation	31
7.3.3. Wildfires/Thermal Degradation	31
7.3.4. Exposure to Chemical Mixtures	36
7.4. End of Life: PVC Releases Dioxins	37
8. Conclusion	38
9. Appendix	41
9.1. Table 3: PVC Manufacturing and Other Facilities Reporting Vinyl Chloride Releases to EPA's Toxic Release Inventory Program - 2021	41

1. FOREWORD BY JUDITH ENCK

Clean drinking water is a basic human right.

In the United States, we attempted to secure this right in 1974 when Congress adopted the Safe Drinking Water Act. The U.S. Environmental Protection Agency (EPA) and state and local governments have traditionally focused on testing our water at the source — reservoirs and rivers and groundwater — to ensure that it is safe for human consumption. However, after the water leaves the reservoir, river, or groundwater source, travels through pipes, and enters our homes to be consumed, it is not typically tested. This is a failure.

The discovery of unsafe levels of lead in drinking water in communities all across the country is a wakeup call that the EPA's testing at the source is insufficient to secure the safety of our drinking water. If a home was built before 1940, the service line that connects the home to the water main very likely contains lead, and that lead may be found in the drinking water. In many communities, lead service lines continued to be used until much later, in some cases until they were federally banned in 1986. Lead's impact on our health has been and continues to be horrific.

The issue is so significant that in November 2021, Congress made \$15 billion available to municipalities to replace lead service lines — a very positive decision that we applaud.

But replace these problematic lead lines with what, exactly? While dealing with the lead problem, will we be unintentionally creating new and different problems?

After Congress voted to provide this \$15 billion, I inquired if they had considered what piping material should be used to replace the lead pipes. The answer was no. I then asked the EPA if it would offer guidance on what material should be used to replace the lead pipes. Again, the answer was no.

Those two answers inspired the publication of this report.

Local governments are being left on their own to make the critical decision about what materials should replace lead. And guess what's often being promoted as the alternative? Plastic. Once again, plastic is being made central to the lives and health of millions of Americans without much, if any, thought and without comprehensive oversight.

One might assume that plastic pipes should be used because they are more affordable, but that is not actually the case. In fact, the bulk of the expense of lead service line replacement comes from the machinery and labor costs of digging up streets and replacing the pipes, not from the costs of the replacement piping. We've reviewed bids that were submitted to several municipalities, and choosing copper rather than plastic raised the total project price by about 5% on average. Needless to say, it would be very expensive to repeat this process if the replacement pipe material proves, as lead did, to be unsafe.

For plastic pipes, most state governments rely on an assurance of safety provided by the National Sanitation Foundation, a private organization that is partially funded by the pipe manufacturers who pay the organization to certify their products. NSF relies on self-reported data from the manufacturers of plastic pipes. This is not an independent process.

Having industry oversee the safety of its own products and materials has not worked out well for our society in the past — nor is it a rational approach. For example, the EPA would not rely on the coal industry to develop air pollution standards. Why is this an acceptable practice for plastic pipes?

While we strongly support the replacement of lead service lines, we need to know that the replacement pipe material used is safe. Beyond Plastics commissioned the well-respected science writer Meg Wilcox to look at the published literature, go beyond my initial inquiries, and examine this issue. What Wilcox found is eye-opening and raises concerns that need to be considered by the state and local officials who will be deciding what type of pipes will be used in their communities, as well as the residents who will be using the water that flows through the pipes.

The data on the safety and sustainability of plastic piping make a very strong case that replacing metal pipes with any type of plastic piping is likely to be a bad decision. As with all plastic products, the risk of leaching chemicals that are harmful to human health is real. There is evidence that this will occur, and the necessary testing to prove otherwise is either inadequate or nonexistent.

will be drinking the water that flows through these pipes. They should review this information and have a voice in how the \$15 billion in federal tax dollars and untold billions in other state and local funding will be used to install new pipes in their communities. We should all be informed about what is bringing water into our homes, into our bodies, into our lives.

**Judith Enck | Former U.S. EPA Regional Administrator
President, Beyond Plastics | April 2023**



Lead pipe is shown after being replaced by a copper water supply line to a home in Flint, Michigan. (AP Photo/Paul Sancya)

Communities that opt to replace their lead service lines with plastic pipes may well be leaping from the frying pan into the fire. And without a well-staffed, fully funded, trustworthy public body to ensure public safety, the profits of the plastics industry will inevitably be an unchecked driving force.

Although this is a complex topic, we've worked hard to make this report user-friendly, including posing some common-sense questions that local government, state government officials, and the public should ask when deciding what type of pipes to use.

Local residents have an important role to play in this process as they are the ones who

2. INTRODUCTION

Local and state governments have a historic opportunity to improve the health of their residents by replacing their lead service lines with a safer pipe material that does not leach the poisonous metal into tap water. Lead-contaminated drinking water in many U.S. communities has caused widespread harm, including intellectual deficits and neurological problems, particularly in children, and cardiovascular disease and death in adults.

On November 15, 2021, President Joe Biden signed the Bipartisan Infrastructure Deal into law, authorizing \$1 trillion in new federal funding for infrastructure improvements. Fifteen billion of this will be used to help state and local governments pay to replace their old lead service lines, which connect underground water mains to building plumbing systems. Water systems can tap into these dedicated funds through each state's Drinking Water State Revolving Fund, a program overseen by the U.S. Environmental Protection Agency (EPA).

The EPA is not, however, providing any guidance to communities to help them select a safer piping material among the options on the market, which include metal pipes, such as copper, and plastic pipes, like polyvinyl chloride (PVC) or high-density polyethylene (HDPE).

All types of water pipes, not only lead, can release chemicals into drinking water. Plastic pipes, which are constructed from potentially dozens of different chemicals, release more contaminants into drinking water than unlined metal pipes, which are built of few materials.¹ Communities need to understand the potential health risks associated with different water pipe materials so that they do not end up with what's known as a "regrettable substitution," or a situation in which a selected alternative turns out to be just as bad, if not worse, as the original option.

This report delves into the potential health risks associated with drinking water from service lines made of PVC or chlorinated polyvinyl chloride (CPVC). It focuses on these pipe materials because they are one of the top plastic pipe choices for service lines. PVC is furthermore unlike all other plastic pipe choices in that it is made with vinyl chloride, which results in a slew of health and environmental problems.

Vinyl chloride exposure is linked to increased risk of liver, brain, and lung cancers, as well as lymphoma and leukemia, according to the National Institute of Health.² The International Agency for Research on Cancer first declared the chemical to be a carcinogen in 1974.³ In response, the



Lead-contaminated drinking water causes intellectual deficits and neurological problems, particularly in children.

Consumer Product Safety Commission banned its use as an aerosol in consumer products,⁴ while the Food and Drug Administration banned its use in cosmetics.⁵

While touted as an inexpensive, durable choice for communities seeking to replace their lead service lines, research shows that dozens of harmful chemicals, including many for which there are no drinking water standards, can leach into tap water from PVC and CPVC pipe walls, fittings, gaskets, and the cements used for installation.

In their review of the research⁶ on chemical release from plastic pipes, Dr. Bonnie Ransom Stern, an independent consultant at BRStern and Associates LLC, and Dr. Gustavo Lagos, a professor at Pontificia Universidad Católica de Chile, warned that, “The health effects of the leachate chemicals that have been evaluated toxicologically are significant, ranging from liver and kidney effects to adverse health outcomes on the reproductive, developmental, immune and nervous systems, endocrine

disruption and/or carcinogenicity.” They said that further study was needed to characterize the human exposures to these many dangerous chemicals, both regulated and unregulated, that leach from plastic pipes.



Beyond the health risks to consumers, the production of PVC and CPVC water pipes can release harmful chemicals into the air and water at each stage of the product’s life cycle, from manufacturing to installation to use to end of life. The February 3, 2023, Norfolk Southern train derailment and explosion that released a toxic mushroom cloud of vinyl chloride and other pollutants in East Palestine, Ohio, is the latest in a string of environmental disasters associated with PVC manufacturing or transport. The train was carrying five tanker cars of vinyl chloride, the fundamental building block of PVC and CPVC, as well as four hopper cars of PVC plastic resin material, likely in the form of pellets.⁷ The contents of all nine cars burned — either during the course of the derailment and its immediate aftermath, or intentionally three days later to avert an explosion.⁸ When vinyl chloride is burned, it can release hazardous chemicals including hydrogen chloride, phosgene, and potentially dioxins.

While this report focuses on the health risks to consumers whose water is delivered by PVC or CPVC pipes, it touches on the dangerous release of chemicals that can occur at other stages of the product’s life, such as during manufacturing and transport. It addresses service lines, which are different from the pipes that are used to transport water inside buildings. The report does not survey or comprehensively compare the different pipe materials that communities may choose to replace their lead service lines. Healthy Building Network provides succinct guidance to help water communities choose safe water pipe products.⁹

Dr. Terry Collins, Teresa Heinz Professor of Green Chemistry and director of the Institute for Green Science at Carnegie Mellon University, gets to the heart of what’s at stake, noting, “The current massive investment in the replumbing of numerous American cities should never be allowed to become an ‘out of the frying pan and into the fire’ process, and contaminant leaching from PVC, or any kind of plastic piping, has the potential to produce exactly this terrible result.”

Key Findings

- 1. Independent researchers have documented as many as 50 different toxic chemicals released by PVC and CPVC pipes into drinking water.**

It is difficult to state with certainty the precise number of chemicals that are released because different product formulations and pipe brands release different chemicals, and at different levels. Moreover, research on this topic is thin. The government does not research chemical release from plastic pipes. Nor does it require pipe manufacturers or the third-party organization that tests and certifies the pipes to provide the public with information on their release of chemicals into drinking water. That leaves it up to independent researchers, who are few and far between, to find the funding to carry out this important work.

- 2. There is a lack of data on chemical releases from PVC and CPVC pipes in a real-world setting and a critical need for more research.**

Most studies on chemical release by PVC and CPVC pipes have been conducted in laboratory settings; it is difficult to relate their findings to in-service water pipes because many factors in a water distribution system influence the release of chemicals from PVC pipes and fittings. Studies are needed on the nature of all liberated chemicals, the dynamics of the liberation processes, the stability of the pipes under assault from microbes or chlorination, and the importance of water variables on the processes.

- 3. PVC and CPVC pipes release hormone-disrupting chemicals, including organotins and potentially phthalates, that can cause myriad health problems particularly in children and developing fetuses.**

Scientists say that exposure to these chemicals alone is enough to raise alarms about the safety of water delivered by pipes built from PVC or CPVC. Moreover, the EPA has not set a legal drinking water exposure limit for organotins.

- 4. Vinyl chloride may be released into drinking water from PVC and CPVC pipes at levels below EPA's legal safe drinking water limit, but at levels of potential health concern.**

Researchers have documented vinyl chloride in tap water at low, but not insignificant, levels. The chemical may accumulate in tap water, particularly in water that has stagnated in pipes. It may not only be released by the pipe material, but be created as a secondary byproduct of disinfection. Vinyl chloride is not routinely tested for in tap water because EPA drinking water standards do not require testing at the tap.

5. Existing drinking water quality standards are insufficient to protect the public's health.

Drinking water standards for synthetic chemicals, like those that plastic pipes can release, apply at the point the water enters the distribution system (i.e., at the water treatment plant), not at the tap. EPA standards therefore offer no protection from chemicals that may be released from plastic service lines. In fact, the safety of our drinking water from chemical release by plastic pipes hinges on standards set by a private organization that is not accountable to the public. Moreover, no drinking water standards factor in the cumulative burden of exposure to mixtures of chemicals in drinking water, or in the environment. There are also no full, publicly available toxicological profiles for many of the chemicals that have been found to leach from PVC and CPVC pipes.

6. When PVC and CPVC pipes burn, they can release even more hazardous chemicals into public water supplies.

Thermal degradation, such as from wildfires, can cause PVC and CPVC pipes to release volatile organic compounds, including cancer-causing benzene and styrene at levels above EPA's health-risk based guidelines. Communities can lose access to safe drinking water for months, or more, after a wildfire when their PVC and CPVC service lines melt or burn.

7. PVC manufacturing and transport release toxic chemicals, including cancer-causing vinyl chloride and dioxins, into nearby communities.

Low-income communities and communities of color bear the brunt of this pollution. Other hazardous chemicals used in the PVC production life cycle include chlorine gas and ethylene dichloride and often asbestos, PFAS, or mercury.



Workers prepare to replace older water pipes with new copper ones in Newark, New Jersey, in October 2021. Photo by Seth Wenig courtesy of AP.

3. RECOMMENDATIONS

from Beyond Plastics, Environmental Health Sciences, and Plastic Pollution Coalition

As local and state officials and the public move forward with replacing their lead service lines, there are some **important questions that need answers, including:**

1. What is the replacement pipe you're considering made of?

Have you considered alternatives to PVC/CPVC?

2. What data is available

about the identities and levels of chemicals that have been found leaching from the pipes in certification testing?

3. Will the pipe you're considering using include a liner?

(Note: We recommend avoiding liners as they may contain bisphenols or plastic materials, which often are endocrine disruptors.)

4. Other research on safer alternatives indicates that copper can be a good choice.

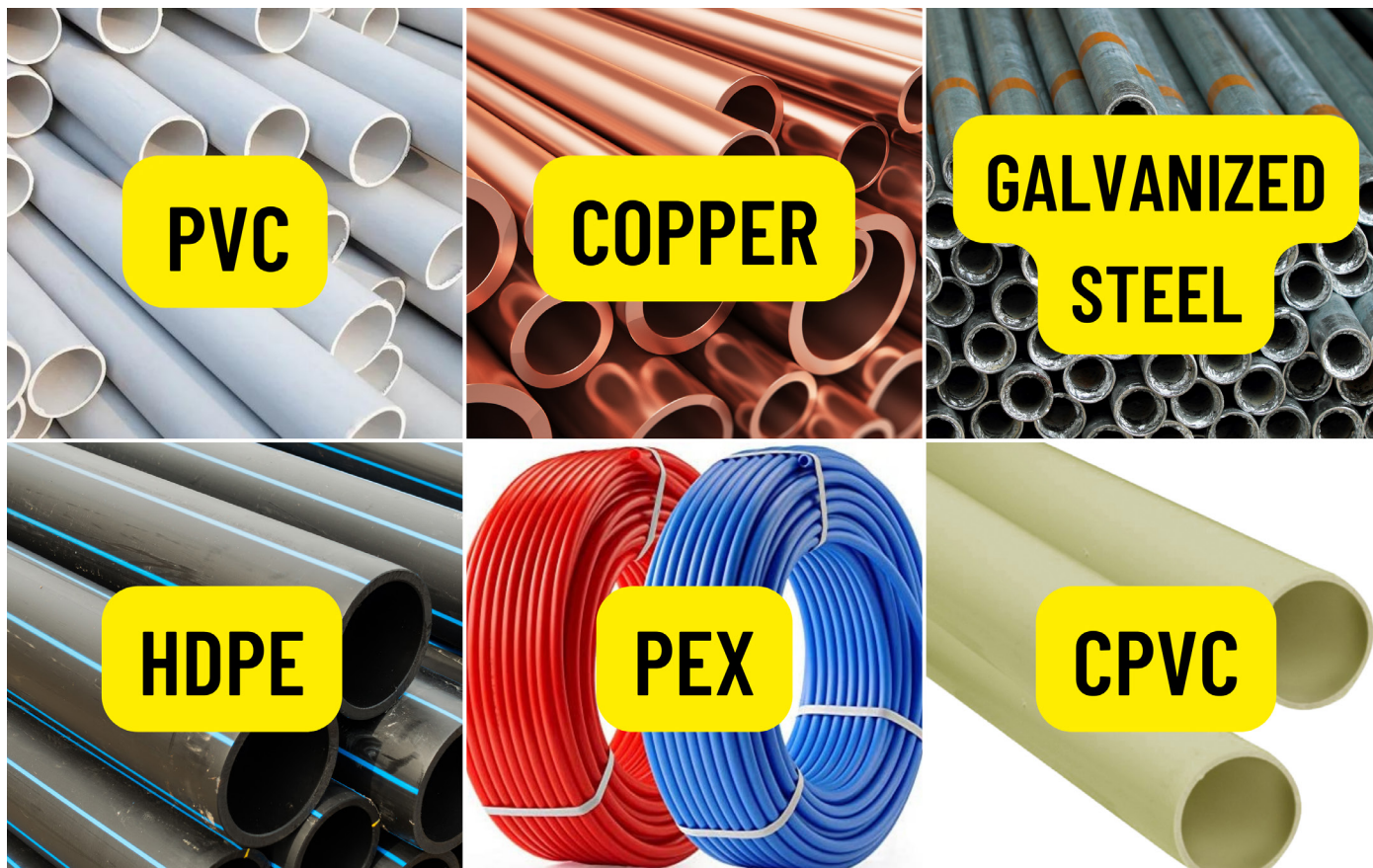
If you're planning to use copper piping, is recycled copper available?

(Note: There are environmental impacts associated with copper mining and smelting, so we recommend considering recycled copper piping if it's available.)

5. What is the breakdown of your project costs?

Review the fees for machinery, labor, and other construction costs, as well as the cost of various replacement piping options. The cost of replacement piping, regardless of the type of piping used, tends to be one of the smaller costs of most lead service line replacement projects.

4. PLASTIC WATER PIPES 101



Plastic water pipes first came on to the market in the 1950s as an alternative to the industry standards at the time: lead, iron, steel, asbestos cement, and vitrified clay. Plastic was thought to be less susceptible to corrosion and more durable than metal pipes, which typically last about 50 years. Lead pipes were not banned by the EPA until 1986, despite the known toxic effects of the metal.

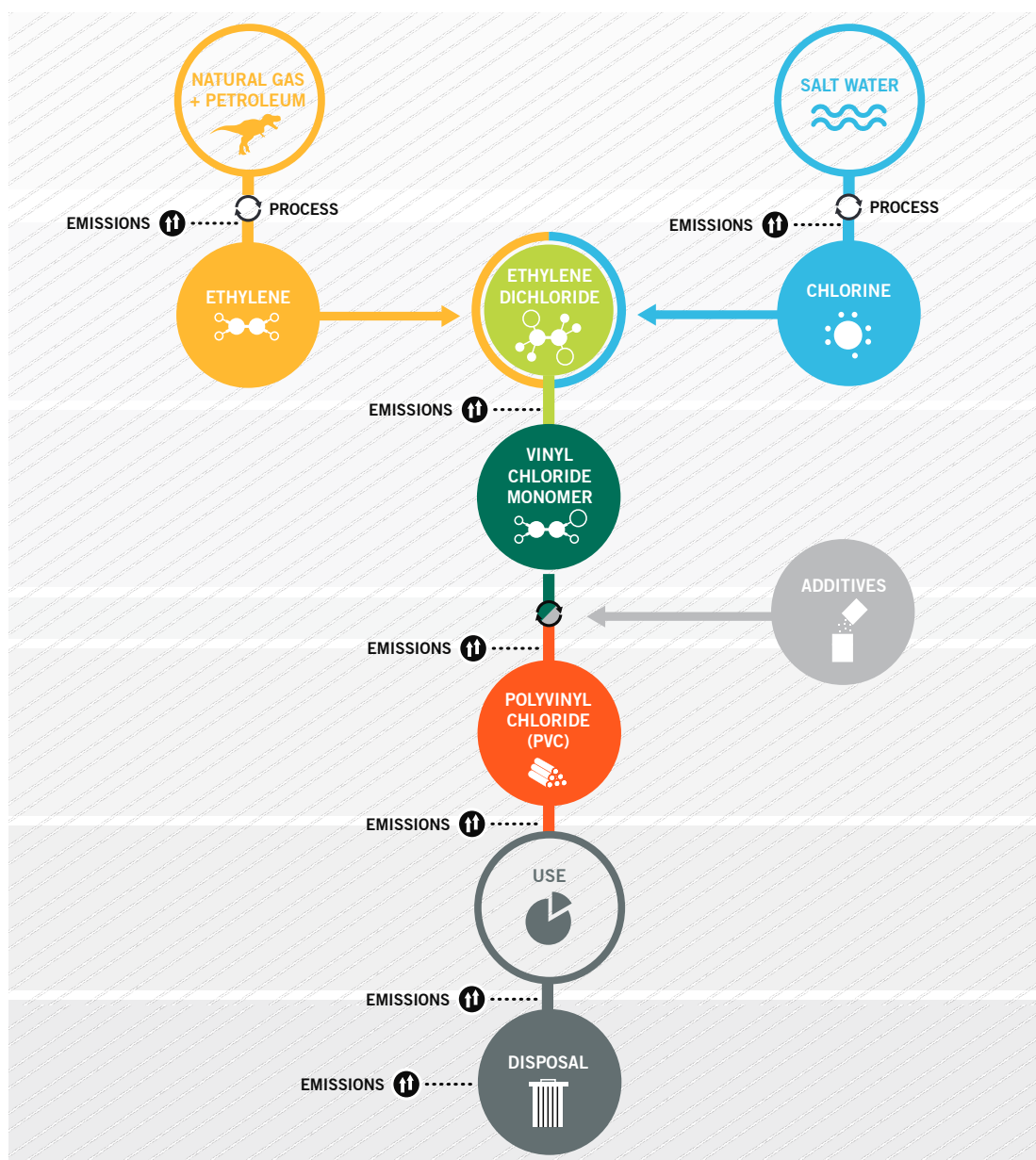
PVC pipes were the first of the plastic pipes to be introduced, and they now account for the majority of all new water and sanitary sewer installations,¹⁰ partially because they are the cheapest. These water pipes are rigid and durable; however, they are susceptible to damage from heat. Chlorinated PVC (CPVC) is polyvinyl chloride with additional chlorine molecules added to create a more durable pipe that can withstand higher temperatures and is more resistant to overall degradation.

Polyethylene pipes are also used for potable water distribution. Several types of water pipe are made from polyethylene, including high-density polyethylene pipes (known as “HDPE”) and cross-linked polyethylene (known as “PEX”). While HDPE pipes are often used for water service lines, PEX pipes are more commonly used for plumbing inside buildings because they are more flexible and require fewer connections. PEX is also able to convey both cold and hot water, while historically HDPE has not had similar hot water performance.

All polyethylene and PVC pipes are plastic resins derived from fossil fuels with many additional synthetic chemicals added to enhance both the manufacturing process and the pipes' final performance, or their ability to convey water in a system. While each of these pipes are chemically and structurally distinct, the starter petrochemical for all of them is ethylene. PVC pipes are created by combining ethylene with chlorine to form ethylene chloride, which is subsequently converted to vinyl chloride. HDPE pipes are formed by creating long chains or polymers of ethylene with a small amount of other hydrocarbons. PEX pipes are similarly made of ethylene polymers, with the addition of increased chemical bonding between the molecules to create a higher-performing material.

Researchers have documented chemical releases from polyethylene-based plastic pipes, as well as from PVC pipes. While a thorough review is beyond the scope of this report, it is worth noting that a potential endocrine disruptor, 2,4-di-tert-butyl-phenol (2,4-DTBP), is one of the predominant chemicals released by HDPE pipes into drinking water.¹¹ 2,4-DTBP is a byproduct of an antioxidant that is added during manufacturing to improve the pipe's performance and slow down its deterioration over time. A range of other organic chemicals, including cancer-causing benzene, have also been identified in water conveyed by HDPE pipes.¹²

The Lifecycle of PVC



Graphic by Perkins + Will, courtesy of Healthy Buildings Network

5. A TOXIC STEW:

Polyvinyl Chloride (PVC) and Chlorinated Polyvinyl Chloride (CPVC) Pipes



PVC pipes are fabricated in a multistep process using toxic chemicals at every stage. In the U.S., production starts with the creation of chlorine gas, which is then combined with ethylene to create ethylene dichloride, a probable carcinogen according to the EPA. Ethylene dichloride is subsequently converted at high temperature to vinyl chloride, a chemical known to cause liver cancer in humans and the fundamental building block of PVC resin. Manufacturers then add chemical catalysts and other additives to vinyl chloride to transform the individual molecules into long chains or polymers of PVC resin, typically in the form of pellets. Downstream manufacturers heat and fabricate PVC pellets into rigid pipe, adding additional chemicals such as organotins to the mix to enhance the products' performance.

Table 1— adapted from a 2013 paper¹³ by Dr. Andrew J. Whelton, professor of civil engineering and environmental and ecological engineering at Purdue University, and Tinh Nguyen, research engineer at the National Institute for Standards and Technology — summarizes the many types of chemical additives used in the manufacture of plastic pipes. Some of these chemicals have been associated with reproductive, developmental, hormonal, nervous, and immune system effects; kidney and liver damage; and even cancer.¹⁴ Research (discussed in the section on Consumer Health Issues) shows that these chemicals can be released from the water pipes into drinking water, though the health significance of this is not well understood.

TABLE 1: Compounds Used for Polymeric Potable Water Pipe Production

COMPONENT	PURPOSE/EXAMPLES
Monomer	Base compound used to create the resin. Vinyl chloride for PVC/CPVC pipes.
Antioxidant	Protects the polymer from oxidation during processing, storage and use. Common antioxidants include alkylphenols.
Accelerant, retardant	Accelerants increase and retarders decrease reaction rates and can include nitrogen- and sulfur-containing compounds.
Catalysts	Initiate chemical reactions between monomer units and/or between monomer and additives. Can include metals. Ammonium peroxodisulfate is commonly used.
Pigment	Colorant, titanium dioxide, for example.
Solvent	Used to dilute mixtures, improve processing. Examples include methyl isobutyl ketone, toluene, and xylenes.
UV stabilizer	2,4-dihydroxybenzophenone
Filler	Fillers lessen the amount of resin needed to reduce cost and improve properties such as strength. Calcium carbonate is commonly applied.
Impact modifier	Improve material resistance to impact. Examples include acrylonitrile butadiene styrene, chlorinated polyethylene and acrylic polymers added to modified PVC pipe.
Flame retardant	Decreases flammability. Examples include antimony trioxide and molybdenum compounds.
Lubricant	Increases polymer slippage during processing. Examples include oxidized polyethylene wax, stearic acid, and many complex esters.
Stabilizer	Calcium stearate, organotin compounds added for heat stabilization.

6. HOW IS DRINKING WATER QUALITY REGULATED?

6.1. U.S. EPA Drinking Water Standards

The EPA is granted authority under the Safe Drinking Water Act to set legal limits on chemical and biological pollutants to protect the public's health. The Safe Drinking Water Act also allows states to set and enforce their own drinking water standards provided that the standards are at least as stringent as those of the EPA. The EPA's legally enforceable drinking water standards are known as maximum contaminant levels, or MCLs. They are the maximum concentration of a chemical or contaminant that is allowed in public drinking water systems. MCLs aim to protect human health by requiring water systems to achieve the best feasible technology. Amendments to the Safe Drinking Water Act enacted in 1996 weakened this law by allowing the EPA to set standards that are based on cost-benefit analysis rather than the best feasible technology.

Drinking water standards are therefore not based on health considerations alone; economics and technological capabilities are also considered. The EPA also sets maximum contaminant goals, which are not legally enforceable, but reflect the preferred level for protecting human health.

When it comes to protecting the public from chemicals that may be released into tap water by plastic pipes, EPA's drinking water standards generally don't apply. The EPA regulates water quality at the point of entry into the distribution system, when it leaves the water treatment plant and enters water mains — not at the tap. Testing for virtually all chemical contaminants (except lead and certain disinfectant byproducts) occurs well before the water travels through service lines, if it occurs at all. Most publicly available tap water testing for chemicals that could be released by plastic service lines is accomplished through independent research.

Regardless, the EPA has set legal limits on only 100 contaminants¹⁵ or so in drinking water. Roughly 65 of the limits are for chemicals. With some 350,000 chemicals¹⁶ registered globally for commercial production, that means there are no legal drinking water standards for the vast majority of chemicals in use today, including dozens that have been found to leach from water pipes, such as organotins.

The EPA proposed new drinking water standards for six per- and polyfluoroalkyl substances (PFAS) in March 2023, and received widespread praise.¹⁷ Prior to this, the EPA had not gone through the byzantine process of setting a new MCL since the law was weakened in 1996. It last updated an MCL for a chemical 15 years ago.¹⁸

Though the proposed new PFAS standard is a positive step forward, the U.S. has become somewhat of a "global laggard in chemical regulation," according to ProPublica, which recently reviewed a half century of legislation, lawsuits, EPA documents, chemical databases, and other records to

piece together how the once global leader has fallen so far behind other nations in banning harmful chemicals.¹⁹ ProPublica chronicles how the industries regulated by the EPA have come to flex their considerable muscles over the agency's rule setting. The brain drain of scientists and policymakers during the Trump administration has further weakened the agency, which dropped to 14,172 employees from 2018 to 2020. Currently, the EPA has 15,115 employees, compared to its highwater mark of 18,110 in 1999.²⁰

The process for setting legally enforceable standards to protect the public from dangerous chemicals has become such a lengthy, contentious process that the EPA has turned to more voluntary approaches. For example, rather than set new MCLs for chemicals in drinking water, the EPA publishes health advisories that are not subject to any national drinking water regulation. Health advisories describe concentrations of drinking water contaminants at which adverse health effects are not anticipated to occur, and serve as technical information to assist federal, state, and local officials, and public water managers.



PVC and CPVC pipes release hormone-disrupting chemicals, including organotins and potentially phthalates, that can cause myriad health problems particularly in children and developing fetuses.

6.2. Pipe Construction Standards

Similarly, the EPA relies on a standard created by a third-party organization, NSF International (formerly known as the National Sanitation Foundation), to ensure the safety of the pipes that deliver drinking water. The NSF/ANSI 61²¹ (American National Standards Institute) standard puts forth minimum health effects requirements for chemicals that could leach from pipes, linings, and fittings into drinking water, and considers many more chemicals than the EPA.

NSF International also runs a certification program for pipe manufacturers, who submit their products for testing at least once annually from each production facility to be certified. Manufacturers pay NSF International to participate in the voluntary program, which certifies that their pipes do not leach chemicals above the levels set by NSF/ANSI 61.

The NSF/ANSI Standard 61 started as a voluntary standard, but most state health departments require their drinking water infrastructure to be NSF-certified. Plumbing codes in the U.S. also require pipe and fittings conveying drinking water to be NSF-certified. While the NSF certification seal confers a minimum level of protection from chemical exposures, environmental health advocates and researchers warn that the standard has its limitations.

6.3. Standard Setting Process

First and foremost are concerns that pipe manufacturers may be able to influence the standard setting process because they contribute large amounts of money to the organization through the certification program and because they participate in the committees that set standards. Industry representatives sit on the Drinking Water Additives Joint Committee, along with regulators, product users, and public health representatives. That committee proposes and votes on standards for drinking water quality, although final approval for standards is granted by NSF International's Council of Public Health Consultants, which does not include product manufacturers.

Industry representatives also participate in the Health Advisory Board, which establishes maximum exposure levels for unregulated chemicals, which is “especially relevant ... for the establishment of action levels in NSF/ANSI/CAN Standards 60 and 61,” states NSF International on its website. Toxicologists and risk assessors from academia and government are also members of this board, according to NSF International; however, it does not disclose the identities of any board members.

NSF International's Council of Public Health Consultants reviews and approves all exposure standards set by other drinking water committees and the Health Advisory Board. Kara Nicolaidis, a representative for NSF International, said that a 90% majority vote is required for a proposed chemical limit to pass this council. A two-thirds majority rule is required for the other two committees. “Any negative votes and comments at both voting stages must be addressed and adjudicated,” she said, adding, “the general public can also comment on ballots during the joint committee voting period.”

NSF International touts its Council of Public Health Consultants as a backstop that protects its public health mission, but that may not always be the case.

There is heavy influence from product manufacturers on the other committees, according to Elin Betanzo, president and founder at Safe Water Engineering LLC. Betanzo is a water engineer who worked on drinking water at EPA from 2000 to 2008. Several years ago, she participated in an NSF International workgroup that was tasked with revising a standard for lead in plumbing devices. “The only people who were active in the room were those who were making a profit,” she said, adding, “the public health voice was absent or very quiet.”

Betanzo stressed the importance of having balanced representation on the committees and workgroups that determine testing and certification protocols for health standards to ensure that the testing procedures uphold the intent of the health standard. If you’re not paying attention, she said, the protocols are so specific and in the weeds, that they can be devised to give the appearance of meeting a health standard. “The sampling protocol has to match the purpose of the health protective level,” she said, “and if there’s not alignment there, that health protective level is not going to be protective.”

In 2018, NSF International faced ethics charges over a conflict of interest in its efforts to lead development of new plumbing standards to reduce the growth of legionella bacteria inside buildings, including hospitals, while forming a for-profit partnership with Homeyer Consulting Services, which helps hospitals meet government requirements for water treatment safety, including Legionnaires’ disease. Twenty-two experts serving on the NSF International standard setting committee wrote a letter demanding that NSF terminate its partnership with Homeyer.²²

NSF International did not back down and then president and CEO Kevan Lawlor told the *Detroit Free Press* that the deal presented no conflict of interest and was similar to other agreements it and other standard setting organizations had made.²³

A May 7, 2018, a LinkedIn post²⁴ about the alleged ethics breach by Jennifer Clancy — executive director at Environmental Science, Policy and Research Institute — generated more than 50 comments from experts. “This decision is worthy of derision,” commented Charles Haas, department head of civil, architectural and environmental engineering at Drexel University and LD Betz professor of environmental engineering. “It is not appropriate for an organization that serves to develop standards to partner with a private for-profit company and garner financial return for the implementation of standards,” Haas said.

“This issue is not new at all,” added Tim Keane, Legionella control, remediation and risk management engineer and principal at Legionella Risk Management Inc. “The issue with NSF International and commercial conflicts of interest did not start with the Homeyer deal; the Homeyer deal is just the tip of the iceberg that everyone is now seeing, what’s floating underneath are much larger issues.”

6.4. Testing and Certification

Researchers also question the soundness of the certification process in which water pipe manufacturers pay NSF International to test and certify that their products do not leach chemicals above the limits set by the NSF/ANSI 61 standard.

Here’s how that process works. Manufacturers are required to submit their products for testing at least once annually from each production facility. Each production facility is initially audited to ensure only authorized ingredients and suppliers are used in the product and that the production process matches submitted documentation. Once NSF-certified, each production facility is inspected twice a year.

NSF International tests PVC pipes for volatile organic compounds, commonly known as VOCs, phenolics, residual vinyl chloride monomers, and metals, such as lead and tin. Volatile organic compounds are chemicals that vaporize easily and do not dissolve readily in water. Vinyl chloride release from pipes is tested at least twice annually.

Table 2 contains a partial list of 66 volatile organic compounds that are routinely tested for in PVC and other plastic pipes because they've been identified as analytes of concern based on decades of testing, according to Nicolaides. Included in this list are BTEX compounds (benzene, toluene, ethylbenzene and xylene), which can harm the blood, nervous system, and immune system, and cause cancer (benzene is associated with leukemia); two toxic PFAS, trichlorofluoromethane and trichlorofluoroethane; and a laundry list of harmful chlorinated hydrocarbon chemicals, like tetrachloroethylene. NSF International also tests for over 100 phenolic compounds in plastic pipes, according to Nicolaides, although the organization did not provide a list of these.

In addition, NSF International reviews manufacturers' product formulations and tests for other potential contaminants it identifies during these reviews. Testing is done over a short-time period (20 or so days), which does not account for potential longer-term, or chronic, exposures to chemicals leaching from the pipes. This is one of researchers' chief concerns; and for PVC, it may especially be a problem.

"PVC is very different from other plastics, like polyethylene," because it has a dense rigid structure. "Its rate of leaching generally is slower than polyethylene," said Dr. Andrew J. Whelton, professor of civil engineering and environmental and ecological engineering at Purdue University. And in fact, some studies show the potential for chemicals to continue leaching from PVC pipes for years. (See the discussion on Consumer Health Concerns.)

Another key concern about the testing and certification program is that it cannot keep up with the wide variability in chemical leaching from pipes that researchers say they typically see in their independent research. "Manufacturers don't have good control and awareness about how variable their batches are," said Dr. Whelton. "They pass the industry-sponsored, pre-market testing protocols [e.g., NSF International], but those don't necessarily represent what's being sent to market."

When asked about the implications of manufacturing variability on pipe certification, NSF International wrote in an email that it did not understand the question. Upon further clarification, Jeremy Brown, regulatory affairs manager at NSF International, skirted the question, writing, "The conclusion of variability in leaching of organic carbon from the Whelton studies should not be compared to certification testing," because the testing done by these studies "was so broad it did not identify any chemical specifically, so no judgment of health effects can be made."

Finally, researchers say that NSF International should be required to publish contaminant migration and concentration data for each certified product over the entire period of testing, while protecting manufacturers' proprietary information. That way, water utilities can make informed decisions and researchers can better focus their investigations into potential health issues associated with plastic pipes. NSF International does not share its testing database with the public, nor publish failure rates. Product failures identified by NSF International testing are reported to the manufacturer so that the manufacturer can correct the problem.

"As designed," wrote Whelton and Ngyuen in their 2013 review paper, "ANSI/NSFI Standard 61 does not fit the demands of a dynamic regulatory drinking water environment in the U.S. and requires revision."

6.5. Standard Setting by a Private Organization

Finally, on a macro level, researchers and advocates question the propriety of ceding standard setting for products that come in contact with drinking water to a private, third-party organization. Standards set by a third party simply cannot protect the public's health as well as standards set by a regulatory agency with enforcement powers. Third-party organizations are not accountable to the public, and they often do not have rigorous conflict-of-interest policies, unlike a government agency. When industry is part of standard setting — as it is with NSF/ANSI 61 — but transparency in proceedings is not required, it erodes trust.

Of course, the EPA's process for setting drinking water quality standards has its own flaws and industry influence. While industry representatives are not granted a vote on proposed standards, as they are on NSF International committees, they exert their influence in other ways. "Industry has their hands in it all along," said Betanzo, who worked on rules for disinfection byproducts, lead and copper, and total coliform bacteria while at the EPA. "They're just whittling away at the rule over months and years, watering down the health protections."

Still, Betanzo said she has more confidence in standard setting by the EPA than by a third party.

"EPA absolutely brings in more environmental groups and health groups to balance the industry conversation."

In a potential blurring of boundaries, EPA representatives sit on NSF International's Health Advisory Board, which means that they work alongside industry (and academic) toxicologists setting third-party standards for unregulated chemicals. That's not necessarily a bad thing, but it's certainly preferable for EPA to set standards with regulatory teeth through a more public process, as it recently did with PFAS.

The EPA did not respond to multiple requests asking it to elaborate on the relationship between NSF International's standard setting and EPA rulemaking. A spokesperson for the agency, Robert Daguillard, simply wrote in an email, "EPA has supported the development of independent third-party testing standards for plumbing materials under NSF/ANSI 61, which has been incorporated into many state and local plumbing codes."

Who Is NSF International?

NSF International was founded in 1944 in Ann Arbor, Michigan, to help standardize sanitation and food safety at a time when there were no protections in the U.S. Since then, NSF International has become a global institution, creating 140 active voluntary standards and independent testing protocols, and offering services in more than 170 countries.

Though this organization is classified as a nonprofit, NSF International's board of directors is tilted toward industry. Five of its 10 members are affiliated with companies including McDonald's, Johnson & Johnson, and Weirton Steel. Notably, there are no toxicologists on the board. Two members are affiliated with public health schools, though one has a history of thwarting regulations that protect the public. Dr. John D. Graham, now dean of the O'Neill School of Public and Environmental Affairs at Indiana University, served as administrator for the Office of Information and Regulatory Affairs at the Office of Management and Budget (OMB) under President George W. Bush. OMB was instrumental in carrying out the Bush administration's anti-regulatory agenda while Dr. Graham served as administrator.²⁵

Terry Collins, Teresa Heinz Professor of Green Chemistry and director of the Institute for Green Science at Carnegie Mellon University, has strong words about the efficacy of NSF International’s standard setting. “I am skeptical of chemical product certification organizations that are clearly not in touch with the Everest of data collected over decades on the health and environmental hazards of endocrine-disrupting chemicals,” he wrote in an email, calling it “simply stunning” that a search of NSF International’s website yielded zero returns for the query “endocrine” in contrast to 188 returns for “cancer,” as well as many others for heavy metal toxicants.

“How can NSF International give trustworthy testing, auditing, and certification of chemical products, such as PVC piping, if it does not recognize endocrine-disrupting chemicals as major threats to public health?” queried Collins.

TABLE 2: Partial List of Volatile Organic Chemicals That NSF International Routinely Tests for in PVC and Other Plastic Pipes

1,1-dichloroethane	Benzene	Methyl isobutyl ketone
1,1-dichloroethylene	Bromobenzene	Methyl-tert-butyl ether (MTBE)
1,1-dichloropropene	Bromochloromethane	Methylene chloride
1,1,1-trichloroethane	Bromodichloromethane	n-butylbenzene
1,1,1,2-tetrachloroethane	Bromoform	n-propylbenzene
1,1,2-trichloroethane	Bromomethane	Naphthalene
1,1,2,2-tetrachloroethane	Carbon disulfide	o-xylene
1,2-dichlorobenzene	Carbon tetrachloride	p-isopropyltoluene (cymene)
1,2-dichloroethane	Chlorobenzene	sec-butylbenzene
1,2-dichloropropane	Chlorodibromomethane	Styrene
1,2,3-trichlorobenzene	Chloroethane	tert-butyl ethyl ether
1,2,3-trichloropropane	Chloroform	tert-butylbenzene
1,2,3-trimethylbenzene	Chloromethane	Tetrachloroethylene
1,2,4-trichlorobenzene	cis-1,2-dichloroethylene	Toluene
1,2,4-trimethylbenzene	cis-1,3-dichloropropene	Total trihalomethanes
1,3-dichlorobenzene	Dibromomethane	Total xylenes
1,3-dichloropropane	Dichlorodifluoromethane	trans-1,2-dichloroethylene
1,3,5-trimethylbenzene	Ethyl benzene	trans-1,3-dichloropropene
1,4-dichlorobenzene	Hexachlorobutadiene	Trichloroethylene
2-chlorotoluene	Isopropylbenzene (Cumene)	Trichlorofluoromethane
2,2-dichloropropane	m+p-xylenes	Trichlorotrifluoroethane
4-chlorotoluene	Methyl ethyl ketone	Vinyl chloride

Source: NSF International. This table shows chemicals that NSF International routinely screens for when it tests PVC and other plastic pipes for certification. These chemicals are selected because they have been identified as “analytes of concern” over decades of testing. They may or may not be found leaching from individual PVC pipes or brands.

7. LIFE CYCLE HEALTH RISKS

PVC pipe manufacturing poses health risks to consumers, workers, and/or communities at each stage of the pipe's life cycle, from manufacturing and installation to use and end of life. This report focuses on the potential health risks to consumers whose water is delivered by PVC or CPVC pipes, but it also touches on potential health risks at other stages of the product's life cycle to give a fuller picture of the material's potential harms. This report does not provide a full life cycle analysis.

7.1. PVC Manufacturing: An Environmental Justice Concern

PVC pipes are fabricated in a multistep process that uses and releases toxic chemicals at every stage. Communities adjacent to PVC production facilities bear the brunt of this toxic pollution. Many are low-income or communities of color in the Gulf Coast and Appalachian regions. The toxic chemicals also impact workers in the vinyl chloride industry who have higher than expected mortality from liver cancer.²⁶

Toxicologists began warning about vinyl chloride's dangers in the 1950s and 1960s, including its ability to cause cancer, but chemical companies suppressed the information. It wasn't until 1974, when the International Agency for Research on Cancer declared the chemical to be a human carcinogen, that the (newly created) Occupational Safety and Health Administration established a vinyl chloride exposure standard of 1 part per million.²⁷ In 1974, the Consumer Product Safety Commission also banned the chemical's use as an aerosol in consumer products.²⁸ The Food and Drug Administration moved to prohibit the use of vinyl chloride in cosmetics.²⁹



PVC production releases persistent toxic chemical pollutants into the air and water, and many are not broken down by natural systems and can build up in the food chain. These chemicals include dioxin, vinyl chloride, ethylene dichloride, and carbon tetrachloride, a carcinogen and potent global warming gas. Chlorine gas production, necessary to make PVC, additionally uses technologies that often rely on mercury, asbestos, or per- and polyfluoroalkyl substances (PFAS), although the asbestos and mercury technologies are being phased out.³⁰ Releases of these chemicals have been documented from chlorine-producing plants, which are often co-located with PVC manufacturing plants.³¹

On Feb. 3, 2023, a Norfolk Southern train derailment and subsequent planned explosion released vinyl chloride and other chemicals into the air and water in East Palestine, Ohio. This event is the latest in a series of toxic disasters associated with PVC manufacturing. Eleven of the 50 cars that derailed were carrying vinyl chloride, PVC pellets, and other harmful chemicals, such as butyl acrylate. After containing the initial fire, authorities ordered a “controlled release” and burn-off of the remaining rail cars filled with vinyl chloride because they feared another explosion of hazardous substances could occur. That burn-off created an enormous, toxic mushroom cloud possibly containing hydrochloric acid, the World War I gas phosgene, and dioxins.³² The mushroom cloud spread across the Ohio-Pennsylvania border and was so large it was visible from space.³³

The Norfolk Southern disaster is still unfolding as this report goes to press, but East Palestine residents worry about the lingering impacts on their long-term health and home values, and the economic future for local businesses.³⁴ In the immediate aftermath of the derailment, Cornell University soil and crop scientist Dr. Murray McBride advised farmers and residents to test their wells over the next few months, writing in a press release, “It is unclear how much of this volatile chemical escaped into the air or burned before entering surface waters and soil, but vinyl chloride is highly mobile in soils and water and can persist for years in groundwater.”³⁵



A man takes photos as a black plume rises over East Palestine, Ohio, as a result of a controlled detonation of a portion of the derailed Norfolk Southern train, Feb. 6, 2023. Photo by Gene J. Puskar, image courtesy of AP.

Dr. Whelton noted in an interview with CNN³⁶ that the plastics and PVC resin in the railcars created thousands of other chemicals when they burned and that sampling of the air, water and soil will be necessary for years to ensure residents' safety.

The East Palestine derailment follows other incidents. In 2012, train cars derailed in Paulsboro, New Jersey, and released a toxic plume of vinyl chloride into the community.³⁷ In 2004, the explosion of Formosa Plastics — a PVC plant that made vinyl flooring in Illiopolis, Illinois — killed workers and released a plume of toxic chemicals.³⁸ Subsequent sampling by the Illinois EPA found elevated concentrations of dioxins in 12 of the 13 soil samples downwind of the Formosa fire.³⁹ Formosa Plastics is one of four top PVC manufacturers that have collectively been cited 245 times for safety and environmental violations, incurring more than \$50 million in fines, since 2000, according to the watchdog group, Good Jobs First.⁴⁰

Communities adjacent to PVC and chlorine production plants may also be chronically exposed to the PVC manufacturing chemicals, which are associated with illnesses including cancer, diabetes, neurological damage, and reproductive and birth defects. While such exposures are known to raise health risks, it is difficult to link health impacts in these communities to PVC-related chemicals because the communities are typically surrounded by multiple industrial facilities with many toxic releases. Dr. Robert Bullard, distinguished professor of urban planning at Texas Southern University's Barbara Jordan-Mickey Leland School of Public Affairs, calls such communities in industrial corridors "sacrifice zones."

"These are environmental sacrifice zones, and the residents of these communities are the victims, if you look at all the health disparities," Dr. Bullard said, noting that chemical exposures can change human biology. "Obesity, hypertension, diabetes, asthma — a lot of these diseases are elevated in certain populations," he said, and they have been associated with chemical exposures.

The community of Mossville, Louisiana, for example, is a small, predominantly Black community that is surrounded by 14 industrial facilities, three of which produce vinyl chloride or PVC. The Centers for Disease Control and Prevention (CDC) has found dioxin levels in Mossville residents' blood to be three times higher than average American dioxin levels, on multiple testing occasions.⁴¹ Further, the dioxin levels found in Mossville residents' yards and in the dust of their attics exceeded regulatory standards typically used for toxic waste remediations of industrial sites. Vegetables in their gardens also tested positive for dioxin. The CDC conducted these investigations after a 1998 health study by the University of Texas Medical Branch at Galveston found that Mossville residents suffered from a host of severe health problems,



Young residents near Mossville, Louisiana, play near PVC plastic facilities. Photo by Gary Little, courtesy of Greenpeace.

including cancer, respiratory ailments, and diseases affecting the kidney and liver, likely associated with industrial pollution.

Many were even forced to leave their homes after a spill of 1 million pounds of ethylene dichloride by the manufacturer Condea Vista created a plume of ethylene dichloride that contaminated groundwater and migrated underneath their homes.⁴²

The Gulf Coast is particularly impacted by PVC production, with nine of the oldest chlorine-producing plants located there, as well as five of the six largest dioxin emitters, according to a 2018 report by Healthy Building Network.⁴³ More recent data from EPA's Toxics Release Inventory show that one of the top five emitters of both dioxin and vinyl chloride is located in Kentucky, with the other major emitters located in Texas and Louisiana.

7.2. Installation

Different methods are used to install PVC and CPVC drinking water pipes depending on the size of the pipe and the fittings. Each method may result in chemical release into drinking water.

For example, larger-diameter PVC pipes are more commonly joined using a gasket seal made of styrene butadiene rubber.⁴⁴ NSF International testing of the gasket material has identified 13 volatile organic chemicals, phenol compounds, and other chemicals, including styrene and methylene chloride, leaching from the material.⁴⁵

Smaller-diameter PVC and CPVC pipe joints and segments are commonly joined using solvent-based cements and primers that seal the pipes through a chemical reaction that bonds the plastic parts together. The materials are applied to the inside of the pipe fitting and to the exterior of the pipe end before inserting the pipe into the fitting. The primer softens the surfaces of the pipe and the fitting, allowing the pipe to chemically fuse together with the fitting. Much of the solvent evaporates during installation; however, residual material could potentially leach into the tap water.

According to Dr. Terry Collins, this chemical bonding method is troubling — not only because the materials themselves may migrate into drinking water, but also because they may liberate other chemicals from the pipe materials when they react with the pipe walls.

Chemicals used in solvent cements include polyvinyl chloride resin, tetrahydrofuran, acetone, methyl ethyl ketone, and cyclohexanone, according to Healthy Buildings Network's Pharos database, which compiled the data by reviewing manufacturers' safety data sheets, searching for patents, and cross-checking with applicable safety standards (ASTM F493).

Tetrahydrofuran is especially worrisome, and not just for people who drink water delivered by PVC pipes, but also for the plumbers who install the pipe. Tetrahydrofuran causes liver and kidney damage and is possibly carcinogenic to humans, based on evidence of carcinogenicity in animals, according to the International Agency for Research on Cancer. California's Proposition 65 Law requires the chemical to be labeled as a carcinogen in consumer products. Tetrahydrofuran has been detected at low levels in water — along with other solvents, such as methyl ethyl ketone — in multiple studies on chemical migration from PVC pipes.

TABLE 4: Examples of PVC Cement Formulations in the U.S.

Table legend: THF is tetrahydrofuran; MEK is methyl ethyl ketone; numbers are the percentage of the chemical that is in the cement formulation.

COMPANY	HQ LOCATION	PRODUCT	THF	MEK	CYCLO-HEXANONE	ACETONE
Christy Enterprise	California	Red Hot Blue PVC Cement	45-70	5-20	10-30	
Contech	Ohio	PVC Pipe Cement	59	22	5	
EZ Weld	Florida	201 ENT Medium Body PVC Cement	10-60	0-25	5-30	10-30
Marsh Laboratories	Pennsylvania	PVC Cement	35-50	5-15	5-15	
Mill Rose Company	Ohio	Blue Monster PVC Cement	48-53	2-7	8-13	10-15
Oatey (Hercules brand)	Ohio	Medium Clear PVC Cement	30-50	10-25	10-20	10-25
Rectorseal	Texas	Gold 844L Clear PVC Solvent Cement	25-45	1-10	10-30	10-30
Spears	California	PVC-00	10-30	25-40	20-30	5-15
Weld-on (IPS)	California	Weld-On 704 PVC Cement	10-30	20-40	15-35	5-15

© Toxics Use Reduction Institute, University of Massachusetts Lowell.

Primers used for pipe installation additionally contain a purple dye, which may be toxic, but manufacturers do not disclose the dye’s chemical identity on their safety data sheets.

Workers who install PVC and CPVC pipes may face the biggest health risks associated with solvent cements. In 1989, the British Medical Journal reported two case studies of plumbers with acute poisoning — with symptoms including nausea, headache, blurred vision, dizziness, chest pain, and cough, as well as elevated liver enzymes — following high-level exposures to tetrahydrofuran in solvents on the job.⁴⁶ Both plumbers recovered from their symptoms after several days; however, their liver enzymes remained elevated for two weeks.

Another study examined solvent exposures among different groups of workers with end-stage renal disease and found that plumbers were among the groups with the highest risks of kidney disease. No

particular solvents were identified in the study, but the authors cited toluene, xylene, gasoline, and ketones as having the strongest association with kidney disease in the group of workers studied.⁴⁷

Some plumbers have voiced concerns about their exposure to these solvent cements. In 2021, members of the Plumbers and Gasfitters UA Local 12 in Boston objected to building-code changes expanding use of PVC pipes inside buildings because of the cements and the dust that's created when pipes are cut.⁴⁸

“It’s the whole joining process; it’s the glue, it’s the cleaner,” Joe King, a plumbing instructor for the union, told CBS News at the time. “You can smell how strong and potent it is. There isn’t one of these chemicals that says it’s safe for you.”

7.3. Consumer Health Issues (Water Pipe Use)

PVC and CPVC pipes may contaminate drinking water in three main ways. First, they may release dozens of chemicals into water from the pipe material, fittings, and adhesives used during installation, through a process known as leaching. PVC pipes can contaminate drinking water by a second process called permeation, which occurs when underground pollutants, such as gasoline leaking from a storage tank, seep through the pipe walls. In general, PVC pipes are less susceptible to permeation than other plastic pipes except at very high levels of contamination (i.e., as in a petroleum or chemical spill). Last, PVC and CPVC pipes may release toxic chemicals into drinking water after exposure to high heat, such as during wildfires or structure fires.

7.3.1. Leaching

Researchers have identified dozens of dangerous chemicals leaching from PVC and CPVC pipes. The potential for these chemical exposures to harm human health is not well understood.

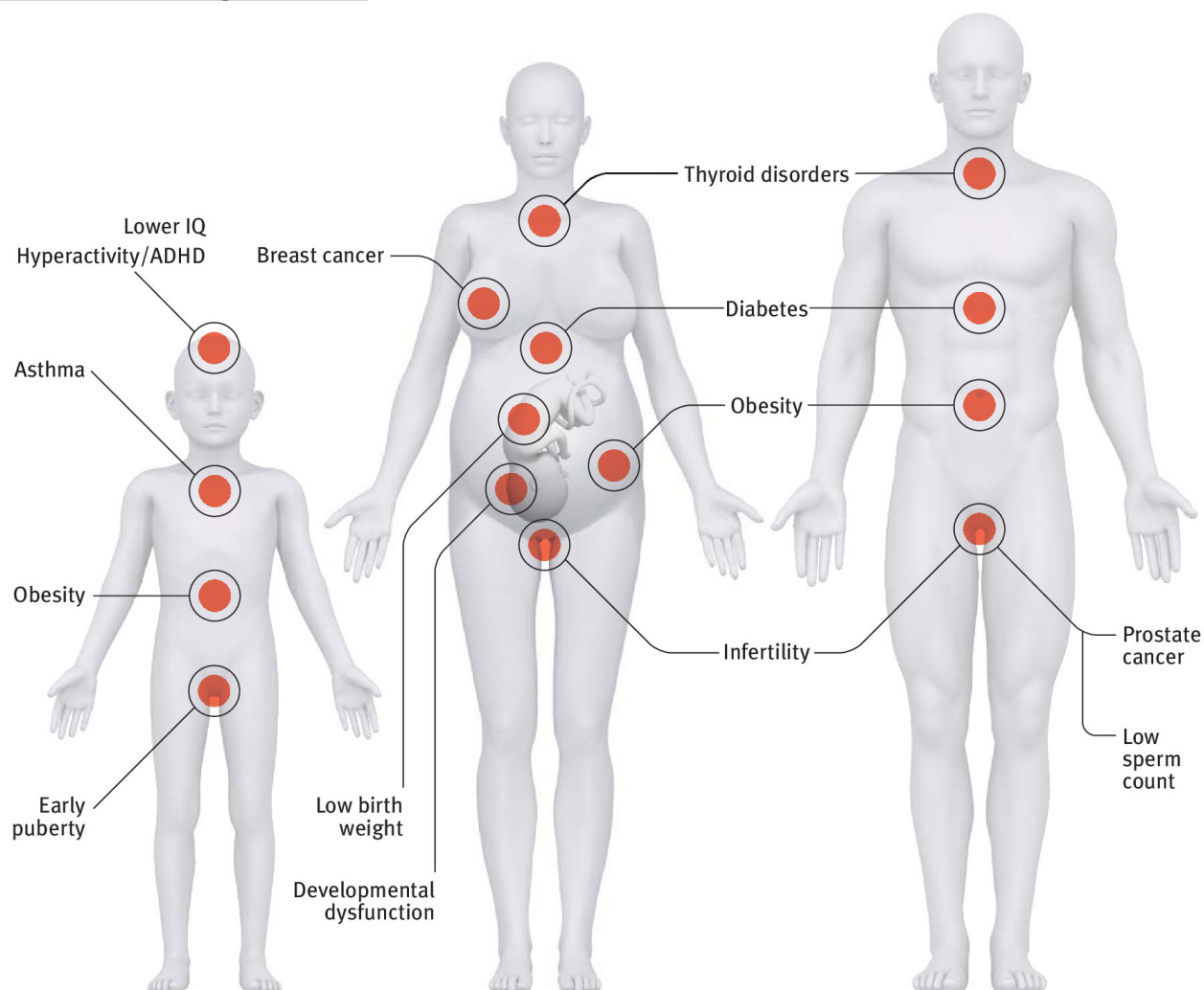
The fundamental reason for this uncertainty is insufficient data. First and foremost, toxicological information is lacking. Many of the chemicals detected do not have full, publicly available chemical hazard assessments. Second, few studies on chemical release from water pipes have been carried out in real-world settings. Most have been conducted in laboratories under varying conditions, which makes it difficult to aggregate the results. Third, many studies have been conducted outside the U.S. on locally manufactured pipes, which may or may not have the same product formulations as U.S. pipes. That matters because researchers note wide variability in the levels of chemicals leaching from different brand pipes, and even with pipes made by the same manufacturer.

Nevertheless, for some scientists enough is known about the chemicals that have been identified leaching from PVC and CPVC pipes to raise concerns.

“The health effects of the leachate chemicals that have been evaluated toxicologically are significant, ranging from liver and kidney effects to adverse health outcomes on the reproductive, developmental, immune, and nervous systems, endocrine disruption and/or carcinogenicity,” said Dr. Bonnie Ransom Stern, an independent consultant at BRStern and Associates LLC, and Dr. Gustavo Lagos, a professor at Pontificia Universidad Católica de Chile, in their 2008 research review.⁴⁹

Other researchers are especially worried about endocrine disruptors, which can hijack the body's hormone functions and cause diseases like cancer or diabetes, as well as reproductive and behavioral harms.⁵⁰ Endocrine disruptors are especially damaging to fetuses and young children whose brains and bodies are still developing. Small amounts of these chemicals, such as in the parts per trillion, can disrupt development. Disruptions in development can cause birth defects and neurodevelopmental diseases, while laying the foundation for other diseases later in life.

Everyday Exposures to Endocrine-Disrupting Chemicals Contribute to Modern Health Epidemics



“PVC is a horror show,” said Dr. Bruce Blumberg, professor of development and cell biology at the University of California Irvine, who studies endocrine disruptors, including organotins, which are used as heat stabilizers in PVC and CPVC pipes. “We don’t have much science on how much gets out [from PVC pipes] and gets into people, but we know a lot about the effects of the chemicals themselves, and we know a fair bit about their effects in animals. We should be concerned about the possible effects on humans.”

Dr. Blumberg’s concerns about endocrine-disrupting chemicals are widely shared. The Endocrine Society released a statement in 2009 that called these chemicals “a significant concern to public health.” The statement cited the widespread presence of hormone-disrupting chemicals in consumer

“PVC is a horror show.”

- Dr. Bruce Blumberg

products and their ability to cause many health impacts. In 2015, the Endocrine Society backed up its initial statement with a large and growing body of research. Additionally, more than 50 researchers and health providers released a scientific consensus statement in 2016 as a national “call to action” to significantly reduce exposures to chemicals and pollutants that are contributing to neurodevelopmental disorders in America’s children.

Drs. Stern and Lagos warn further about the issue of exposure to a mixture of chemicals leaching from plastic pipes. “Many of these substances target the same organ systems, leading to concerns that leachates whose

drinking water concentrations are individually below a chemical specific SPAC [single product allowable concentration] may have additive and synergistic effects when considered as a chemical mixture,” they said in their 2008 article.

Jane Muncke, an ecotoxicologist who serves as the managing director and chief scientific officer at the Food Packaging Forum, elaborated on the issue of multiple exposures raised by Drs. Stern and Lagos. “Even though you may test substance by substance, and you ensure there’s a threshold for substance A, B, or C, as soon as you have a mixture of ABC, and during fetal development in particular, those same thresholds may be fairly irrelevant. Individually those substances may be present below their safe levels, but as a mixture they may cause adverse effects. We’re just not testing them.”

7.3.1.1. Summary of Relevant Research on Chemical Migration From PVC Pipes

A recent summary of 39 peer-reviewed or government-led studies by the consulting firm Gradient identified a total of 163 dangerous substances leaching from all types of plastic pipe; 74 of these had no drinking water standard. For PVC pipes in particular, the researchers identified 59 chemicals — including benzene, styrene, toluene, organotins, epichlorohydrin, and tetrahydrofuran — leaching from the material. For CPVC pipes, 32 chemicals were found to migrate from the pipe walls. Note, however, that this study itself was not peer-reviewed. The researchers found that hydrocarbons, halogenated compounds, and organotins leached especially from PVC and CPVC pipe materials, but they cautioned that not all the hazardous substances they identified were found under actual use conditions in drinking water systems.

Halogenated hydrocarbons are carbon-based chemicals with at least one chlorine, fluorine, or bromine atom, and they are a “red flag for human health,” said Dr. Jane Muncke. Examples found leaching from PVC pipes in the Gradient paper included carbon tetrachloride and trichloroethylene, both probable carcinogens.

An earlier review of some 100 plastic pipe studies by Dr. Andrew Whelton and Mr. Nguyen found organic compounds leaching from PVC and CPVC pipe “directly related to the compounds used to

create the polymer and the pipe's processing conditions." For example, it identified tetrahydrofuran and methyl ethyl ketone, frequently used as solvents, and vinyl chloride, the building block of PVC and a known human carcinogen, in studies on PVC pipe leachate. The authors stressed that many factors are known to affect leaching from piping material — such as water quality, pH, and temperature — and even the procedure itself (i.e., whether water is allowed to flow through the pipe or the pipe material is immersed in water), and that it can be difficult to draw inferences from laboratory tests to actual use scenarios.

Researchers at Taibah University in Saudi Arabia conducted several studies testing chemicals leaching from PVC pipes in the laboratory and from tap water in Saudi homes. They identified a number of volatile organic and phenolic compounds leaching from the pipes and in tap water delivered by PVC pipes, including benzene, carbon tetrachloride, toluene, dibromomethane, and phenol. Some chemicals were found at levels above the World Health Organization's recommended guidelines. While these studies cannot be compared to the U.S., it is worth noting that they identified many of the same chemicals that U.S. based researchers have identified leaching from PVC pipes.

Moreover, the Saudi Arabian researchers noted variability in levels and types of chemicals leaching from different brands of pipes, as other researchers have found. Dr. Andrew Whelton said he typically sees wide variability in chemicals leaching from different plastic pipes made from the same material in his studies. "Manufacturers don't have good control and awareness about how variable their batches are," he said. "They pass the industry-sponsored, pre-market testing protocols [e.g., NSF International], but those don't necessarily represent what's being sent to market."

Dr. Andrew Whelton's observations may be why EPA's 2002 report on permeation and leaching noted that, "Despite the availability of NSF International's approved materials and standards, it is not possible to ensure continuous adherence to existing standards under all circumstances." In other words, just because a particular pipe brand passes NSF International certification, there is no guarantee that every pipe bought from that product line will perform the same when it comes to releasing chemicals into drinking water.

As Dr. Whelton put it, "There's this huge delta or variability between the plastics that leach. One utility may say, 'Well, I have this great PVC pipe; it's fine.' Another may say, 'We didn't have a good experience with it.' Well, these are two potentially truthful statements. And the fact of the matter is, there's no one running point on overseeing this issue."

7.3.1.2. *Organotins*

Organotins are complex chemical compounds with at least one tin-carbon bond. Chronic health impacts — including immune suppression, hormone disruption, stimulation of adipose tissue (obesity), and nervous and reproductive system impacts — have been associated with certain organotins, such as tributyltin. The toxicity of organotin compounds depends on the particular chemical structure that the tin's atoms are bonded to, and the number of tin-carbon bonds, according to Dr. Blumberg. Generally, the more toxic forms of organotins have three or more tin-carbon bonds.

Organotins are used as heat stabilizers for PVC and CPVC pipe in North America, in a classic case of regrettable substitution. Previously, lead and cadmium were added to the plastics to stabilize their chemical structures during manufacturing, and to enhance the pipes' ability to convey hot water. North American manufacturers phased out lead and cadmium in the 1990s because of their neurotoxic and other health effects, and replaced them with similarly troubling chemicals, organotins.

Manufacturers do not disclose the particular organotins they use, but according to NSF International, mono/dibutyl tin and mono/dimethyl tin are most commonly reported in U.S. PVC pipe formulations. The more toxic tributyltins have also been found in studies on PVC pipe extract, likely because manufacturers use crude mixtures of dibutyltins that also contain tributyltin.

The EPA has not set a drinking water standard for organotin compounds. The NSF/ANSI 61 procedure requires the total of any potentially leachable amounts of tin added to PVC pipe to be less than 4 parts per billion (for mono- and dibutyl/dimethyl species). NSF International also set a single allowable product concentration for tributyltin oxide of 0.2 parts per billion and a maximum contaminant level of 2 parts per billion.

Studies on organotins leaching from PVC and CPVC pipes have generally found levels of organotins in drinking water below the NSF International criteria.

Canadian researchers detected methyltin and dimethyltin in tap water at concentrations ranging from 0.5 to 257 parts per trillion and 0.5 to 6.5 parts per trillion, respectively, in approximately 45% of the homes tested. In a follow-up study, the same researchers found organotin compounds, primarily methyltins and butyltins, at concentrations up to 22 parts per trillion and 43.6 parts per trillion, respectively, in six Canadian water distribution systems. Water samples from PVC pipe segments analyzed in the lab contained consistent patterns of organotins, confirming that the organotins were indeed coming from the pipe materials.

An earlier laboratory study on CPVC pipes found that the organotin levels initially decreased rapidly and then much more slowly, suggesting that long-term leaching from new CPVC delivery systems was likely to occur. The authors also noted considerable variability in leachate levels occurred among CPVC pipes obtained from different manufacturers.

The World Health Organization, in a 2004 report on dialkyltins in drinking water, noted that “the concentrations observed in drinking water are several orders of magnitude lower than the doses reported to cause developmental effects in rats and mice.”

In a different kind of study, researchers focused on pinpointing which particular chemical additives used in plastics manufacturing cause the most toxic impacts to human cells. First, they extracted and identified chemical additives from five commonly used PVC polymer pellets and from three plastic products, including PVC water pipes. Next, they tested the effect of these chemical additives on several markers of toxicity in human cells. The researchers concluded that, organotins were the key driver of toxicity in PVC leachate from plastic pipes, out of all 56 chemical additives identified.

The authors additionally tested the migration potential for organotins from PVC pipe into tap water by leaching a small sample into ultrapure water at room temperature for 14 days. They found fairly low levels, 0.452 to 1.63 parts per billion of dibutyltin and 0.0016 to 0.0699 parts per billion tributyltin.

The EPA has not set a drinking water standard for organotin compounds.

Despite the relatively low levels of organotins detected in all of these studies, Dr. Blumberg, who researches the endocrine-disrupting properties of organotins, is not convinced that the levels leaching from PVC and CPVC pipe are safe.

The “numbers are suspect for how much leaches,” he said, explaining that it’s very difficult to measure organotins properly because they stick to the laboratory plasticware used for sample collection and storage, and that means that levels leaching from plastic pipes might actually be higher than what laboratories can measure. “We really don’t know how much anyone is exposed to,” he adds, stressing, however, that organotins are active at “extremely low doses.”

7.3.1.3. *Phthalates*

Phthalates are a group of chemicals used to make PVC plastics more flexible. They are often called plasticizers. Many phthalates are hormone-disrupting chemicals that can impact reproductive health and have been linked to asthma and developmental problems. The Consumer Product Safety Commission has, in fact, banned many phthalates from children’s toys because of their endocrine-disrupting effects.

Phthalates have been found leaching from PVC pipes in multiple studies (summarized in this section) even though the PVC pipe industry says that phthalates are not intentionally added to rigid PVC pipes. A life cycle assessment commissioned by the PVC Pipe Association states, for example, “Rigid PVC water and wastewater pipe, manufactured in the U.S. and Canada, does not use or contain phthalates, lead, or cadmium.”

NSF International echoes this message in its materials, stating, “Rigid PVC pipe and fittings certified by NSF do not contain phthalates or phthalate plasticizers.” A representative for the organization, Kara Nicolaidis, said in an email that NSF International’s routine testing for PVC pipes does not include phthalates because they are not reported in formulations.

This is troubling because it means that no one is testing for the possible presence of these endocrine-disrupting chemicals in drinking water delivered by PVC and CPVC pipes. Phthalates may not be reported in formulations, but they are sometimes present in chemical leachate coming from PVC and CPVC pipes.

For example, a study that identified organotins as the key driver of toxicity in PVC water pipe extracts also found low levels of phthalates in both PVC pre-production polymers and PVC pipes. Similarly, a 2017 paper found three phthalates in CPVC pipes, at concentrations higher than those found in cross-linked polyethylene (PEX) pipes, but at orders of magnitude below EPA and state drinking water standards. The researchers concluded that phthalate exposure from drinking water delivered by CPVC and PEX pipes is low compared to other dietary sources but is not negligible. They hypothesized that the phthalates could be coming from cross contamination during manufacturing, or from pigments or other additives not reported on safety data sheets.

Phthalates were also identified in leachates of PVC pipe materials in both the Gradient and Dr. Andrew Whelton literature reviews. Even a 2004 study examining odor and taste in drinking water that was based on a published analysis of an NSF International database reported diethylhexyl phthalate (DEHP) and diisononyl phthalate (DINP) as chemicals leaching from PVC and CPVC pipe. While manufacturers may not intentionally add phthalates to rigid PVC and CPVC pipes, studies suggest that these endocrine disruptors are nevertheless present, and that the NSF International should test for them on a routine basis. More importantly, the EPA should conduct independent tests.

While the levels found may be extremely low, Dr. Terry Collins warns that there is no acceptable low dose for hormone-disrupting chemicals. “The idea that, by lowering the dose of the chemical, you eventually get to a dose where it’s harmless is not the way the endocrine system works. You can have a very low dose produce a big effect, and a higher dose will not produce that effect.”

7.3.1.4. Vinyl Chloride

Prior to 1976, PVC pipes were found to leach vinyl chloride at levels of health concern. As a result, U.S. manufacturers modified their processes to include a step to remove most of the residual chemical, and the NSF revised its criteria for vinyl chloride, setting the level 10 times lower than EPA’s maximum contaminant level. Despite these changes, one study shows that PVC pipes may still leach this carcinogen into water though at levels below EPA’s legal limit, which is two parts per billion. Note, however, that vinyl chloride is measured at the point of entry into the water treatment and distribution system, not at the tap; that means that, even if PVC service lines were leaching significant levels of vinyl chloride into drinking water, it would not be detected under current EPA regulations.

Public water systems with PVC pipes manufactured before the industry change may continue to leach unsafe levels of vinyl chloride into tap water. The Kansas Health Department in 1998, for example, found that 10% of 125 rural water systems tested had vinyl chloride levels exceeding the EPA MCL of 2 parts per billion, with levels reaching as high as 8.9 parts per billion. Two of 167 public drinking water systems in Missouri had vinyl chloride levels above the MCL in 1998. St. Louis University researchers found the chemical at levels at 0 to 11.6 parts per billion in a Missouri water system, while research commissioned by the Water Research Foundation did not detect it in tap water from four locations in New York State.

New PVC pipe manufactured in the U.S. may continue to leach vinyl chloride at levels below the EPA MCL but higher than the NSF criteria of 200 parts per trillion. A 2011 study conducted by researchers at Cornell University found that vinyl chloride levels tested in the laboratory and in the tap water of consumers’ homes reached in the tens of parts per trillion range after a few days, and hundreds of parts per trillion after two years. Long-term studies in the lab suggested equilibrium concentrations of about 300 parts per trillion.

Vinyl chloride was found to accumulate in tap water to detectable levels mainly in small diameter (less than 1-inch) pipes. The researchers noted considerable differences in vinyl chloride levels across different manufacturers. Significantly, they suggested that vinyl chloride may accumulate not only from chemical leaching but also as a secondary byproduct of disinfection and that this is more pronounced than what is observed in other pipe materials. A life cycle assessment commissioned by the PVC Pipe Association acknowledged the possible impact of chlorination on vinyl chloride levels as well, stating, “Monitoring for vinyl chloride in water systems can be challenging since studies show that vinyl chloride can be a disinfection byproduct from chlorinated treatment systems.”

Dr. Muncke commented on broader concerns about using chlorine to disinfect water delivered by PVC and CPVC pipes. “When you have pipes made of PVC and you use chlorination to disinfect your drinking water, you’ll have a lot of chlorinated chemicals floating around in your drinking water.” Little research has been conducted on this, however, in comparison to other pipe types. Most research on the impact of chlorination has focused on the structural integrity of PVC pipes, though at least one study evaluated the chemical structure of PVCs pipes in chlorinated water and noted onset of degradation in the top layer of the pipes.

7.3.2. Permeation

The EPA reports that about 5,000 new petroleum spills occur annually in the United States from leaking underground storage tanks at locations such as service stations, marinas, municipal school bus garages, and military bases. In addition, some 60,000 old leaking underground storage tanks await cleanup, though the EPA has made great strides at cleaning up more than half a million of these old sites, which can release up to tens of thousands of gallons of fuel into the groundwater and soil.

Petroleum is just one of many contaminants that pollutes soil and groundwater. When underground pollution in soil or groundwater seeps through pipe walls into drinking water, permeation occurs. The EPA's "2002 Summary of Permeation and Leaching" identified more than 100 incidents of permeation of chemicals into water pipes at industrial areas, former fuel station sites, near underground storage tanks and in residential areas. All of the incidents occurred with plastic pipes; none occurred with metal pipes.

PVC pipes made up 15% of all incidents reported by the EPA. Most of the remaining incidents occurred with polybutylene (a pipe material that is no longer used) or polyethylene pipes. Chemicals identified permeating PVC water pipes at levels above EPA's maximum contaminant levels included the highly toxic benzene, vinyl chloride, and methylene chloride. The authors state that, when pollution levels are low, "PVC is virtually impenetrable," because of its rigid polymer structure. "However, when exposed to high activity (e.g., saturated) organic conditions, such as those that would occur during gross chemical spillage, PVC pipe is softened to the point of failure."

More recent research on the potential for permeation through PVC pipe joints and gaskets, however, found that gasoline is able to permeate through gaskets made of styrene-butadiene rubber and nitrile-butadiene rubber. Benzene broke through the gaskets, but not the intact pipe, after 21 days. The researchers concluded that "although PVC pipe joints were found to be permeated by free-product gasoline, water flow in pipes would dilute the benzene in drinking water to below the maximum contamination level (MCL)." Once again, because the EPA does not require monitoring of water at the tap after it passes through service lines, such problems are not likely to be detected unless severe contamination resulted in taste and odor problems that triggered complaints.

7.3.3. Wildfires/Thermal Degradation

Unlike metal pipes, plastic pipes are combustible and can burn or melt in fires. Emerging research documents that drinking water systems can become contaminated with high levels of dangerous organic chemicals after wildfires and potentially after structure, or building, fires.

Since 2017, dozens of volatile organic compounds have been found in 12 water distribution systems, following wildfires, at levels above safe drinking water exposure limits, according to a recent summary of research by Dr. Andrew Whelton and others. Benzene, a cancer-causing chemical, was detected in all 12 water systems, at levels ranging from 1 part per billion to as high as 40 parts per million, which is orders of magnitude above EPA's maximum contaminant level of 5 parts per billion. In 10 of these water systems, benzene was found at levels exceeding the EPA maximum contaminant level.

Notably, the water mains impacted by the 2017 Tubbs fire in Northern California, where the highest levels of benzene were found, were 84% PVC.

TABLE 5: Benzene Concentrations Found in Water Distribution Systems After Wildfires (2017-2020)

CONC., PPB	EVENT/LOCATION	POPULATION	SYSTEM NAME	YEAR
5.5	Echo Mountain Fire/Oregon	120	Whispering Pines Mobile Home Park	2020
11.3	Echo Mountain Fire/Oregon	362	Hiland WC - Echo Mountain	2020
1.1	Echo Mountain Fire/Oregon	760	Panther Creek Water District	2020
76.4	Almeda Fire/Oregon	6,850	City of Talent	2020
44.9	Lionshead Fire/Oregon	205	Detroit Water System	2020
1.8	CZU Lightning Complex Fire/California	1,650	Big Basin Water Co.	2020
42	CZU Lightning Complex Fire/California	21,145	San Lorenzo Water District	2020
>2,217	Camp Fire/California	26,032	Paradise Irrigation District	2018
38.3	Camp Fire/California	924	Del Oro Water Co.-Magalia	2018
8.1	Camp Fire/California	1,106	Del Oro Water Co.-Lime Saddle	2018
530	Camp Fire/California	11,324	Del Oro Water Co.-Paradise Pines	2018
40,000	Tubbs Fire/ California	175,000	City of Santa Rosa	2017

Dr. Whelton’s study notes that, in addition to benzene, dozens of other VOCs were detected in these damaged water distribution systems. Semi-volatile organic compounds (SVOC), which are chemicals that do not diffuse as readily as VOCs and may stick around longer in soil and water, were also detected in a few distribution systems. Examples of SVOCs that were found include 4-chloro-3-methyl phenol, benzaldehyde, and benzyl alcohol.

Other volatile organic chemicals found in drinking water systems, following wildfire, at levels exceeding both short- and long- term exposure limits include vinyl chloride, styrene, tetrahydrofuran, methylene chloride, and naphthalene, among others. Each of these chemicals is potentially or definitively linked with different types of cancer.



“Thermal damage to plastic pipes is a real problem,” noted Kristofer Isaacson, a graduate student at Purdue University who has researched the issue with Dr. Andrew Whelton. “The data show that thermally degraded plastics generate contaminants that can go into and through drinking water systems, including through intrusion of smoke. We cannot attribute right now the degree that this happens, but what we can tell you is this is definitely a potential source.”

The 2018 Camp Fire that burned down Paradise, California — destroying 14,600 homes and killing 86 people — left a toxic legacy in the community’s water supply that continues to linger. Close to 100 organic compounds were identified in a highly contaminated water service line. Thirty-two of the compounds found were associated with PVC pyrolysis, or thermal decomposition at high temperatures. Benzene was initially detected at 2.2 parts per billion, lower than the EPA’s maximum contaminant level, but above the state of California’s safe level at 1 part per billion. Subsequent testing reported by the Plastics Pipe Institute reported average benzene levels found in 8.5% of samples collected across the water system at 0.5 to 15 parts per billion. Chemical contamination and water restrictions remained an issue for homes and businesses impacted by these two fires for more than one year.

Water contamination lingers in part because when plastic pipes melt or burn, they release organic compounds into the water that can then backflow into the system and adhere to the insides of other pipes. It can become difficult to flush that out.

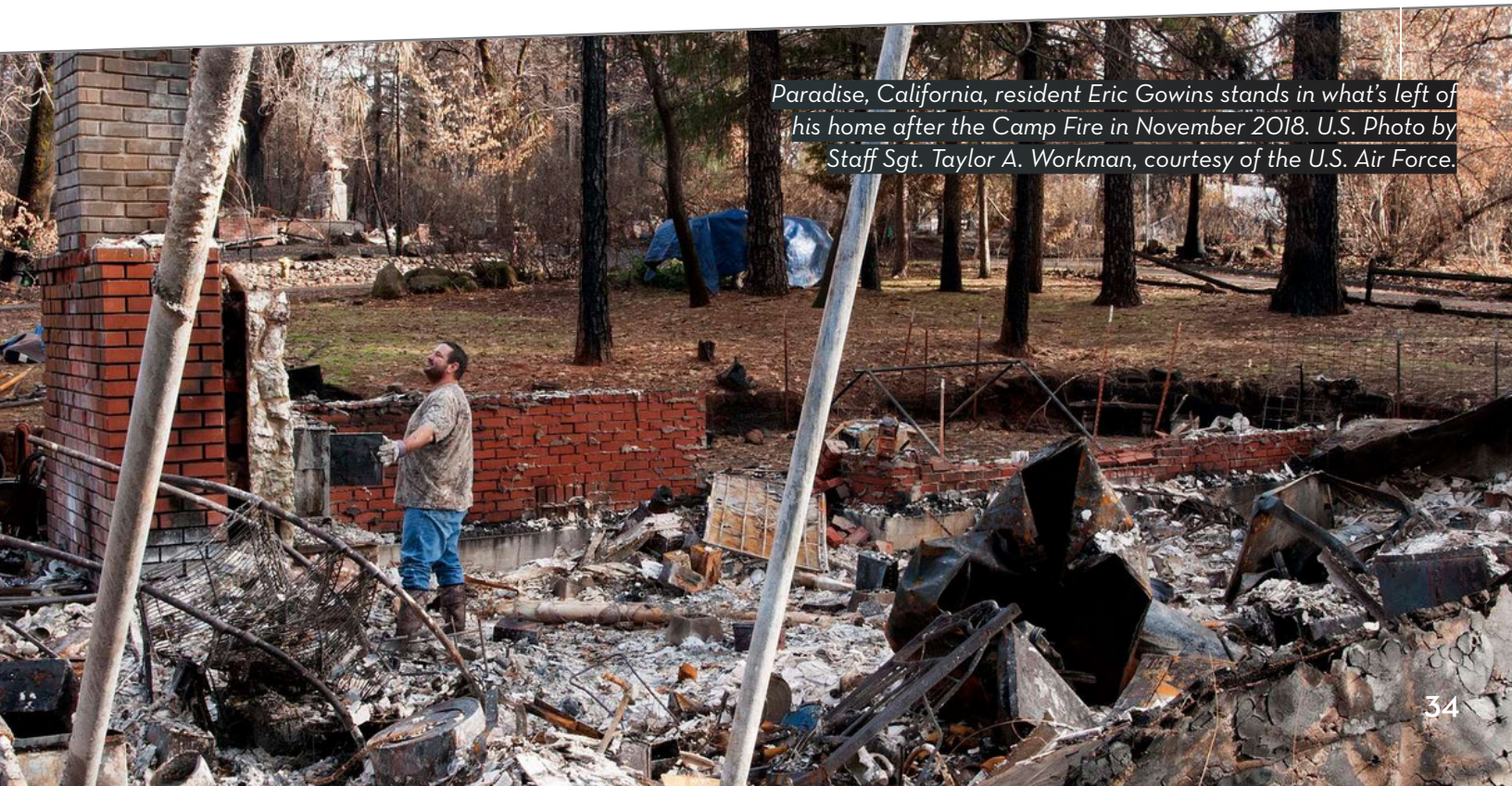
The Plastics Pipe Institute conducted its own investigation on the source of the chemicals in Paradise’s drinking water system and concluded that there was “no evidence that the heating or burning of HDPE or PEX plastic pipe is responsible for the contamination of the water system.” Notably, the industry association was silent about PVC pipe as a possible source of the contamination, even though its report says that 35% of water mains in Paradise were PVC, and that PVC was also used for some service lines.

The crux of the Plastics Pipe Institute’s argument that HDPE and PEX pipes were not the source of the benzene and other volatile organic compounds is that they did not find any clear patterns linking contaminant levels to particular pipe materials. But linking benzene levels to the hodgepodge of materials used for water mains (e.g., PVC, steel, ductile iron, asbestos cement, and cast iron) and service lines (e.g., steel, polybutylene, copper, PVC, and HDPE) in the community isn’t an easy exercise. What’s more, the industry group did not provide actual data or an analysis to back up its claim.

To better understand the potential for burning plastic pipes to release chemicals into drinking water, Dr. Whelton and Mr. Issacson tested 11 different plastic pipe materials across eight brands, thermally degrading the pipes up to 400 degrees Celsius, and extracting chemicals out of the remains. They concluded that exposing commercially available plastic drinking water pipes to heat can generate detectable levels of BTEX (benzene, toluene, ethylbenzene, and xylene) which can then leach from cooled plastics into water. Low amounts of benzene and toluene, in particular, were found to leach from thermally degraded PVC pipes. Benzene was the only BTEX found to leach from damaged CPVC pipe. Other chemicals were tentatively identified, including hydrocarbons, aromatic compounds, and ketones.

Dr. Andrew Whelton stressed that much uncertainty remains about chemical releases from plastic pipes following fire, and that’s a problem for public health. “We know organic chemicals leach out of all plastic pipes, but there’s no rule to understand what you should be looking for. When lead pipe is thermally damaged, or copper pipe is thermally damaged, you’re not saying the lead is going to transform into some other chemical, but for plastics it is. And when you have a structure that burns or gets heated, and you don’t know what to look for, you don’t set yourself up for protecting public health.” The threat of wildfires is not limited to the arid west. More than 68,000 wildfires have occurred annually, on average, in the U.S. over the past two decades. These fires have burned, on average, a total of 7 million acres of land each year.

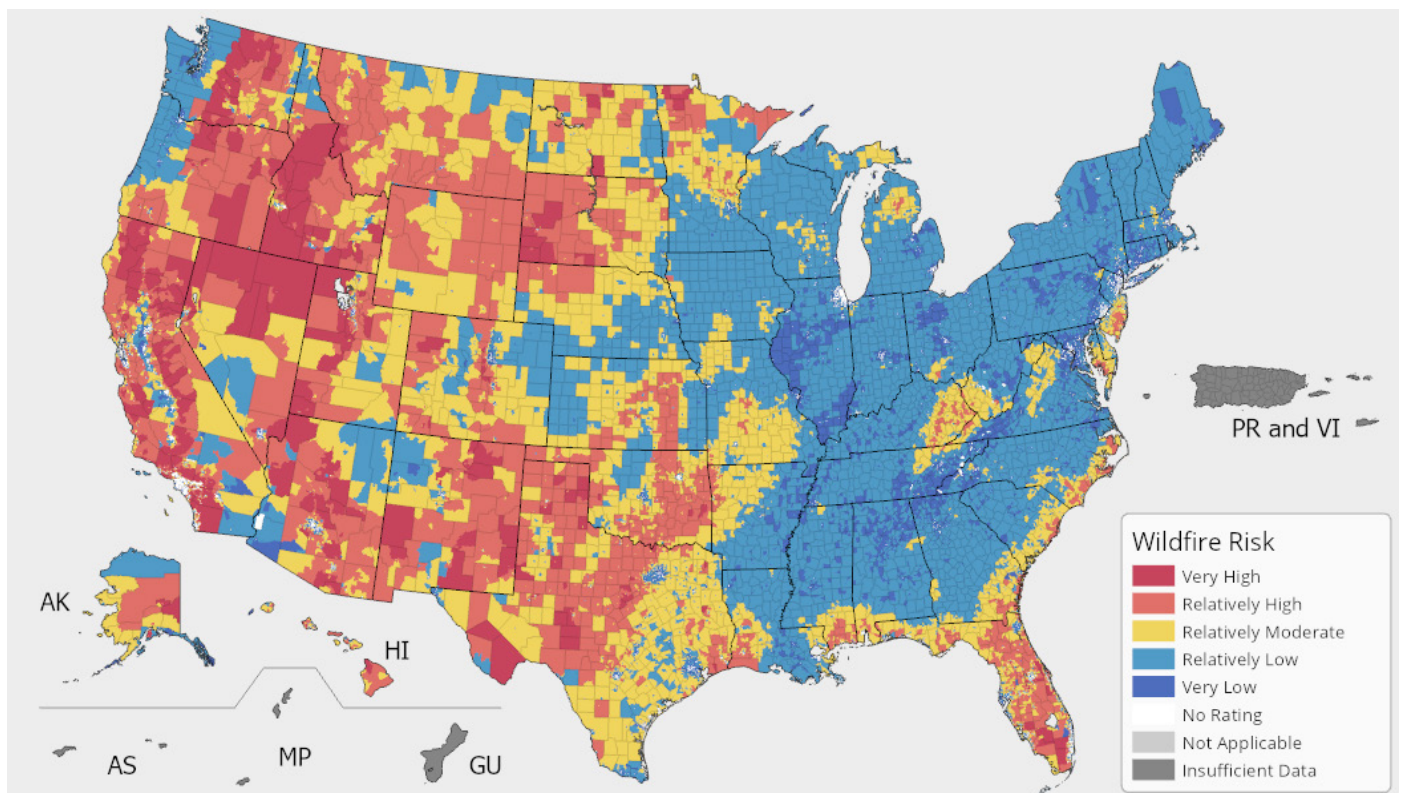
The threat of wildfires is not limited to the arid west. More than 68,000 wildfires have occurred annually, on average, in the U.S. over the past two decades. These fires have burned, on average, a total of 7 million acres of land each year.



Paradise, California, resident Eric Gowins stands in what's left of his home after the Camp Fire in November 2018. U.S. Photo by Staff Sgt. Taylor A. Workman, courtesy of the U.S. Air Force.

“We know that when plastics burn, they emit carcinogens and increase the risk of occupational illness and death for firefighters.”

- Harold Schaitberger, IAFF General President



Map of wildfire risk in the United States, courtesy of FEMA.gov.

“We know that when plastics burn, they emit carcinogens and increase the risk of occupational illness and death for firefighters,” IAFF General President Harold Schaitberger said in a press release. Burning plastic pipes also pose a threat to the health of emergency responders. In fact, in 2019, the general presidents of the International Association of Fire Fighters (IAFF) and the United Association of Plumbers, Fitters, Welders and Service Techs US issued a joint statement calling on developers, builders and code officials to reduce and restrict the use of plastic pipes installed in buildings.

The six most common plastics [including PVC] used for water piping pose similar levels of risk, according to multiple studies and field experiences. Each of these plastics may release chemicals, hydrocarbons and/or dangerous carcinogens while transporting water and when exposed to fires.

7.3.4. Exposure to Chemical Mixtures

All researchers interviewed commented on the toxic cocktail of endocrine-disrupting and other chemicals that people are exposed to on a daily basis from personal care products, food packaging, medical devices, and household dust from home furnishings. It's imperative, they said, that we don't create another pathway for exposure from drinking water delivered by PVC and CPVC pipes.

Dr. Jane Muncke commented on emerging research that points to the dangers of daily exposure to multiple chemicals from plastics materials. "In everyday life, chronic exposure to untested or sometimes inappropriately tested synthetic chemicals is huge. It's hundreds and hundreds of man made, synthetic chemicals that scientists are measuring in umbilical cord fluid, umbilical cord blood, or in blood and urine of pregnant women, or in adult men and children," she said.

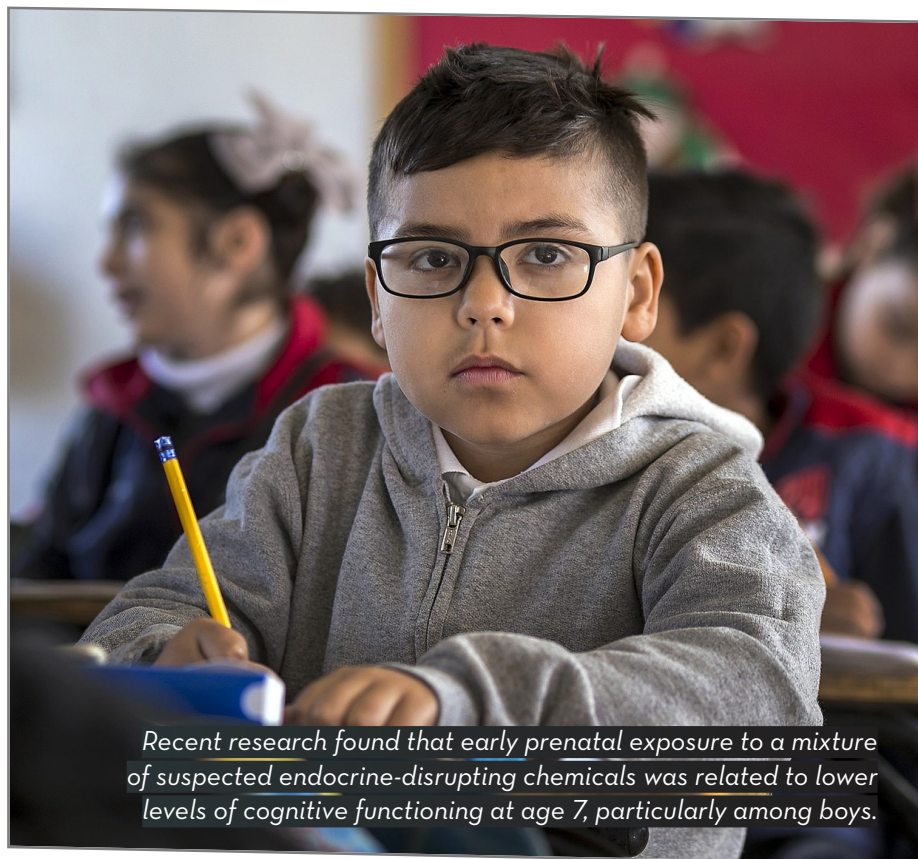
She pointed to recent research that found that early prenatal exposure to a mixture of suspected endocrine-disrupting chemicals was related to lower levels of cognitive functioning at age 7, particularly among boys and another study that found increased odds of language delay. In the latter study, the researchers concluded that the results emphasized "the need to take mixtures into account during chemical testing and risk assessment and provide an integrative framework to guide risk assessment strategies."

The problem, of course, is teasing out which particular plastic materials are responsible for the elevated levels of chemicals showing up in human blood and harming children and developing fetuses.

For both Dr. Jane Muncke and Dr. Terry Collins, assigning blame isn't the point. Products should not be put on the market without adequate testing for their potential to disrupt hormones, or cause other health problems, at low-dose exposures.

"Products containing these untested, unknown man made chemicals get put on the market by people who make a lot of money, and at the same time some of these man made chemicals are linked to health impacts or lower IQ values or language delays in children, and society or the affected individuals pay the brunt of that," Muncke said.

"It is totally inexcusable to sell chemical technology that exposes either people or the environment to endocrine disruptors," Collins agreed. "We will not have a sustainable chemical enterprise, including a sustainable water industry, until we come to terms with how the endocrine hormone system works in the design of everything that we do."



Recent research found that early prenatal exposure to a mixture of suspected endocrine-disrupting chemicals was related to lower levels of cognitive functioning at age 7, particularly among boys.

7.4. End of Life: PVC and Dioxins

Of the 40 million tons of plastic waste generated in the United States in 2021, a paltry 5% to 6% was recycled. The vast majority of plastic waste is sent to landfills, burned in incinerators, or shipped overseas. Managing plastic waste has become an enormous global problem, with much of the waste ending up in our oceans where it kills thousands of mammals, seabirds, and turtles every year and breaks into tiny microplastics that can harm many other species of marine life.

The Vinyl Institute touts the recyclability of PVC, and reports that pipes are one of the top-end markets for recycled vinyl based on a survey of over 100 vinyl recyclers in North America. Its survey reported that roughly 500,000 tons of vinyl materials were recycled in 2013. EPA data from 2018 in contrast reported a “negligible” recycling rate for the 840,000 tons of PVC waste that passed through municipal solid waste facilities, though the waste stream likely contained PVC consumer products, such as shower curtains or hoses.

Nevertheless, many recyclers consider PVC difficult to recycle because of its many hazardous chemical additives and its inherent chlorine content. As a result, PVC requires separation from other plastics before recycling. Difficulty with recycling the material is one of the reasons why the European Commission asked the European Chemicals Agency to investigate whether the use of PVC and/or its additives cause a risk for the environment and/or human health, and whether regulations restricting the material may be necessary, according to Muncke.

“One of the concerns with the use of PVC is that it’s hard to recycle,” said Dr. Jane Muncke. “If you’ve got a material that contains known hazardous chemicals, you don’t want to be using that material in the first place. But you also don’t want to be recycling it because you just perpetuate spreading those hazardous chemicals in your recycling streams.”

When PVC pipes are eventually disposed of in landfills and incinerators, they can contribute to the release of dioxins, considered to be the most toxic man-made chemicals on the planet.

As the U.S. Green Building Council noted in its Technical Science Advisory Committee (TSAC) final report, “When we add end of life with accidental landfill fires and backyard burning, the additional risk of dioxin emissions puts PVC consistently among the worst materials for human health impacts.”

8. CONCLUSION

The publicly available research on the long-term leaching of vinyl chloride, halogenated hydrocarbons, organotins, and other toxic contaminants from PVC water distribution piping is inadequate. While there is ample evidence that PVC and CPVC pipes can release toxic compounds into drinking water, including after multiple years following installation, the full spectrum of chemicals and levels of contamination that they release are not well understood. This is particularly the case when chlorinated water interacts with these pipes for a prolonged period, because the chlorine can react and produce chemical byproducts with certain plastic pipes.

Chemical leaching has also been found to vary by product formulation, and manufacturers are not required to disclose the chemical ingredients of their pipes, nor report their chemical release testing data. That makes it hard to ascertain the full group of chemicals that may be released in a given water distribution system.

At a minimum, PVC and CPVC pipes have been found to release endocrine-disrupting chemicals — organotins and possibly phthalates — which can harm children and developing fetuses at very low levels. As Dr. Andrew Whelton stated, “If we put lead pipes in our system, we know we need to look for lead. If we put iron in our system, we know we need to look for iron. But if we put ‘black box’ pipes in our system, we don’t know what we should be looking for.” In other words, public health researchers are hard-pressed to monitor the safety of drinking water delivered by plastic pipes when they are made of dozens of chemicals that are unknown (and hence a “black box”) because of trade secrets. “Public health officials, municipal engineers, and even industry are so far behind in understanding the materials,” he added.

For some researchers, that information alone is enough to raise serious concerns about the safety of drinking water delivered by these plastic pipes. Moreover, PVC and CPVC pipes undoubtedly release mixtures of harmful chemicals and there are no existing drinking water standards that factor in the cumulative burden of exposure to these mixtures.

The way to address the concerns about endocrine-disrupting and other harmful chemicals is to measure the levels in humans, and especially in pregnant women and children, said Dr. Blumberg. “They’re the most sensitive, and we’re simply not doing that.”

At a minimum, PVC and CPVC pipes have been found to release endocrine-disrupting chemicals — organotins and possibly phthalates — which can harm children and developing fetuses at very low levels.

Additionally, PVC and CPVC, like all plastic pipes, thermally degrade during wildfires or building fires. And when they do, they can release benzene and other chemicals into drinking water at levels above what the EPA considers safe. It has taken one California community more than a year to restore its drinking water quality after a severe wildfire. Firefighters and other emergency responders are additionally exposed to harmful chemicals associated with burning plastic pipes, and have called on developers, builders, and code officials to restrict their use in buildings.

NSF International asserts that the PVC and CPVC products that it certifies are safe. “We are confident the NSF standard and certification process are thorough, robust, and protective of public health. The NSF standards process is open and transparent for anyone to suggest improvements or changes through the Drinking Water Additives Joint Committee,” noted Jeremy Brown, regulatory affairs manager of NSF International, in a written statement.

It is difficult to evaluate its claims, however, when it does not publicly release its decades of testing data. It is further difficult to take the PVC pipe industry’s claims of safety at face value when its commissioned life cycle assessment includes no discussion on the potential for chemical leaching, other than vinyl chloride, and simply states, “Rigid PVC water and wastewater pipe, manufactured in the U.S. and Canada, does not use or contain phthalates, lead, or cadmium. As a result, PVC pipe is recognized as a safe product and beneficial to public health.”

“The industry claims that they’ve been safe for 50 years,” said Betanzo. “If they’ve been safe for over 50 years, they should have volumes and volumes of data to prove it. But I just haven’t seen the data I would like to see to back up those claims.”

More research is needed to understand chemical leaching from plastic piping material, said Dr. Terry Collins, who urges governments worldwide to fund research into the safety of drinking water from plastic pipes, and manufacturers to release all of their leaching data, so that municipalities and water utilities can make informed decisions.

“I think we should have expanded studies into the nature of all liberated chemicals, the dynamics

of the liberation processes, the stability of the piping under microbial assault, the nature of the chemicals liberated by that assault, and importance of water variables on the processes,” he said, flagging yet another concern with plastic pipes: the ability of certain microbes to break them down

“If municipalities want to swap out their lead pipes, and they have conditions that allow for copper, I encourage copper because there’s more known about that material than the plastics.”

-Dr. Andrew Whelton

in the environment over time. Microorganisms can form biofilms inside of the pipes and, once they get a solid footing, attack the PVC. Chlorinated byproducts are a logical end result of the process, according to Dr. Collins.

For some researchers, the unknowns with plastic pipes are too great when a better alternative exists. If municipalities want to swap out their lead pipes, and they have conditions that allow for copper, I encourage copper because there's more known about that material than the plastics," said Dr. Andrew Whelton.

"Sometimes the plastic alternative doesn't cause problems, but sometimes it does," he continued, noting how frequently plastic pipe industry representatives have told him that plastic pipes are inert and don't leach, but "that's simply not true." Dr. Whelton encourages the EPA "to get up to speed on plastics," stating, "they have no staff who understand plastics, but they're legally required to help keep our drinking water safe."

To avoid replacing one toxic material (lead) with another one, Beyond Plastics, Environmental Health Sciences, and Plastic Pollution Coalition encourage decision-makers to carefully consider the questions posed in the Recommendations section on page 7.



The bulk of the expense of replacing lead service lines comes from the costs of heavy machinery and labor, rather than from the cost of the replacement piping, regardless of what piping material is used. Lead service line replacement in progress in Stoughton, Wisconsin. Images by Casey Sweeney, courtesy of the Wisconsin Department of Natural Resources.

9. APPENDIX

TABLE 3: PVC Manufacturing and Other Facilities Reporting Vinyl Chloride Releases to EPA's Toxic Release Inventory Program - 2021

	<u>FACILITY</u>	<u>VINYL CHLORIDE TOTAL ON-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL OFF-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL ON- AND OFF-SITE DISPOSAL OR OTHER RE-LEASES</u>
1	Formosa Plastics Corp Texas 201 Formosa Dr. Point Comfort, TX 77978 (Calhoun)	68,346	0	68,346
2	Westlake Vinyls, Inc 2468 Industrial Pkwy, Calvert City, KY 42029 (Marshall)	59,329	7	59,336
3	Westlake PVC Corp 230 Johnson Riley Rd, Calvert City KY 42029 (Marshall)	57,053	.	57,053
4	Westlake Lake Charles North 1600 Vcm Plant Rd, Westlake LA 70669 (Calcasieu Parish)	21,137	.	21,137
5	Mexichem Specialty Resins Inc 76 Porcupine Rd - Po Box 420, Pedricktown NJ 08067 (Salem)	20,488	10	20,498

	<u>FACILITY</u>	<u>VINYL CHLORIDE TOTAL ON-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL OFF-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL ON- AND OFF-SITE DISPOSAL OR OTHER RE-LEASES</u>
6	<u>Westlake Vinyls Co</u> 36045 Hwy 30, Geismar LA 70734 (Ascension Parish)	19,300	.	19,300
7	<u>Mexichem Specialty Resins Inc</u> 1546 County Rd 1450N, Henry IL 61537 (Marshall)	19,115	21	19,135
8	<u>Axiall LLC</u> 26100 Hwy 405 S, Plaquemine LA 70764 (Iberville Parish)	18,922	.	18,922
9	<u>Formosa Plastics Corp Louisiana</u> Gulf States Rd, Baton Rouge LA 70805 (East Baton Rouge Parish)	18,249	.	18,249
10	<u>Shintech Inc</u> 5618 Hwy 332 E, Freeport TX 77541 (Brazoria)	17,721	.	17,721
11	<u>Shintech Plaquemine Plant</u> 26270 Hwy 405, Plaquemine LA 70764 (Iberville Parish)	16,265	.	16,265

	<u>FACILITY</u>	<u>VINYL CHLORIDE TOTAL ON-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL OFF-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL ON- AND OFF-SITE DISPOSAL OR OTHER RE-LEASES</u>
12	<u>Oxy Vinyls LP Pasadena PVC Plant</u> 4403 Pasadena Fwy, Pasadena TX 77503 (Harris)	15,599	.	15,599
13	<u>Shintech Louisiana LLC - Addis Plant A</u> 9750 Louisiana Hwy 1 S, Addis LA 70710 (West Baton Rouge Parish)	15,192	.	15,192
14	<u>Occidental Chemical Corp</u> 4133 Hwy 361, Gregory TX 78359 (San Patricio)	15,008	.	15,008
15	<u>Oxy Vinyls LP Deer Park Caustic</u> 1000 Tidal Rd, Deer Park TX 77536 (Harris)	10,583	.	10,583
16	<u>Oxy Vinyls LP La Porte VCM Plant</u> 2400 Miller Cutoff Rd, La Porte TX 77571 (Harris)	7,350	88	7,438
17	<u>Eagle US 2 LLC</u> 1300 Ppg Dr, Westlake LA 70669 (Calcasieu Parish)	5,287	1	5,288

	<u>FACILITY</u>	<u>VINYL CHLORIDE TOTAL ON-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL OFF-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL ON- AND OFF-SITE DISPOSAL OR OTHER RE-LEASES</u>
18	<u>Axiall LLC-Aberdeen</u> 715 Hwy 25 S, Aberdeen MS 39730 (Monroe)	4,779	.	4,779
19	<u>Oxy Vinyls LP</u> <u>Deer Park-VCM Plant</u> 5900 Hwy 225 Gate 8a, Deer Park TX 77536 (Harris)	3,977	.	3,977
20	<u>Oxy Vinyls LP</u> Rt 130 & Porcupine Rd, Pedricktown NJ 08067 (Salem)	3,929	.	3,929
21	<u>Occidental Chemical</u> <u>Holding Corp -</u> <u>Geismar Plant</u> 8318 Ashland Rd, Geismar LA 70734 (Ascension Parish)	3,232	51	3,283
22	<u>Freeport Olin BC</u> 2301 N Brazosport Blvd, Freeport TX 77541 (Brazoria)	2,418	.	2,418
23	<u>Daikin America Inc</u> 905 State Docks Rd, Decatur AL 35601 (Morgan)	1,820	.	1,820

	<u>FACILITY</u>	<u>VINYL CHLORIDE TOTAL ON-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL OFF-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL ON- AND OFF-SITE DISPOSAL OR OTHER RE-LEASES</u>
24	<u>Lubrizol Advanced Materials Inc</u> 4200 Bells Ln, Louisville KY 40211 (Jefferson)	1,144	1	1,145
25	<u>The Chemours Co</u> Hwy 361, Gregory TX 78359 (San Patricio)	942	.	942
26	<u>Corteva Freeport Operations</u> 698 Midway Rd, Freeport TX 77541 (Brazoria)	613	.	613
27	<u>Basf Corp - Hannibal Site</u> 3150 Hwy Jj, Palmyra MO 63461 (Marion)	287	.	287
28	<u>Clean Harbors El Dorado LLC</u> 309 American Cir Union, El Dorado AR 71730 (Union)	6	108	114
29	<u>Rowmark Custom Laminations</u> 182 Industrial Park Dr, Trenton NC 28585 (Jones)	68	.	68

	<u>FACILITY</u>	<u>VINYL CHLORIDE TOTAL ON-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL OFF-SITE DISPOSAL OR OTHER RELEASES</u>	<u>VINYL CHLORIDE TOTAL ON- AND OFF-SITE DISPOSAL OR OTHER RE-LEASES</u>
30	Clean Harbors Environmental Services Inc 2247 S Hwy 71, Kimball NE 69145 (Kimball)	23	2	25
31	Clean Harbors Deer Park LLC 2027 Independence Parkway South, La Porte TX 77571 (Harris)	25	.	25
32	Huntsman Ethyleneamines Plant 307 County Rd 624 A1 A38 Block, Freeport TX 77541 (Brazoria)	15	.	15
33	Mexichem Specialty Resins Inc. 33653 Walker Rd, Avon Lake OH 44012 (Lorain)	10	.	10
Total		428,233	289	428,522
TOTAL DISPOSAL OR OTHER RELEASES OMITTING DOUBLE COUNTED AMOUNTS				428,522

ENDNOTES

- 1 EPA (2002). Permeation and Leaching, United States Environmental Protection Agency - Office of Ground Water and Drinking Water, Washington, D.C.
- 2 National Cancer Institute. Vinyl Chloride. Available: <https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/vinyl-chloride>
- 3 Oxford Journals (2002). Preventable Exposures Associated With Human Cancers. Available: https://monographs.iarc.who.int/wp-content/uploads/2019/07/Cogliano_2011_JNCI_Preventable_Exposures.pdf
- 4 United States Consumer Product Safety Commission (1974). CPSC Ban on Vinyl Chloride in Aerosols. Available: <https://www.cpsc.gov/Newsroom/News-Releases/1974/CPSC-Issues-Ban-On-Vinyl-Chloride-In-Aerosols>
- 5 GovInfo (2016). Use of vinyl chloride as an ingredient, including propellant of cosmetic aerosol products. Available: <https://www.govinfo.gov/app/details/CFR-2016-title21-vol7/CFR-2016-title21-vol7-sec700-14>
- 6 Bonnie Ransom Stern & Gustavo Lagos (2008). Are There Health Risks from the Migration of Chemical Substances from Plastic Pipes into Drinking Water? A Review, *Human and Ecological Risk Assessment: An International Journal*, 14:4, 753-779.
- 7 U.S. EPA (February 2023). Manifest of train contents; link to online manifest returns a “404 not” found message. See also “Ohio Train Manifest Reveals Full List of Chemicals Released from Derailment.” Aleks Phillips. *Newsweek*, 2/16/23.
- 8 Simon Ducroquet et al (Feb. 18, 2023). *Washington Post*. “Here’s what the derailed Ohio train was carrying – and what was burned: A visual timeline of how the Norfolk Southern train disaster unfolded.”
- 9 The Healthy Building Network. Potable Water Piping Product Guidance. Available: <https://healthybuilding.net/products/12-water-pipes>
- 10 Bob Walker, North America’s Cinderella Pipe Story: A Look at PVC Pipes’ Climb to the Top, *Journal of ASTM International*, Vol. 8, No. 7, 2010.
- 11 Ingun Skjevrak, Anne Due, Karl Olav Gjerstad, Hallgeir Herikstad, Volatile organic components migrating from plastic pipes (HDPE, PEX and PVC) into drinking water, *Water Research*, 37 (8), 2003, pp 1912-1920.

- 12 Bonnie Ransom Stern & Gustavo Lagos (2008), Are There Health Risks from the Migration of Chemical Substances from Plastic Pipes into Drinking Water? A Review, *Human and Ecological Risk Assessment: An International Journal*, 14:4, 753-779.
- 13 Andrew J. Whelton & Tinh Nguyen (2013), Contaminant Migration From Polymeric Pipes Used in Buried Potable Water Distribution Systems: A Review, *Critical Reviews in Environmental Science and Technology*, 43:7, 684.
- 14 Bonnie Ransom Stern & Gustavo Lagos (2008), Are There Health Risks from the Migration of Chemical Substances from Plastic Pipes into Drinking Water? A Review, *Human and Ecological Risk Assessment: An International Journal*, 14:4, 753-779.
- 15 EPA, National Primary Drinking Water Regulations. Accessed March 2023. <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations>
- 16 Zhanyun Wang, et al. Toward a Global Understanding of Chemical Pollution: A First Comprehensive Analysis of National and Regional Chemical Inventories, *Environmental Science & Technology* 2020 54 (5), 2575-2584.
- 17 EPA, Biden-Harris Administration Proposes First-Ever National Standard to Protect Communities from PFAS in Drinking Water, press release, March 14, 2023.
- 18 Annie Snider, What Broke the Safe Drinking Water Act? <https://www.politico.com/agenda/story/2017/05/10/safe-drinking-water-perchlorate-000434/>, May 10, 2017.
- 19 Neil Bedi, Sharon Lerner and Kathleen McGrory (Dec. 14, 2022.) Why the U.S. Is Losing the Fight to Ban Toxic Chemicals, *ProPublica*.
- 20 U.S. EPA. EPA's Budget & Spending, accessed March 2023. Available: <https://www.epa.gov/planandbudget/budget>
- 21 NSF/ANSI 61 - 2016. Drinking Water System Components - Health Effects, NSF International Standard and ANSI International Standard.
- 22 John Wisely (July 5, 2018). Ethics Charges could hurt fight against Legionnaires disease, *Detroit Free Press*.
- 23 John Wisely (July 5, 2018). Ethics Charges could hurt fight against Legionnaires disease, *Detroit Free Press*.
- 24 Jennifer Clancy, NSF International's Breach of Ethics and Trust Is A Threat To Public Health, Linked In, May 7, 2018.
- 25 Osha Gray Davidson (January 2009). The Bush Legacy, An Assault on Public Protections, OMB Watch.
- 26 Elizabeth Ward et al. (2001), Update of the Follow-up of Mortality and Cancer Incidence Among European Workers Employed in the Vinyl Chloride Industry, *Epidemiology*, 12:6, 710-718.

- 27 Morando Soffritti, Jennifer Beth Sass, Barry Castleman and David Gee, (2013). Vinyl Chloride, a Saga of Secrecy. <https://www.eea.europa.eu/publications/late-lessons-2/late-lessons-chapters/late-lessons-ii-chapter-8/view>
- 28 Chris Mueller (March, 6, 2023). Fact check: Vinyl chloride was banned in aerosols in 1974, but is still used in other ways, *USA Today*.
- 29 U.S Food and Drug Administration, Prohibited & Restricted Ingredients in Cosmetics. Available: [https://www.fda.gov/cosmetics/cosmetics-laws-regulations/prohibited-restricted-ingredients-cosmetics#:~:text=The%20use%20of%20vinyl%20chloride,problems%20\(21%20CFR%20700.14\).](https://www.fda.gov/cosmetics/cosmetics-laws-regulations/prohibited-restricted-ingredients-cosmetics#:~:text=The%20use%20of%20vinyl%20chloride,problems%20(21%20CFR%20700.14).)
- 30 EPA (April 5, 2022). EPA Proposes to Ban Ongoing Uses of Asbestos, Taking Historic Step to Protect People from Cancer Risk, news release.
- 31 Vallette, J. (2018). Chlorine & Building Materials Project: Phase 1 Africa, The Americas, and Europe. *Healthy Building Network*. p. 39-43.
- 32 Justine McDaniel (February 15, 2023). What's known about the toxic plume from the Ohio train derailment, *Washington Post*.
- 33 NOAA Satellites <https://twitter.com/NOAASatellites/status/1626283272463429632>
- 34 The Associated Press, Ohio sues Norfolk Southern over the train derailment in East Palestine, March 14, 2023.
- 35 Cornell University, media release. February 15, 2023. Vinyl chloride 'highly mobile in soils and water.' East Palestine area farmers advised to test crop sites.
- 36 CNN State of the Union with Paula Reid. February 19, 2023.
- 37 NOAA Office of Restoration (2012) A Train Derails in Paulsboro, N.J., Releasing 23,000 Gallons of Toxic Vinyl Chloride Gas. Available: <https://response.restoration.noaa.gov/about/media/train-derails-paulsboro-nj-releasing-23000-gallons-toxic-vinyl-chloride-gas.html>
- 38 CSB (2007). CSB Issues Final Report and Safety Video on Formosa Plastics Explosion in Illinois, Concludes That Company and Previous Owner Did Not Adequately Plan for Consequences of Human Error. <https://www.csb.gov/csb-issues-final-report-and-safety-video-on-formosa-plastics-explosion-in-illinois-concludes-that-company-and-previous-owner-did-not-adequately-plan-for-consequences-of-human-error/>
- 39 Toxic-free future. (February 17, 2023). Ohio train derailment vinyl chloride disaster is another painful reminder of PVC plastic's toxic lifecycle.
- 40 Schulyer Mitchell (February 18, 2023). The Myth of Safe Plastics Persists, Despite Risk of Disasters Like East Palestine, *The Intercept*.
- 41 Mossville Environmental Action Now, et al (2007). Industrial Sources of Dioxin Poisoning in Mossville, Louisiana: A Report Based on the Government's Own Data, Mossville, LA.

- 42 Center for Health, Environment and Justice, Environmental Justice & the PVC Chemical Industry.
- 43 Vallette, J. (2018). Chlorine & Building Materials Project: Phase 1 Africa, The Americas, and Europe. Healthy Building Network.
- 44 PVC Pipe Association, Technical Brief: PVC Pipe Gasketed Joints— PART 2: Technical Considerations.
- 45 Toumboulia P. et al, Materials used in drinking water distribution systems: contribution to taste-and-odor, *Water Science and Technology*, Vol 49 (9) pp 219-228, 2004.
- 46 R Garnier et al. (1989). Tetrahydrofuran Poisoning after Occupational Exposure, *British Journal of Industrial Medicine*, 46:9, 677-678.
- 47 S. Jacob et al. (2007), New Insight Into Solvent-Related End-Stage Renal Disease: Occupations, Products and Types of Solvents at Risk, *Occupational and Environmental Medicine*, 64:12.
- 48 CBS Boston, I-Team: Plumbers say PVC Pipe is Long-Term Health Hazard, June 10, 2021.
- 49 Stern and Lagos, 2008.
- 50 Gore, A. C., Chappell, V. A., Fenton, S. E., Flaws, J. A., Nadal, A., Prins, G. S., Toppari, J., & Zoeller, R. T. (2015). EDC-2: The Endocrine Society's Second Scientific Statement on Endocrine-Disrupting Chemicals. *Endocrine Reviews*, 36(6), E1-E150. <https://doi.org/10.1210/er.2015-1010>
- 51 Bennett Deborah et al. (2016). Project TENDR: Targeting Environmental Neuro-Developmental Risks The TENDR Consensus Statement. *Environmental Health Perspectives*, 124(7), A118-A122. <https://doi.org/10.1289/EHP358>
- 52 Evanthia Diamanti-Kandarakis, et al, Endocrine-Disrupting Chemicals: An Endocrine Society Scientific Statement, *Endocrine Reviews*, Volume 30, Issue 4, 1 June 2009
- 53 Gore, et al (2015).
- 54 Bennett Deborah, et al (2016).
- 55 Stern and Lagos, 2008.
- 56 Daniella M. Pizzurro, Ifeolouwa A. Bamgbose, David B. Mayfield (2018), Characterization of Leachable Chemical Substances from Common Drinking Water Piping Materials [White paper].
- 57 Andrew J. Whelton and Tinh Nguyen (2013).
- 58 Muhammad M. Shaikh et al (2019), Release of Organic Contaminants Migrating from Polyvinyl Chloride Polymetric into Drinking Water Under Three Successive Stagnant Periods of Time, *Desalination and Water Treatment*, 14, 105-116.

- 59** EPA, Permeation and Leaching, United States Environmental Protection Agency – Office of Ground Water and Drinking Water, Washington, D.C. (2002).
- 60** Tsuyoshi Nakanishi, Endocrine disruption induced by organotin compounds; organotins function as a powerful agonist for nuclear receptors rather than an aromatase inhibitor, *J Toxicol Sci*, 2008 33(3):269-276.
- 61** Felix Grün, Bruce Blumberg, Environmental obesogens: organotins and endocrine disruption via nuclear receptor signaling, *Endocrinology*, 2006, 147(6 Suppl):S50-5.
- 62** Igor Ferraz da Silva et al, Organotins in Neuronal Damage, Brain Function, and Behavior: A Short Review, *Front Endocrinol*, 2017, 8: 366.
- 63** Jones Bernardes Graceli et al, Organotins: a review of their reproductive toxicity, biochemistry, and environmental fate, *Reprod Toxicol*, 2013, 36:40-52.
- 64** A. Sadiki et al (1996), Pilot Study on the Contamination of Drinking Water by Organotin Compounds from PVC Materials, *Chemosphere*, 32:12, 2389-2398.
- 65** A. Sadiki and D Williams (1999), A Study on Organotin Levels in Canadian Drinking Water Distributed Through PVC Pipes, *Chemosphere*, 38:7, 1541-1548.
- 66** Forsyth DS and Jay B. 1997. Organotin leachates in drinking water from chlorinated poly(vinyl chloride) (PVC) Pipe Appl Organometal Chem 551-58
- 67** World Health Organization, Dialkyltins in drinking water, (2004).
- 68** Wanzhen Chen et al, Defining the Chemical Additives Driving In Vitro Toxicities of Plastic, *Environ. Sci. Technol.* 2022, 56, 20, 14627-14639.
- 69** Ioanna Katsikantami et al, A global assessment of phthalates burden and related links to health effects, *Environment International*, Volume 97, 2016, Pages 212-236.
- 70** Consumer Product Safety Commission, CPSC Prohibits Certain Phthalates in Children's Toys and Child Care Products, News Release, October 20, 2017.
- 71** Sustainable Solutions Corp. (2017). Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials.
- 72** Wanzhen Chen et al. (2022)
- 73** Faust, D. R., Wooten, K. J., and Smith, P. N. (2017). Transfer of phthalates from c-polyvinyl chloride and cross-linked polyethylene pipe (PEX-b) into drinking water. *Water Supply*, 17(2), 588-596. <https://doi.org/10.2166/ws.2016.164>
- 74** Toumboulou P. et al, Materials used in drinking water distribution systems: contribution to taste-and-odor, *Water Science and Technology*, Vol 49 (9) pp 219-228, 2004.
- 75** Ryan K. Walter, Po-Hsun Lin, Marc Edwards, and Ruth E. Richardson (2011), Investigation of Factors Affecting the Accumulation of Vinyl Chloride in Polyvinyl Chloride Piping Used in Drinking Water Distribution Systems, *Water Research*, 45:8.

- 76 Ralph L. Flournoy, David Monroe, Naima-Halim Chestnut, Vinita Kumar (1999), Health Effects from Vinyl Chloride Leaching from Pre-1977 PVC Pipe, American Water Works Association.
- 77 Michael Beardsley and Craig Adams, Modeling and Control of Vinyl Chloride in Drinking Water Distribution Systems, *Journal of Environmental Engineering*, 129(9) 2003.
- 78 Water Research Foundation, Vinyl Chloride and Organotin Stabilizers in Water Contacting PVC Pipes, Denver, CO (2009).
- 79 Ryan K. Walter, Po-Hsun Lin, Marc Edwards, and Ruth E. Richardson (2011), Investigation of Factors Affecting the Accumulation of Vinyl Chloride in Polyvinyl Chloride Piping Used in Drinking Water Distribution Systems, *Water Research*, 45:8.
- 80 Sustainable Solutions Corp. (2017).
- 81 Kowalska B., T. Klepka, D. Kowalski, (2016), Influence of Chlorinated Water on Mechanical Properties of Polyethylene and Polyvinyl Chloride Pipes, *WIT Transactions in the Built Environment* Vol. 165, 63-74.
- 82 United States Environmental Protection Agency, National UST Program Cleans Up Over 500,000 UST Releases, May 26, 2022.
- 83 United States Environmental Protection Agency - Office of Ground Water and Drinking Water, Permeation and Leaching, Washington, D.C. (2002).
- 84 Feng Mao, James A. Gaunt, Say Kee Ong, and Chu-Lin Cheng (2011), Permeation of Petroleum-Based Hydrocarbons Through PVC Pipe Joints with Rieber Gasket Systems, *American Society of Civil Engineers*, 137:12, 1128-1135.
- 85 Andrew J. Whelton et al. (2023) The Marshall Fire: Scientific and policy needs for water system disaster response, *AWWA Water Science*, [Volume 5, Issue 1](#).
- 86 Kristofer P. Isaacson et al. (2021). Drinking Water Contamination from the Thermal Degradation of Plastics: Implications for Wildfire and Structure Fire Response, *Environmental Science: Water Research & Technology*, 7:2, 274-284.
- 87 Andrew J. Whelton et al. (2023).
- 88 National Public Radio, Paradise, Calif. Water is Contaminated, but Residents are Moving Back Anyway, April 26, 2019.
- 89 William M. Draper et al. Organic Chemical Contaminants in Water System Infrastructure Following Wildfire, *ACS EST Water* 2022, 2, 2, 357-366.
- 90 Kristofer P. Isaacson et al. (2021).
- 91 Plastics Pipe Institute, Investigation of Benzene in Drinking Water Following the “Camp Fire” in Paradise, CA. July 2020.
- 92 Plastics Pipe Institute (2020).

- 93** Kristofer P. Isaacson et al. (2021).
- 94** NOAA, National Center for Environmental Information. Available: <https://www.ncei.noaa.gov/access/monitoring/monthly-report/fire/202213>
- 95** UA, Firefighters Union Question Use of Plastic Pipe in Construction, March 31, 2019.
- 96** Eva M. Tanner et al. (2020), Early Prenatal Exposure to Suspected Endocrine Disruptor Mixtures is Associated with Lower IQ at age Seven, *Environment International*, 134.
- 97** Nicolo Caporale et al. (2022), From Cohorts to Molecules: Adverse Impacts of Endocrine Disrupting Mixtures, *Science*, 375:6582.
- 98** Beyond Plastics, The Real Truth About the U.S. Plastics Recycling Rate, May 2022.
- 99** Krock, R., & Tarnell, S. (2015). Recycling as a Sustainability Practice in the North American Vinyl Industry.
- 100** United States Environmental Protection Agency, Advanced Sustainable Materials Management: 2018 Tables and Figures, (2020).
- 101** European Chemical Agency (2022) Background note Call for evidence for the investigation on PVC and its additives. Available: <https://echa.europa.eu/documents/10162/ff9f8561-2af7-e84a-Od84-59b11417c57b>
- 102** Center for Health Environment and Justice (2004) PVC, Bad News Comes in Threes.
- 103** USGBC (2007) Assessment of the Technical Basis for a PVC Related Materials Credit for LEED, p 88.
- 104** UA, Firefighters Union Question Use of Plastic Pipe in Construction, March 31, 2019.
- 105** Sustainable Solutions Corp. (2017). Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials.
- 106** R.A. Wilkes, L. Aristilde, Degradation and metabolism of synthetic plastics and associated products by *Pseudomonas* sp.: capabilities and challenges, *Journal of Applied Microbiology*, 123 (3) 2017.