POISON IN THE PIPES
Is Copper the New Lead?

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Is Copper
The New Lead?

As mankind has pushed back new frontiers, there have been setbacks. One such setback was the discovery that lead, used for centuries in drinking glasses and later in gasoline, was actually a potent toxin.

An understandable reaction to such news is to take immediate action but sometimes that can result in an **"out of the frying pan and into the fire situation"**. Specifically, there is funding to replace lead pipes, so we need to ensure that the replacement pipes do not cause a new set of problems.

Recently, a man came to our house asking us to take a water sample, so that they could analyze our drinking water. I asked what they analyze for, and he said that by law they have to analyze drinking water nationwide for dissolved lead and copper. It was news to me that copper is considered toxic like lead and that the government are concerned enough to mandate regular testing across the whole country.

Recently, Beyond Plastics, a self-professed environmental group, released a report claiming that copper pipes were ideal for drinking water. Their name however, suggests an agenda that has them finding ways to diminish the use of plastics in society. One result of agenda driven (as opposed to fact driven) campaigns is they often lead to unintended consequences. If societal health and safety is a core goal of the Beyond Plastics organization, they are encouraging those dangerous consequences with their campaign to replace lead pipes with copper rather than safe plastic alternatives.

In their report, Beyond Plastics emphasized how safe copper pipes are. Initially, I accepted that claim, as it sounded plausible and because I had not yet looked into the safety of copper pipes. However, after that surprise visit to my own door from a man telling me that water was monitored for toxic levels of copper in drinking water, my scientific curiosity was aroused, and I decided to do a literature search to see what peer-reviewed science has to say about the safety of copper, copper pipes and the drinking water that emerges from them.

EPA - Lead and Copper Rule

40 CFR Part 141 Subpart

In 1991 EPA published a regulation to control lead and copper in drinking water

"The treatment technique for the rule requires systems to monitor drinking water at customer taps. If lead concentrations exceed an action level of 15 ppb or copper concentrations exceed an action level of 1.3 ppm in more than 10% of customer taps sampled, the system must undertake a number of additional actions to control corrosion."

https://www.epa.gov/dwreginfo/lead-and-copper-rule

The World Health Organization (WHO) reported that 104 countries have a regulation or guideline for copper in drinking water, with a median value of 1.5mg/L and a range of 0.05–3 mg/L.

So, copper is considered toxic at levels of over ~1 part per million, which is just ~0.0001% copper in water. Clearly then, copper is a powerful toxin to be regulated worldwide at such extremely low levels. That is not as toxic as lead, but still a real concern to health. As of 2021, the EPA passed as new rule requiring copper testing in schools and child care facilities. Here is a clipping from the safety datasheet for copper metal which tells is how dangerous or safe a substance is.

As a **PhD chemist,** I can attest that this is not the safety datasheet of a harmless substance. It is even clear to the layperson that there are clear and severe consequences from copper exposure.

You may be wondering how this compares to the same section of the safety datasheet for polyethylene, and other plastics that are also used to make drinking water pipes.

Toxic

Acute toxicity (oral, dermal, inhalation), category 2

Irritant

Eye irritation, category 2A
Skin sensitization, category 1

Health hazard

Germ cell mutagenicity, category 1A
Specific target organ toxicity following repeated exposure, category 2

Acute toxicity - Oral - Category 2: H300 Fatal if swallowed.

Acute toxicity - Inhalation - Category 2: H330 Fatal if inhaled.

Specific target organ toxicity - Repeated exposure - (Oral,Inhalation) - Category 2: H373 May cause damage to digestive system, hematopoietic system, kidneys, nose, respiratory system, and/or skin through prolonged or repeated exposure if inhaled Hazards Not Otherwise Classified - Combustible Dust Not classified for physical or health hazards under GHS.

Hazards Not Otherwise Classified - Combustible Dust Serious Eye Damage/Eye Irritation - Category 2: H319 Causes serious eye irritation.

Skin sensitizers-Category 1: H317 May cause allergic skin reaction.

Germ cell mutagenicity - Category 1: H340 May cause genetic defects.

Hazardous to aquatic environment - acute hazard - Category 1: H400 Very toxic to aquatic life.

Signal Word: Danger

2. Hazard(s) identification

Classification

Classification under 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200)

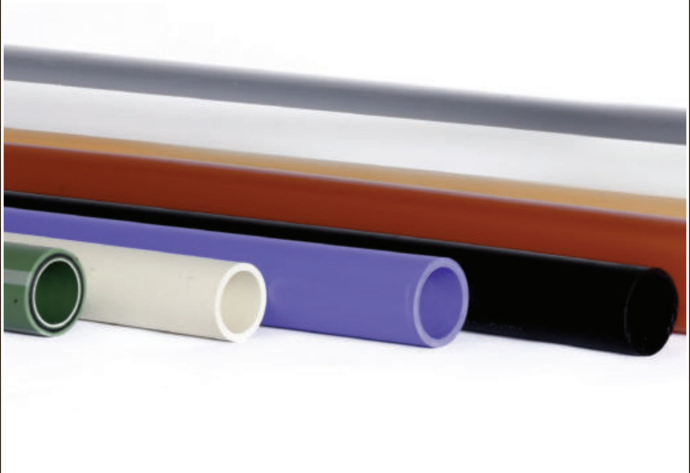
Based on available data, the classification criteria are not met

Label Elements

None required

Hazards not otherwise classified (HNOC)

None identified



Polyethylene, PEX, polypropylene and uPVC are all considered so safe that no warnings of any kind are required on the safety datasheet.

Health risks:	Dust can cause mechanical irritation.
Hazards for the environment:	Based on our information, there is no danger to the environment. The product is according to Directive1999/45/EC and its annexes are not classified as dangerous.
Composition / Information on Ingredients.	
Chemical characterization:	Polyvinyl chloride.
Hazardous substances:	Product contains no hazardous ingredients liable to be disclosed.

In addition to the safety datasheets, we can find the absolute toxicity of each material expressed as the amount needed to be a lethal dose. This is called the LD50 value, which is the oral dose needed to kill 50% of a group of rats or mice. The EPA classifies toxicity into various groups as shown in the table.

Material	LD50 70kg	NOAEL 70Kg
Sugar	~2000g	700g
Alcohol	~500g	~700g
Polyethylene	>350g	>50g
Polypropylene	>350g	>150g
uPVC	>350g	NA
Iron powder	>350g	14g
Copper metal	30g	~1g
Cu dissolved	3.5g	0.005g
Cyanide	0.1g	0.7g

EPA toxicity ratings I-IV: Practically Non-Toxic Slightly Toxic Moderately Toxic Very Toxic Extremely Toxic
LD50 figures from rat or mouse testing from The Dose Makes the Poison in Assessing Toxic Risk

Copper metal itself is classified as **"Very Toxic"** which is disturbing. In pipes, the copper corrodes, so the copper is present as carbonates and other chemical forms of copper that can dissolve in the stomach. Dissolved copper is classified as **"Extremely Toxic"** like cyanide.

H. H. Dieter, Biochemische Essentialitat und Toxikologie von Kupfer. Gesundh.- Wes, 51, pp 222-227, 1989

The no observable adverse effect level (NOAEL) is another way to measure toxicity and it shows that copper is over 10 000 times more toxic than plastics like PE and PP.

The conclusion is that copper is known to be **"very toxic"** to **"extremely toxic"** whereas the plastics that pipes are made of are known to be safe. Why would Beyond Plastics make claims that are flatly contradicted by the evidence? This information can be found in seconds with a simple Google search, so it appears that Beyond Plastics either did not look for safety information on copper, or they may have known and decided not to present it for some reason.

Knowing these facts, would a move from lead pipes to copper wise? We must investigate further to be certain.

Copper Toxicity Symptoms

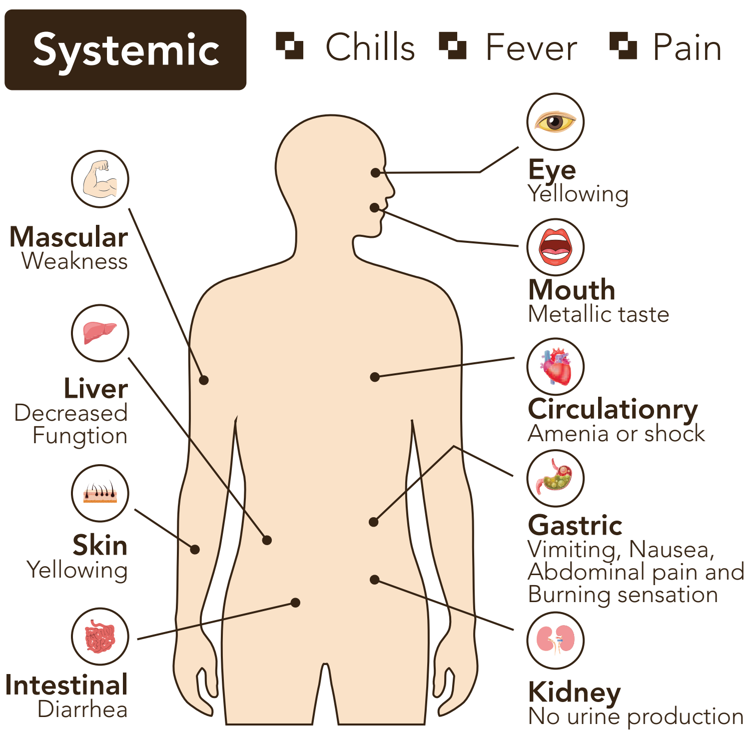
So how toxic is copper and what are the symptoms?

Fatal when severe. Too much copper can be fatal. You could get severe toxicity from ingesting large amounts of copper salts through your skin. Copper can work its way through your internal organs and build up in your brain, liver, and lungs.

People who have copper toxicity can become very unwell. Nausea and vomiting are two symptoms of it. Others to watch out for are:

- **Diarrhea** (may have a bluish color or contain blood).
- **Fever and bodily chills.**
- **Muscular convulsion or**
- **weakness.**
- **Pain or burning sensation in the abdominal area.**
- **Yellowing of the eyes and skin** (jaundice).
- **Anemia.**
- **Metallic taste in your mouth.**
- **Lack of urine due to kidney malfunction.**

Symptoms of copper poisoning



This text is copied verbatim from WebMD: https://www.webmd.com/diet/what-to-know-copper-toxicity

Figure 2-1. Overview of the Number of Studies* Examining Copper Health Effects

Most studies examined the potential gastrointestinal & hepatic effects of copper.

More studies have evaluated health effects in humans than animals (counts represent studies examining endpoint).

The US government has even expressed concern, and conducted an extensive review of the toxic effects of copper which is summarized in the chart below:

*Includes studies discussed in Chapter 2; studies examined multiple endpoints. A total of 161 studies (including those finding no effect) have examined toxicity.

U.S. Department of Health and Human Services Toxicological Profile for Copper 2022.

They cited 161 studies showing the adverse health effects from copper. It was found that copper in drinking water is especially toxic to humans because of the chemical form of the copper. The copper in food is in the Cu^{+} oxidation state and the human body has processes to deal with and use copper in that form. Dissolved copper in drinking water however is in the Cu^{2+} form and the human body has no means to handle that form because it is not one that we have been exposed to regularly before.

Are there Copper Poisonings?

"Drinking water, particularly tap water, is potentially one of the major dietary copper sources. Copper is present in fresh water typically less than 0.075 mg/L, but copper concentration in drinking water can increase up to 90 mg/L as it travels from reservoir to residential homes through copper pipes that are widely used for home plumbing system."

J. H. Hong et al., Evaluation of the operationally defined soluble, insoluble, and complexing copper consumed through drinking water in hu man saliva, European Food Research Technology, 231, pp 977-984, 2010

That is alarming as the permissible limit is only ~1 mg/L and amounts almost 100x higher than that have been reported. Clearly, toxic levels of copper in drinking water is very real, and not a theoretical threat.

The study goes on to say:

"Off-flavors in drinking water generated by copper are described as metallic, bitter, sour, salty, or astringent taste, which can be detected at as low as 0.5-13mg/L. Because odor and taste have been important indicators of potential contamination, these unpleasant sensory qualities with a low sensory threshold are assumed to be an initial biological hazard detection mechanism to protect humans from copper toxicity."

The scientists are saying that if there is enough copper such that you get a metallic taste in your mouth, then that is your body warning you that the levels are toxic. Who among us has never detected a metallic taste from drinking water?

"Unlike the relatively narrow range of µg/L concentrations in freshwater, copper concentrations in drinking water vary significantly, primarily due to the corrosion of copper pipes and variations in pH, hardness, dissolved oxygen, oxidizing and complexing agents, and stagnation time in the pipes (NRC, 2000). Soluble copper is more common in drinking water than particulate copper, and levels in standing water are generally much higher than in flushed water. Copper levels ranged from 0.005 to 18 mg/L in a variety of flushed and standing drinking-water samples from throughout the USA (USEPA, 1991)."

"When blue water situations occur due to the presence of particulate copper, drinking water can contain up to 500–1,000 mg/L copper, although 3–10 mg/L of copper is most common (Edwards et al., 2000)."

A. M. Dietrich et al., Health and aesthetic impacts of copper corrosion on drinking water, Water Science and Technology, 49 (2) pp 55–62, 2004

The upper copper value mentioned is about 1000x higher than the recommended safe limit for copper in drinking water and it comes primarily from pipes. Next time you detect a metallic taste in water, it would be wise to stop drinking immediately.

How Much Copper Comes from Drinking Water Pipes?

"Most domestic water pipes in Scandinavia are copper, and almost all copper in drinking water originates from pipes."

"About 10% of the children had a copper intake above the level recommended by the World Health Organization."

R. Pettersson & F. Rasmussen, Daily Intake of Copper from Drinking Water among Young Children in Sweden, Environmental Health Perspectives, 107 (6), 1999

The Swedish study also found that copper in drinking water comes mainly from the copper pipes.

"This study examines arsenic, copper, lead and manganese drinking water contamination at the domestic consumer's kitchen tap in homes of New South Wales, Australia. Analysis of 212 first draw drinking water samples shows that almost 100% and 56% of samples contain detectable concentrations of copper and lead, respectively. Of these detectable concentrations, copper exceeds Australian Drinking Water Guidelines (ADWG) in 5% ofsamples and lead in 8%."

P. J. Harvey et al., Widespread copper and lead contamination of household drinking water, New South Wales, Australia, Environmental Research, 151, pp 275-285, 2016

A significant percentage of people in Australia are drinking water with copper and lead levels above established safe limits.

"In 1993, the levels of copper (Cu) in much of Nebraska's drinking water exceeded the U.S. Environmental Protection Agency's (EPA) action level of 1.3 mg/L."

S. D. Buchanan et al., Copper in Drinking Water, Nebraska, 1994, International Journal or Environmental Health, 5, pp 256-261, 1999

The Nebraska case is another real world instance of unacceptable copper levels in drinkingwater, values several times higher than the allowed limit were reported.

Copper from School Drinking Fountains in the USA

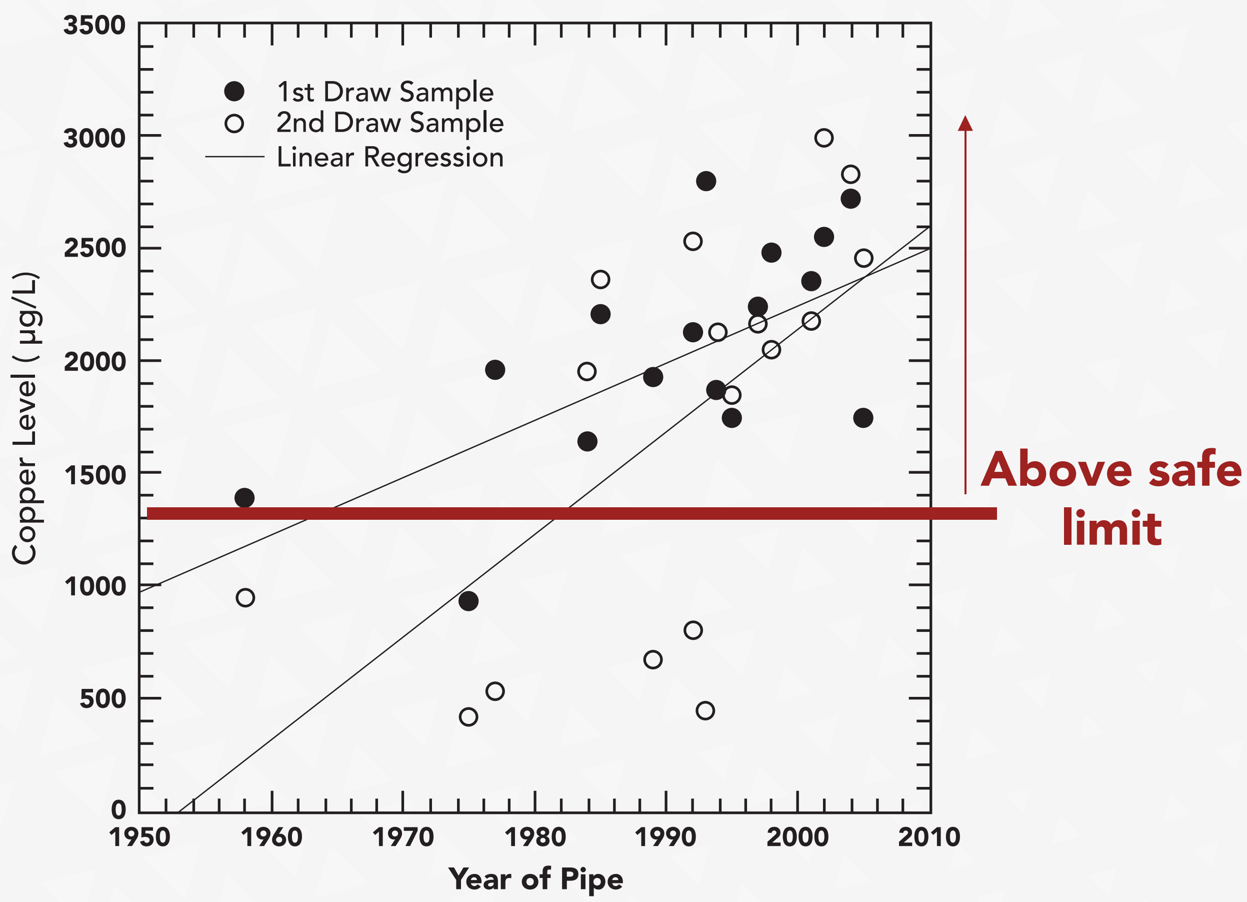
Another study looked at water from school drinking fountains in the USA. Some measurements were up to ~10x higher than the safe limit of 1mg/L. They recommended flushing of the water fountains more regularly than the normal amount of once per day

Parameter	Fast Draw	10 minute Flush	Lunchtime
Lead (mg/L)	BD-0.135	BD-0.074	BD-0.075
Copper (mg/L)	BD-10.2	BD-7.8	BD-8.5
pH	4.1-8.7	5.0-7.9	4.4-8.8
Temperature (°C)	9-33	9-28	9-33
Number of Samples	101	100	100

E. A. Murphy, Effectiveness of flushing on reducing lead and copper levels in school drinking water, Brief reports, Environmental Health Perspectives, 101 (3), pp 240-241, 1993

Copper Pipe Age

It has been claimed that the amount of copper dissolving in water would decrease due to a protective layer of corrosion on the copper metal surface. That was investigated and found to be the case, but even copper pipes decades old still produced copper concentrations well above the safety limit of **~ 1mg/L (1000μg/L).**



N.F. Turek et al., Impact of plumbing age on copper levels in drinking water, Journal of Water Supply: Research and Technology-AQUA, 60 (1), pp 1-15, 2011

Copper and Alzheimer's Disease

"Humans were not exposed to divalent copper until the 20th century, due to the use of copper plumbing and supplement pills containing copper, and that exposure, which occurs in developed countries, does not occur in undeveloped countries. Data in support of the hypothesis show that tiny amounts of divalent copper added to drinking water of Alzheimer's disease animal models greatly enhance Alzheimer's disease, and ingestion of copper (which is always divalent copper)- containing supplement pills by humans is quite toxic to cognition."

G. J. Brewer, Avoiding Alzheimer's disease: The important causative role of divalent copper ingestion, Experimental Biology and Medicine, 244 (2), pp 114–119, 2019

"It is clear that, over time, copper's cumulative effect is to impair the systems by which amyloid beta is removed from the brain," Deane said in a press release accompanying the study. "This impairment is one of the key factors that cause the protein to accumulate in the brain and form the plaques that are the hallmark of Alzheimer's disease."

Professor Rashid Deane, University of Rochester Medical Center Department of Neurosurgery & Leading expert on copper's role in Alzheimer's

"Astrocyte dysfunction by aging or other means, together with environmental Cu exposure may result in the loss of neuroprotective and antioxidative capacity of the brain and increased susceptibility to cognitive decline and Alzheimer's Disease."

H. W. Hsu et al., Environmental and Dietary Exposure to Copper and Its Cellular Mechanisms Linking to Alzheimer's Disease, Toxicological Sciences, pp 1-8, 2018

“…in the US, 10% of those 60 years and older, 20% of those 70 and over, and 30% of those 80 and over have Alzheimer’s Disease.

Humans evolved to handle copper-1 safely, but not copper-2. Alzheimer’s is at least in part, a copper-2 toxicity disease, while Wilson’s is a general copper overload disease. In this review, we will show that the epidemiology of the Alzheimer’s epidemic occurring in developed, but not undeveloped countries, fits with the epidemiology of exposure to copper-2 ingestion leached from copper plumbing and from copper supplement pill ingestion. Increased meat eating in developed countries is also a factor, because it increases copper absorption, and thus over all copper exposure.

…280 samples of drinking water from all over N. America was studied [33]. It was found that about one third had copper content 0.1 ppm or higher, the level toxic in AD animal models, about one third were below 0.01 ppm, a level deemed safe, and about one third were between these levels, and of unknown safety. Thus, one- to two-thirds of samples of household drinking water had copper levels of known or possible toxicity, if the animal models are a guide.”

G. J. Brewer, Copper-2 Ingestion, Plus Increased Meat Eating Leading to Increased Copper Absorption, Are Major Factors Behind the Current Epidemic of Alzheimer’s Disease, Nutrients, 7, pp 10053–10064, 2015

“Drinking water can be tested, and if it contains more than 0.01 ppm copper, an alternate source to be used.”

G. J. Brewer, Copper excess, zinc deficiency, and cognition loss in Alzheimer’s disease, Biofactors, 38 (2), pp 107-13, 2012

Dr. Brewer recommends a safe copper level one tenth of the present limit set by the US EPA.

It should be noted that the studies mentioned here are just a few of the many scientific reports on copper & Alzheimer’s Disease.

Copper and Cancer

There is limited evidence linking copper to damage of DNA, the formation of cancer and growth of cancer cells but so far no definitive proof that copper causes cancer.

> “Catalytic copper, because of its mobilization and redox activity, is believed to play a central role in the formation of reactive oxygen species (ROS), such as O^{2-}• and • OH radicals, that bind very fast to DNA, and produce damage by breaking the DNA strands or modifying the bases and/or deoxyribose leading to carcinogenesis.”

T. Theophanides & J. Anastassopoulou, Copper and carcinogenesis, Critical Reviews in Oncology / Hematology, 42, pp 57-64, 2002

"The relationship between copper metabolism and tumor development has been extensively investigated. Cancer cells require higher levels of copper to meet their energy demands for rapid proliferation compared to normal cells."

X. Tang et al., Copper in cancer: from limiting nutrient to therapeutic target, Frontiers in Oncology, 1 3, 2023

"In a study of over 6,700 male workers at a Chinese copper mine, there was a significantly increased risk for cancer (all sites combined) (standardized mortality ratio [SMR] =123; 95% confidence interval [CI] =109–139), a significantly increased risk for stomach cancer (SMR=131; 95% CI=105–161), and a significantly increased risk for lung cancer (SMR=147; 95% CI=112–189) (Chen et al. 1993). The cancer risk increased with the duration of employment and time since first exposure (time between first exposure and cancer diagnosis)."

U.S. Department of Health and Human Services Toxicological Profile for Copper 2022

Copper Bioavailability and Toxicity from Drinking Water

Researchers found that copper is more bioavailable and toxic from drinking water as compared to copper from food. They concluded that the limits for the safe level of copper in drinking water should be lowered based on this discovery.

"In recent years, the safety of copper in drinking water has increasingly been questioned. Copper speciation is an important factor that affects its bioavailability and toxicity; thus, it is critical to investigate the speciation of copper that is ingested from food and drinking water during in vitro digestion. After digestion, water- and food-derived copper formed 60 ± 4% 0.1-1 kDa and 49 ± 6% 10-1,000 kDa copper complexes, respectively. Under simulated fasting drinking water conditions, up to 90 ± 2% 0.1-1 kDa copper complexes formed. In addition, using ion selective electrode analysis, water-derived copper was detected that contained higher Cu^{2+} concentrations after digestion than those of food-derived copper. These results indicate that water-derived copper forms smaller-sized species and exhibits higher Cu^{2+} concentrations during digestion than those of food-derived copper, thereby highlighting the importance of reassessing the safety limit for copper in drinking water."

M. Wu et al., In situ analysis of copper speciation during in vitro digestion: Differences between copper in drinking water and food, Food Chemistry, 371, 2022

Formula-Fed Infants

Babies are particularly vulnerable to copper and the acceptable amounts are far lower than those set for adults. In particular, baby formula already contains the required healthy amount of copper, so if the formula is made using tap water containing copper, then the infant receives too high a dose.

> “Formula-fed infants, particularly those receiving most sustenance from powdered formulas, are a group of particular concern. Virtually all fluid of young infants on a powdered formula diet can come from tap water, and the powder formulation is designed to provide the copper requirement.”

> “WHO (1996), after considering copper concentrations not associated with detrimental effects in adult humans, set a value of 150 μg/kg-day as the upper limit of the safe range for mean copper intake for infants.1 The above value is roughly half the intake for infants on a powdered formula diet made with water containing copper at the MCLG. The copper concentration in tap water corresponding to the WHO upper limit is 0.44 mg/L for the average infant fed for the first 6 months of “life on standard powder formula. Formula-fed infants consuming water contaminated at 6 mg/L would approach doses of 1 mg/kg per day, a dose associated with cases of liver toxicity in genetically sensitive infants by some researchers (Table 6-3) and approximately a factor of 10 of doses with observed effects in chronic exposure animal studies.”

Copper in Drinking Water, National Research Council, National Academy Press, Washington D.C., 2000

Copper Pipe Fittings

“It was found that the lead pick-up in a building is subject to variations. Newly constructed fittings can release 200–300 μg of lead per fitting over a 16 hour or overnight period. The release of lead decreases over 4–5 weeks to 10–30 μg per fitting. The lead released from joints removed from a building after five years of use showed a mean value of 22 μg per fitting.”

T. D. B. Lyon & J. M. A. Lenihan, Corrosion in Solder Jointed Copper Tubes Resulting in Lead Contamination of Drinking Water, British Corrosion Journal, 12 (1), pp 41-45, 1977

This illustrates that the copper pipe itself is one source of toxic contamination in water but not the only source. The lead used to join copper pipes is another significant source of potent toxin that continues to leach for years.

Copper & Lead Pipes Joined

Replacing lead pipes is time-consuming and expensive, so sometimes only a partial replacement is made. Scientists found that if a lead pipe is joined to a copper pipe then galvanic corrosion leads to a massive increase in dissolved and particulate lead. In contrast, no such problem was found when plastic was joined to the lead pipes. This is therefore another reason to be cautious about recommending copper pipes to replace lead.

Y. Wang et al., Impact of galvanic corrosion on lead release from aged lead service lines, Water Research, 46 (16), pp 5049-5060, 2012

Anti-bacterial Effect of Copper

It is often claimed that copper has an anti-bacterial effect which protects us from biofilm formation in pipes and drinking water contamination from such bacteria. However, it was shown that this is only the case for new copper pipes. Brand new copper pipes give high levels of copper which can be toxic to bacteria and humans. After 200 days, the copper pipe has corroded to give a layer of minerals that lowers the rate at which copper dissolves. This helps reduce the amount of toxic copper humans are exposed to but also removed the anti-bacterial effect.

"The formation of biofilm was slower in copper pipes than in the PE pipes, but after 200 days there was no difference in microbial numbers between the pipe materials. Copper ion led to lower microbial numbers in water during the first 200 days, but thereafter there were no differences between the two pipe materials."

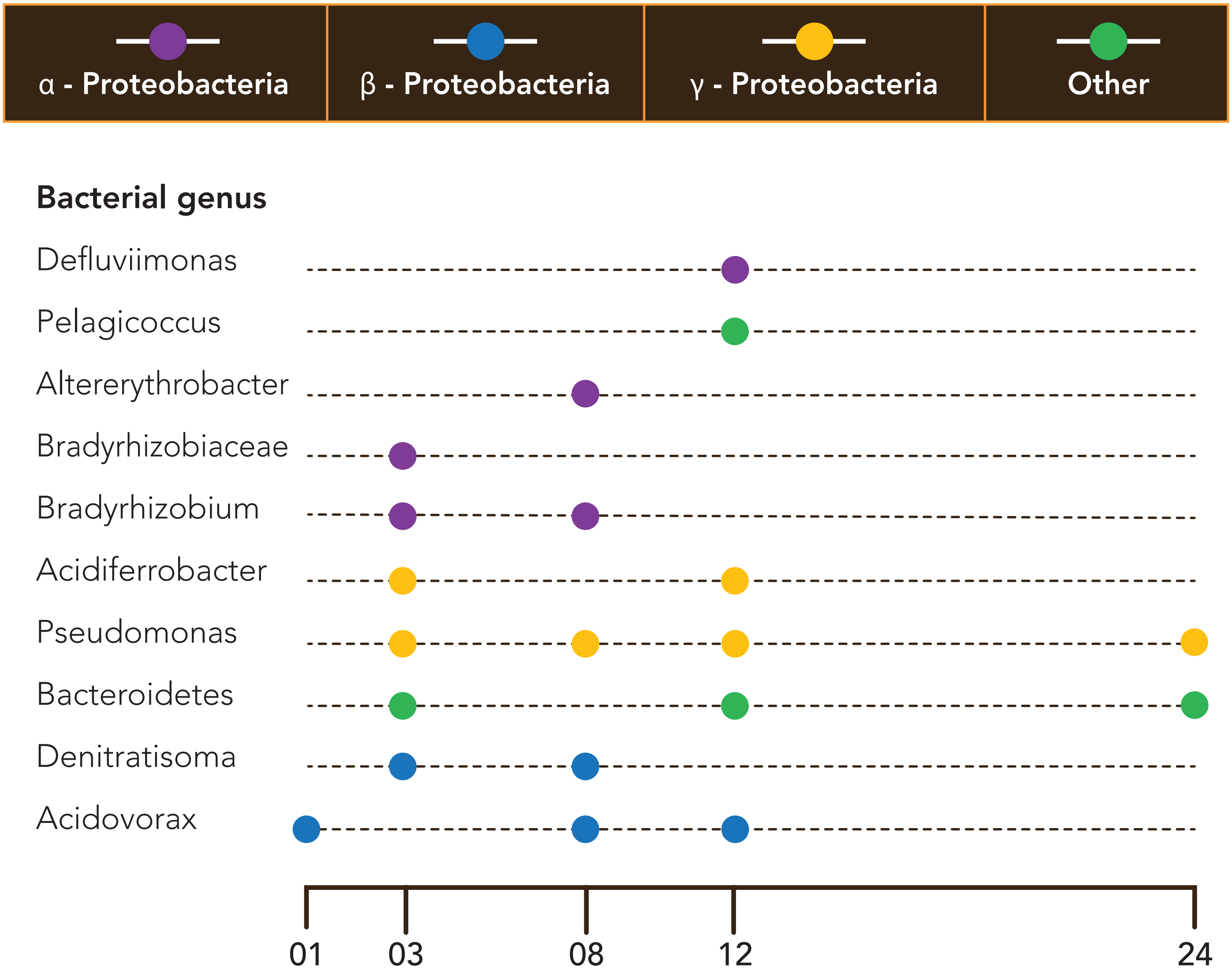
M.J. Lehtola et al., Microbiology, chemistry and biofilm development in a pilot drinking water distribution system with copper and plastic pipes, Water Research, 38, pp 3769–3779, 2004

> Bacteria isolated from copper have also developed some important survival strategies. Nearly 50% of the bacteria isolated from drinking water systems with copper corrosion had genes similar to those conferring copper resistance in Pseudomonas syringae (Lin and Olson, 1995). There is concern that even if copper pipe initially minimizes bacterial growth, resistance could develop and temper copper's biocidal properties.
>
> A. M. Dietrich et al., Health and aesthetic impacts of copper corrosion on drinking water, Water Science and Technology, 49 (2) pp 55–62, 2004

Note that although the amount of copper coming from pipes older than 200 days is not enough to provide anti-microbial protection, as shown earlier here, even those reduced copper levels are still frequently above the safety limit set for human drinking water even for decades old copper pipe.

A further study examined the effect of such bacteria biofilms on the corrosion rate of copper pipes.

> The mechanisms of Pseudomonas associated with copper corrosion are related to the capacity of the biofilm formation and its enzymatic activity. Regarding the latter, Pseudomonas has both oxidase and catalase activity, which generate a constant cycle of oxygen renewal on the surface of a copper pipe, thereby promoting an increase in the cathodic current and thus an increase in the overall corrosion process [54–56]. Our results suggest that Pseudomonas form the main core of biofilm owing to their prevalence and other characteristics. The control of Pseudomonas attachment on a metallic surface would be an appropriate strategy for reducing or controlling the copper corrosion. Other studies have reported a similar prevalence of Pseudomonas in drinking water systems concerning corrosion and biofilm production.
>
> C. Galarce et al., Dynamics of Biocorrosion in Copper Pipes under Actual Drinking Water Conditions, Water, 12, pp 1036 2020



They reported that Pseudomonas and several other bacteria types can live on the inner copper pipe wall and that their presence accelerates corrosion. Far from being safe and inert as claimed by Beyond Plastics, the copper is a breading ground for bacteria.

Copper & Chlorinated Water

The release of copper is increased for drinking water that is chlorinated.

> "The leaching of lead and copper from plumbing materials is a source of metals in drinking water and is a public health concern."

> "The presence of free chlorine commonly employed for disinfection of drinking water is found to cause an increase of dissolved copper metal from plumbing materials."

P. K. A. Hong & Y.-Y. Macauley, Corrosion and Leaching of Copper Tubing Exposed to Chlorinated Drinking Water, Water, Air, and Soil Pollution 108, pp 457–471, 1998

> "The corrosion of copper plumbing used for the conduction of potable water is a common problem. The problem resides almost exclusively with the consumer, since copper is not usually used in distribution systems. The general indicator of copper corrosion is blue-green staining, but a more serious and costly manifestation is tubing failure, often by pitting. The Town of Amherst, MA, has had an unusually large number of plumbing failures due to copper pitting within the last few years."

> "The study demonstrates that free chlorine is the agent chiefly responsible for the corrosion of copper in chlorinated domestic water supplies, and that dissolved oxygen plays a comparatively minor role. The impact of chlorine is enhanced at low pH values by the pH dependence of the HOCl electrode reactions, and because of the greater oxidizing strength of hypochlorous acid over that of hypochlorite ion."

D. Atlas, J. Coombs & O. T. Zaji¬cek, The Corrosion of Copper by Chlorinated Drinking Waters, Water Research, 16, pp 693-698, 1982

Copper & Water Softeners

Clearly, water softeners have a marked effect, increasing the rate of copper corrosion leading to early failure and greater levels of toxic copper in drinking water.

> "Electrochemical tests, as well as surface and chemical analysis were used to investigate the cause of pitting failure of copper tubing in a drinking water distribution system. The results show that localized pitting was the cause of failure and copper corrosion problems were observed under a green deposit. The pitting corrosion was associated with the Cl- and SO_4^{2-} ions introduced by the water softening treatment. These ions promoted the corrosion and the influence of Cl- ion was much greater than that of the SO_4^{2-} ion."

Z. Jia et al., Analysis of Copper Pitting Failure in Drinking Water Distribution System, Journal of Failure Analysis and Prevention, 11, pp 152-157, 2011

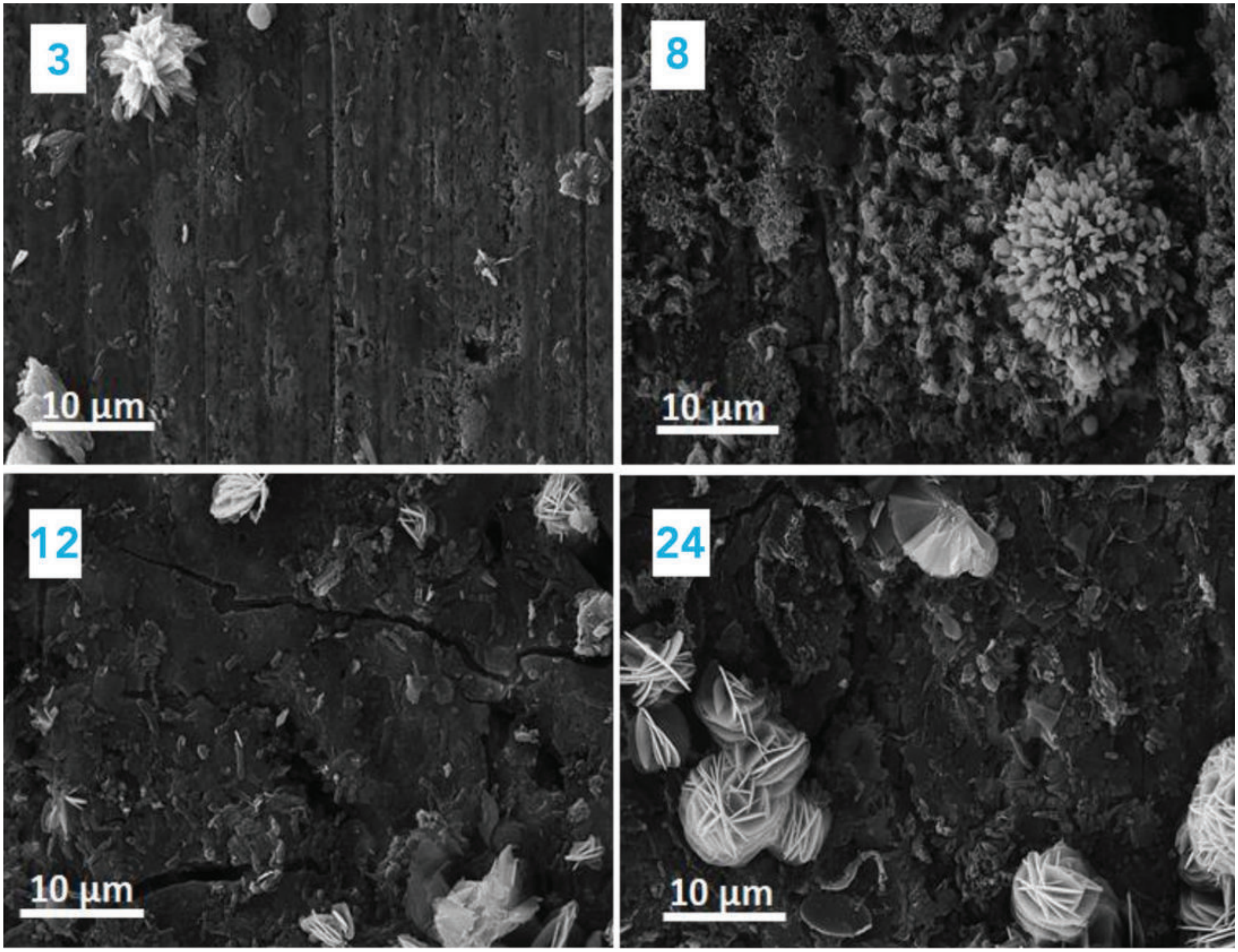
Non-Intentionally Added Substances (NIAS)

Copper Corrosion Products

As soon as water comes into contact with copper, it begins to corrode because it is a reactive metal. Over the long term, that can lead to leaks and costly damages to clean up after flooding and replace the pipe. People are generally aware of those longer term downsides but most people have probably not thought as much about the effects of that corrosion before catastrophic failure occurs.

Scientists have examined the inside of copper pipes to see what is happening over time. The study in question was conducted on copper pipe attached to a real drinking water network in order to ensure maximum realism and validity.

Below is a picture of such a pipe at 3, 8, 12 and 24 months. One can see all manner of unsightly crystals and growths, which are the chemical substances formed as the copper corrodes. There is a lot of focus on non-intentionally added substances, abbreviated to NIAS because these are often not considered when evaluating the safety of the material.



C. Galarce et al., Dynamics of Biocorrosion in Copper Pipes under Actual Drinking Water Conditions, Water, 12, pp 1036 2020

The Beyond Plastics report mentioned NIAS in plastics in their report but once again, they completely failed to mention NIAS from copper. This type of skewed reporting of the science can give a distorted and misleading picture to the public and policy-makers alike, so here we will investigate what they "forgot" to.

"The most common Cu compounds found on pipe walls are cuprite **(Cu_2O)**, tenorite **(CuO)**, malachite **[$Cu_2(CO_3)(OH)_2$]**, langite **[$Cu_4(OH)_6SO_4H_2O$]**, atacamite **[$Cu_2(OH)_3Cl$]**, brochantite **[$Cu_4(SO_4)(OH)_6$]**, azurite **[$2CuCO_3Cu(OH)_2$]**, and cupric hydroxide **[$Cu(OH)_2$]**."

G. E. Lagos et al., Aging of Copper Pipes by Drinking Water, Journal of the American Waterworks Association, 93 (11), pp 94-103, 2001

Clearly, there is an assortment of NIAS coming from copper pipes and reported in numerous other studies cited by the authors going all the way back to the 1960s. Why no mention from Beyond Plastics when these facts have been known for half a century?

As this report is unfunded, I cannot devote the time to look up the toxicity of each of the NIAS chemicals found. It is enough to say that they are present, not intended to be present and that salts of copper are far more of a concern for humans than the metal because they are more soluble e.g. in stomach acid and far more toxic to aquatic life as well. In the next section, we will look at what happens when these newly formed chemicals break off as particles and contaminate our drinking water.

H. H. Dieter, Biochemische Essentialitat und Toxikologie von Kupfer. Gesundh.- Wes, 51, pp 222-227, 1989

Lead from Copper Pipes

As we all know, lead is highly toxic, which is why Congress have allocated **$15BN** to replace lead drinking water pipes. Copper pipes have been said to be an ideal replacement material and indeed copper drinking water pipes must be lead free. It is therefore shocking to learn that **“lead free”** copper pipes are not actually free of lead. The rules allow copper drinking water pipes to be called “lead free” even if they contain up to a quarter of a percent of lead.

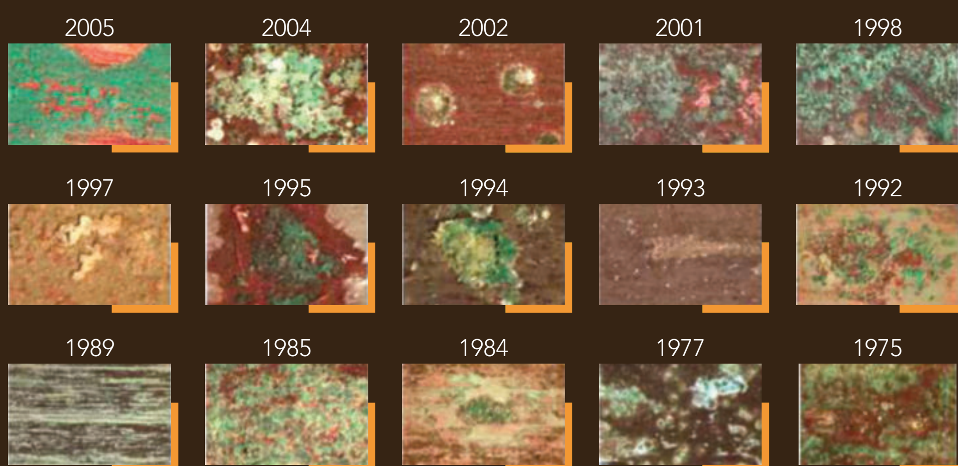
It is beyond belief that Beyond Plastics made a report highlighting the potential for pipes to leach substances into drinking water but completely failed to mention that there is toxic lead in the copper pipes they wholeheartedly endorsed.

> “Section 1417 of the Safe Drinking Water Act (SDWA) establishes the definition for “lead free” as a weighted average of 0.25% lead calculated across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture and 0.2% lead for solder and flux. The Act also provides a methodology for calculating the weighted average of wetted surfaces.”

https://www.epa.gov/sdwa/use-lead-free-pipes-fittings-fixtures-solder-and-flux-drinking-water

Copper Pipes & Nanoparticles

Copper pipes corrode rather rapidly leading to a rough, unsightly surface. This can also, increase drag, decrease flow and provide a place for bacteria to attach.



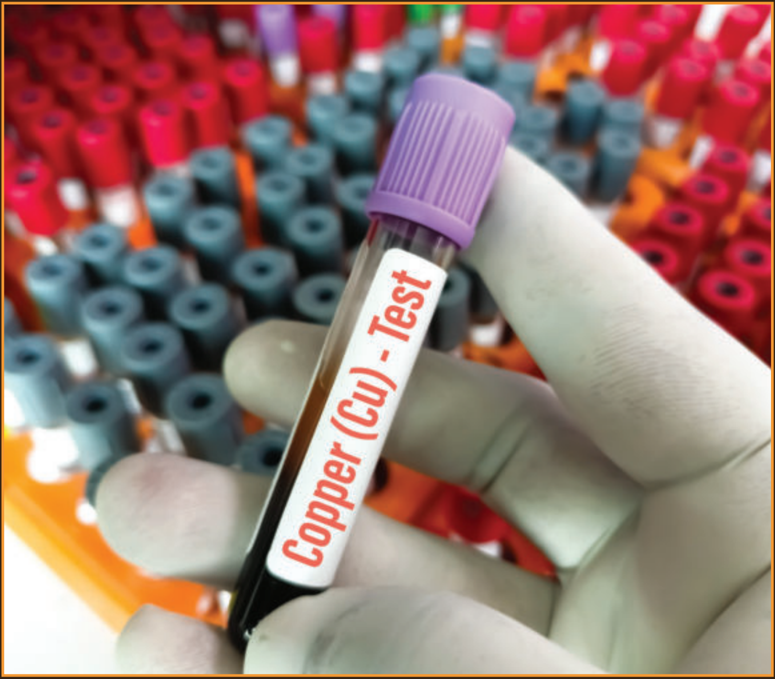
This led researchers to look at the surface to see whether it released any copper containing particles. They confirmed the release of submicron and nanoparticles from the copper pipe inner surface into drinking water.

N. F. Turek et al., Impact of plumbing age on copper in drinking water, Journal of Water Supply: Research and Technology – AQUA, 60.1, 2011

The amount of nanoparticles is remarkable with tens of millions of particles coming from an area of pipe the size of a pin head. With millions of miles of pipe installed, this means an unimaginable amount of copper containing nanoparticles released every year, which are toxic to humans but much more toxic to fish and other aquatic life.

From another study which found release of copper and silver nanoparticles from copper pipes.

> "Standard measurements of dissolved copper are made by filtering water samples through 0.45 µm pore-size membranes. However, the surface of corroding metallic surfaces may be covered by topographic features < 0.2 µm and structures that can be detached into the bulk water as nano-sized particles. A SEM, EDX, and AFM characterization of a corroding pipe after flow events revealed surface cavities, detached particles and attached particles with sizes between 0.05 and 0.2 µm. Our findings show that the release of colloidal and nanoparticles of corrosion by-products into the water can result in an increase of the dissolved copper measurements."



> "Additionally, 53 µg of copper was released per liter tap water on average. The measurements included tap water from different sampling days and from four different buildings with varying ages, whereas Ag-b-NPs could be detected in the tap water of two buildings. Silver traces in the copper pipe material of 27.5 ± 4.4 µg g^{-1} were found to be responsible for the release of nanoparticulate silver into the tap water."

I. T. Vargas et al., Increase of the concentration of dissolved copper in drinking water systems due to flow-induced nanoparticle release from surface corrosion by-products, Corrosion Science, 52, pp 3492-3505, 2010

Particle Size (µm)	Copper / particle (ng)	Number of Particles in 12µm²	Number of Particles in 0.785mm²	Estimated Mass of Copper (µg)
0.02	0.01	39	2,600,000	0.02
0.05	0.15	11	720,000	0.11
0.1	1.2	2	130,000	0.16
0.2	9.7	1	660,000	0.64

The study shows that copper pipes can also release silver nanoparticles into drinking water.

A. Wimmer et al., Copper Drinking Water Pipes as a Previously Undocumented Source of Silver-Based Nanoparticles, Environmental Science & Technology, 53, pp 13293–13301, 2019

Copper Compared to Plastic

Copper pipes are not alone when it comes to migration into water. Plastic pipes made of **PE, PEX, PP, uPVC** or **CPVC** have the potential to leach chemicals, but those additives are known to be safe and are only 1% or less of the plastic pipe material. While plastic pipes may give an off taste if the water is left standing, the same as for copper, the safety level between the two is very different. The additives in plastics are not considered a safety hazard, so regular drinking water testing is not required.

It is odd that Beyond Plastics claimed that plastic pipe additives are a problem when they are not considered to be. In contrast to plastics that contain low levels of safe additives, copper pipes are 100% by weight copper, which is not only toxic but proven to be a real threat.

What about price? Should the **$15BN** from Congress to replace lead pipes be spent on copper pipes? How does the price compare to the alternative pipe option?

Material	Price (USD/ft)	Material + labor (USD/ft)
Copper	$2-8	$3-10
PEX	$0.4-2	$1.5-3
CPVC	$0.5-1	$1.4-4
Galvanized Steel	$~8	$9-10
Cast Iron	$2-10	$3-12

https://www.bankrate.com/homeownership/what-types-of-plumbing-pipes-cost-the-most/

As shown in the first report rebutting the unjust allegations against plastic pipes, every life cycle analysis concludes that copper and other metal pipes are much worse for the environment. One of the factors is the carbon dioxide or so-called greenhouse gasses created by the manufacture of copper compared to plastic. The following table shows just how much of an environmental and monetary mistake it would be to choose copper. Four kilograms of GHG are given off for every kilogram of copper made compared to only 0.15 kilograms of GHG for every kilogram of polyethylene, polypropylene or PVC.

The table also reveals the high price of copper compared to the other materials relative to the GHG emissions. The reason is that copper is in short supply because it is in high demands for our transition to electric vehicles and other green energy initiatives. It would be foolhardy to use precious copper for drinking water pipes when other much higher value applications desperately need the copper.

Material	Footprint Kg/Kg	Price $/ton
Gold	30,000	67,000,000
Platinum	15,000	30,000,000
Silver	100	800,000
Aluminium	10	2300
Copper	4	8000
Paper	1	1000
Plastic	0.15	1000
Concrete	0.1	60
Limestone	0.02	35

> "The small city of 29,000 saved $2.2 million by using plastic to replace its own 1930s-era water system after state regulators alerted the city to critically needed fixes. For a municipality struggling with a dwindling tax base, those savings were huge."

https://www.nytimes.com/2017/11/10/climate/water-pipes-plastic-lead.html

Materials and the Environment: Eco-Informed Material Choice 3rd Edition, Michael F. Ashby, Butterworth-Heinemann / Elsevier, Oxford, page 232, UK, 2021

Finally, this table below summarizes how the different alternatives compare. By making a fair comparison based on peer-reviewed evidence, it becomes much easier to make a rational decision.

Material	Green?	Cheap?	Safe
Copper	NO	NO	Questionable
Steel	NO	NO	Yes
Polyethylene	Yes	Yes	Yes
Polypropylene	Yes	Yes	Yes
PEX	Yes	Yes	Yes
PVC	Yes	Yes	Yes

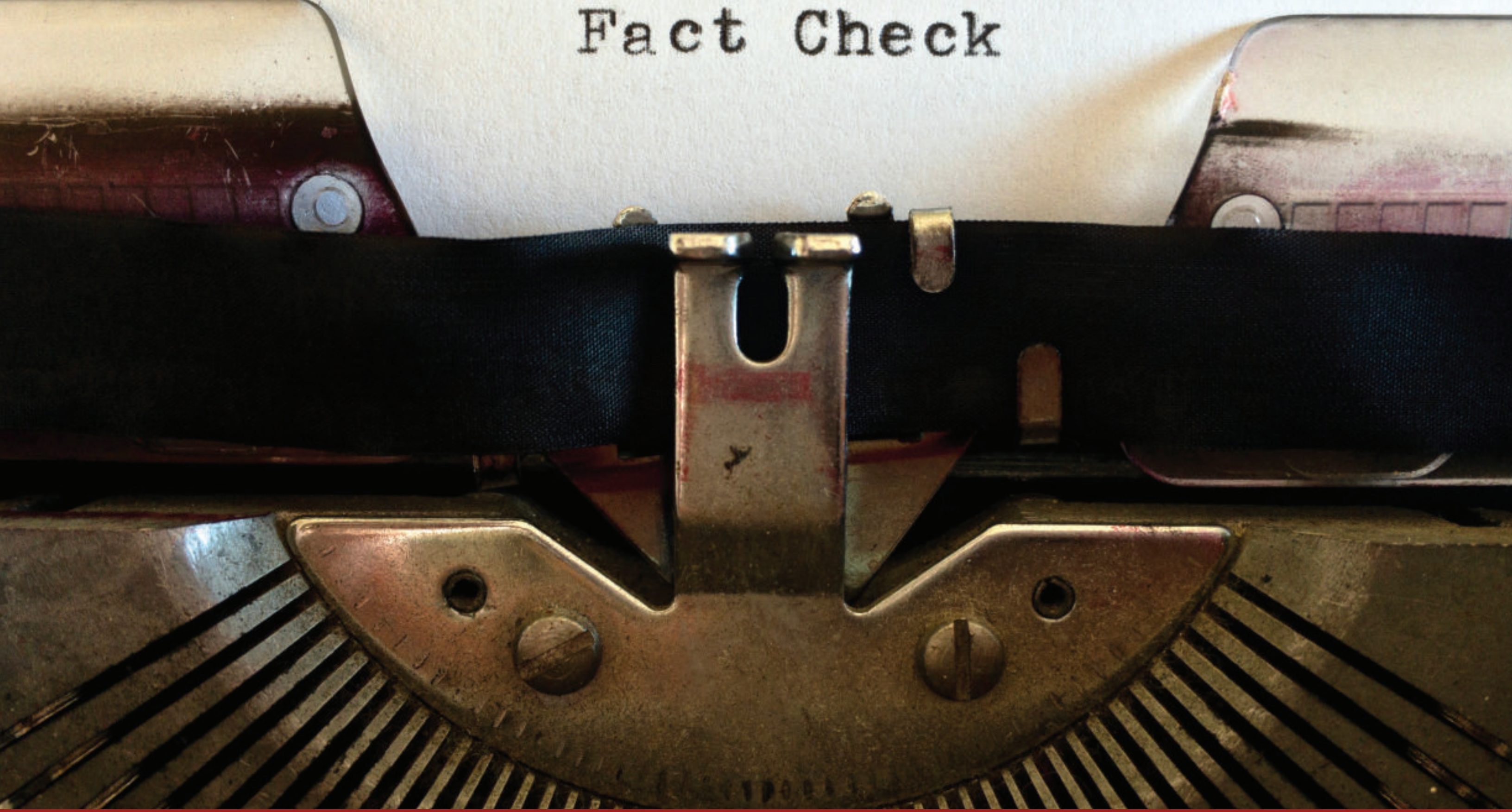
* note - copper pipes fail the NSF/ANSI/CAN 61 toxicity safety test at high and low pH

While plastic pipes are tested at high, low and neutral pH and pass under all three test conditions, copper pipes fail at high and low pH as so much copper is released from the pipes into water. Their answer is to only test copper at neutral pH, which is misleading because people with acidic or basic water may be exposed to toxic levels of copper in their drinking water.

Copper release from water pipes is worse when:

- **The water has low pH**
- **The water has high pH**
- **The water is chlorinated**
- **The water is soft**
- **The water is hot**
- **The pipes are new**
- **There are organic substances in the water**
- **The water has been left to stand**

It is recommended to flush the water for a minute or more if the water has been standing in copper pipes overnight or for several hours.



Conclusions

The recent report from Beyond Plastics was an unfounded attack on plastic water pipes and a suspiciously strong endorsement for the use of copper pipes in particular. Examination of the claims in that report showed them to be misleading in the extreme. In fact, multiple life cycle studies agree that copper, and other metal pipes, are much worse for the environment than plastic pipes like PE, PEX, PP or uPVC. Therefore, choosing copper pipes would mean more GHG, more fossil fuel used, more toxicity and more overall harm.

In addition, metal pipes are several times more expensive. Why would an alleged environmental group advise us to spend $15BN from Congress on pipes that are damaging to the environment and a waste of taxpayers' money? One can only speculate as to their motives, but it is worth noting that they made no declaration about their funding for the report or any conflicts of interest.

The Beyond Plastics report was lambasted and shown to not be credible by various organisations, however, one claim in the report that went unchallenged at the time was their declaration about the safety of copper pipes. Not only did they claim safety, but they also heralded them as a safer alternative to plastic pipes. As this new report has demonstrated, there is world-wide concern about toxic effects from copper drinking water pipes and no such concern over plastic pipes, which are shown to be safe as attested by decades in service. While widespread instances of copper toxicity have been reported world-wide, no such instances have occurred with plastic pipe material.

With scores of scientific studies questioning the safety of copper from pipes, one has to doubt the wisdom of spending $15BN on yet more copper piping, because that would inevitably exacerbate the problem, exposing more of the population to unsafe levels of copper. With millions of miles of copper water pipes already installed and causing concern, why make the problem worse?

It has been demonstrated beyond doubt that Beyond Plastics' glorification and unequivocal endorsement of copper pipes is neither credible, nor in the public interest. Their motives remain murky, and I urge anyone with knowledge of their motives or funding for the report to step forward and clarify the mystery. Beyond Plastics are located at Bennington College and questions have been asked as to why the college allows such reports to be released and whether there is any conflict of interest. Was tax-payer's money used to fund their work or were other, commercial interests, involved?

To summarize:

- **Copper pipes massively increase environmental harm compared to the alternatives according to multiple life cycle (LCA) studies**
- **Copper pipe is far more expensive and a waste of taxpayer's money**
- **Copper pipe is not as safe as claimed and indeed, according to the science, appears to be far less safe than the alternatives**

Copper is toxic like lead, so why would we replace one toxic metal with another when the alternatives are cheaper, greener and safer? Let's make wise choices for a better future based on evidence and logic.

Conflict of Interest

Scientific publications contain a **"conflict of interest"** statement where the authors disclose whether, for example, they were funded by an interested party, which could potentially cast doubt on the impartiality and credibility of the authors. The Beyond Plastics report contains no such statement. Without conflict statements from all contributors to the report, that document must be viewed with skepticism, especially as $15BN of public money is at stake.

In contrast, this report was researched and written by an independent scientist without any funding or external influence. It was written because I care about facts and leaving a better planet for future generations. Note also that this report looks only at the evidence and makes no endorsement of any product.

This report has been checked and validated by an independent, team of professors and scientists working voluntarily.

BIOGRAPHY

Chris DeArmitt

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President

– Phantom Plastics LLC

Chris is considered one of the top plastic materials experts and problem-solvers in the world, which is why companies like HP, Apple, Exxon, P&G, iRobot, Eaton, Total, and Disney come to him for help.

A deep understanding of materials combined with high creativity allows Chris to quickly solve even the toughest challenges. As one example, he solved a serious production issue that had plagued BASF for 30 years and cost them millions. Chris has also received six open innovation cash prizes, placing him among the top 0.01% of innovators.

In 2016, he published the book Innovation Abyss which reveals the true reasons for innovation failure and the proven path to success. In 2018, he was featured on CBS's 60 Minutes with Scott Pelley as an expert witness in a class-action lawsuit related to Marlex mesh plastic implants. He helped thousands of women get settlements. Later television appearances include Sky News and the BBC in addition to numerous radio appearances.

Chris has a multitude of granted patents as well as numerous articles, book chapters, encyclopaedia chapters, and conference presentations to his name. He is an award-winning keynote speaker on plastic materials, environment, and innovation-related topics. In 2020 Chris published The Plastics Paradox, the first comprehensive overview of plastics materials and the environment covering waste, litter, microplastics, degradation and other important topics.