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Technical Memorandum

For:	Bay Area Pollution Prevention Group
Prepared by:	Stephanie Hughes, P.E.
Date:	June 25, 2014
Subject:	Preliminary Comparison of PEX and Copper for Potable Water Piping

Summary

The wastewater community has long been interested in upstream pipe materials. In particular, BAPPG and member agencies have been promoting pollution prevention opportunities in the design and installation of copper piping systems since the late 1990s. Meanwhile, both CPVC[1] and PEX[2] have become options in the California plumbing code for potable water. Those actions initiated BAPPG members' interest in the differences between copper and plastic pipe. To date, such reviews have focused primarily on the potential leaching of chemicals from the pipe material. While that is clearly important, I have sought to look at a wider picture, surveying available literature (both peer-reviewed and industry-sponsored publications) to incorporate installation and life cycle aspects. I have focused on PEX (rather than CPVC) in part because unlike other plastics, it uses brass fittings rather than epoxies, and it is being promoted in local hardware stores as a relatively simple do-it-yourself installation. I have assembled my findings in the pages that follow. In summary, my tentative findings are as follows:

1. LIFE CYCLE: When viewed from a life-cycle perspective, PEX appears to have a lower global warming potential compared to copper and may have reduced impacts in other areas as well.
2. WORKER HEALTH: From an installer *respiratory* perspective, PEX may be preferable to copper pipe.
3. WATER QUALITY: PEX leaches a number of organic materials, at least within the initial months following installation. Copper pipe leaches copper for the initial years following installation. Depending on installation practices, copper pipe may also leach flux chemicals. Both materials may leach metals from brass fittings and fixtures.
4. MUNICIPAL WATER DISTRIBUTION: Municipalities use PVC and HDPE as materials for drinking water distribution systems, providing some context for a discussion about consumer choice with regards to plastic pipes.
5. CONSUMER CHOICE: A consumer's choice of plumbing material is subjective and there are variety of factors that impact consumer decision-making, including health, taste and odor, corrosion resistance, warranty, cost, and convenience of installation.

Please review the pages that follow for details on each of these subject areas. BAPPG may want to use this information to conduct additional research and/or update messages with respect to potable plumbing alternatives.

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[1] CPVC = chlorinated polyvinyl chloride, approved for potable water pipe in California in 2008.
[2] PEX = crosslinked polyethylene, approved for potable water pipe in California in 2010.

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Background

Copper pipe corrosion has been a major concern to the wastewater community for more than a decade. For many years, the messages have been about proper installation and the use of a water-based flushable flux (ASTM B813 flux); petrolatum-based, non-ASTM fluxes increase pipe corrosion long after the joint has been soldered. The BAPPG message is in good standing, as the Universal Plumbing Code (UPC) requires the use of ASTM B813 flux when installing copper pipe.

The reality appears to be that there is a disconnect between standards and plumbing practices. While water-based flux is the standard in the UPC for potable water, the standard appears to be virtually universally ignored. The boots-on-the-ground plumbers and trainers appear to have concerns about the water-based flux, both from a workability perspective and from a health/fume perspective. In addition, of five plumbing stores surveyed in San Francisco, petroleum-based fluxes were the ONLY fluxes available in two stores.[3]

These observations led to the conclusion that the vast majority of copper pipe may have been and may continue to be installed with the petrolatum-based flux. This led to questioning whether it is sufficient to provide plumbing messages only about copper pipe, given that at least one key pollution prevention message is ignored. This further led to a consideration of whether the wastewater community should understand the bigger environmental picture regarding copper versus plastic pipe. Therefore, this literature search has been an initial effort to try to better understand the life cycle, public health, worker safety and environmental impacts of these plumbing alternatives.

Literature Review and Discussion

1. <u>Life Cycle Analyses</u>

Life cycle analyses (LCAs) evaluate a material or product throughout the "life" of the material. Such analyses can vary greatly with respect to boundary conditions and the types of impacts that are analyzed. For instance, the analysis might be "cradle-to-factory gate" (thus, before reaching the ultimate consumer) or "cradle-to-grave" (i.e., include final disposal). Such analyses might analyze only one metric, such as global warming potential or might evaluate multiple environmental metrics (such as ozone depletion and ecotoxicity). Thus, it is difficult to evaluate and compare life cycle analyses.

Very few LCAs were uncovered for copper and/or PEX pipe materials. Further, typically the LCA was conducted for or by a particular industry (i.e. copper versus plastic) rather than published in a peer-reviewed application. Nevertheless, the results are intriguing and valuable to understand. The following papers were collected and reviewed:

Copper LCA Only

1. European Copper Institute, Brussels, Belgium, "The Environmental Profile of Copper Products," (a summary factsheet), date not provided (obtained March 3, 2014 from www.copper-life-cycle.org).

[3] One plumbing store staff person indicated that while they used to sell the water-based product, no one was buying it, so they took it off the shelves.

PEX LCA Only

2. Carolin, S., Vanderreydt, I, et al., “THIRD PARTY REPORT: Life Cycle Assessment of a PEX Pipe System for hot and Cold Water in the Building,” prepared under the authority of The European Plastic Pipes and Fittings Association, May 2011.

Copper and PEX LCAs

3. Franklin Associates, Prairie Village Kansas, “Life Cycle Inventory of the Production of Plastic and Metal Pipes for Use in Three Piping Applications,” prepared for the Plastic Pipe and Fittings Association, June 2008.
4. Geberit (multinational plumbing part manufacturer and supplier, based in Switzerland) “Life Cycle Assessment: Supply pipes for buildings,” January 2009
5. Lee, Juneseok, and Easterling, Andrew, San Jose State University, “Application of the EIO-LCA and LCIA to Premise Plumbing Materials,” World Environmental and Water Resources Congress 2012, ASCE.

The results of the five LCAs are summarized in the tables and graphics that follow.

1. **“The Environmental Profile of Copper Products,” European Copper Institute, Brussels, Belgium.**	
Materials evaluated	Only copper
Boundary conditions	Cradle-to-factory gate
Specific Findings:	
Global warming potential	900 lb CO_{2e} / 1000 ft for 0.6 inch diameter pipe
Conclusions	“Copper mines are multi-metal mines.” Extraction and processing are primary impacts. Increased recovery and recycling is important, especially since global copper use is so large. The annual scrap available now equals the production rate of 20-50 years ago. While this copper-only study did not compare the results to PEX or other materials, it is useful to note that the global warming potential (GWP), as measured in carbon dioxide equivalents (CO_{2e}), is within the range of estimates for copper in the LCA Study #3 (below).
Funder	Study provided by the European Copper Institute.

2. **Carolin, S., Vanderreydt, I, et al., "THIRD PARTY REPORT: Life Cycle Assessment of a PEX Pipe System for Hot and Cold Water in the Building," prepared under the authority of The European Plastic Pipes and Fittings Association, May 2011**	
Materials evaluated	PEX only, including the brass fittings
Boundary conditions	Included the extrusion, transportation, and disposal of the PEX pipe and brass fittings (assuming 50 years of service). Assumed that 85% of the material was disposed in a landfill while 15% was incinerated with energy recovery. Evaluated abiotic depletion, acidification, eutrophication, global warming, ozone depletion, and photochemical oxidation.
Specific Findings:	Their "functional unit" for their LCA, rather than a specific length of pipe, was the entire set of piping and fittings needed for a 100 m^2 European apartment. This included multiple lengths and diameters of pipe and numerous associated fittings. Therefore, it would be challenging and time consuming to compare their calculations with the other studies. That said, below is a summary of the major contributors to the environmental impacts.
Global warming potential	Primary impact is from the production of the raw materials for the PEX pipe. The extrusion of the pipe and the production of the fittings are the next most important life cycle phases for global warming potential.
Abiotic depletion	Primary impact is from the production of the raw materials for the PEX pipe.
Acidification	Primary impact is from the production of the raw materials for the PEX pipe and the production of the brass fittings.
Eutrophication	Primary impact is from the production of the brass fittings.
Ozone layer depletion	Primary impact is from the production of associated plastic fittings.
Photochemical oxidation	Primary impact is from the production of the raw materials for the PEX pipe and associated plastic fittings.
Conclusions	End of life stage, which assumed that 85% of the material was disposed in a landfill while 15% was incinerated with energy recovery, was the least impacting life cycle phase for all the environmental impacts evaluated.
Funder	"Study accomplished under the authority of the European Plastic Pipes and Fittings Association"

3. **"Life Cycle Inventory of the Production of Plastic and Metal Pipes for Use in Three Piping Applications," Franklin Associates, Prairie Village Kansas, June 2008.**		
Materials evaluated	Copper, PEX, and CPVC for a ¾ inch pipe for hot and cold water distribution	
Boundary conditions	Raw material extraction through pipe fabrication and transportation from manufacturer to the customer. Includes manufacture and disposal of transportation packaging. Does not include installation, fittings, adhesives, or solder for pipe connections.	
Specific Findings:	**Copper**	**PEX**
Global warming potential	Approx. 800-1500 lb CO_{2e} / 1000 ft of 3/4 inch diameter pipe	Approx. 380 lb CO_{2e} / 1000 ft of 3/4 inch diameter pipe
Solid Waste (included process wastes, fuel-related wastes, and post-consumer wastes)	If zero recycled – NA, this analysis was not included.[4] If 50% recycled, approx. 200-400 lb of waste per 1000 ft of 3/4 inch diameter pipe. If 100% recycled, approx. 50-75 lb of waste per 1000 ft of 3/4 inch diameter pipe.	If zero is recycled, approx. 145 lb of waste per 1000 ft of 3/4 inch diameter pipe. If 50% recycled, approx. 80 lb of waste per 1000 ft of 3/4 inch diameter pipe. If 100% recycled, approx. 30 lb of waste per 1000 ft of 3/4 inch diameter pipe.
Conclusions	"The use of energy resources as raw materials for plastic resins increased the total energy for plastic pipe systems; however, this is more than offset by the heavier weight of copper pipe and the large amounts of energy required to produce the primary and secondary copper." "Over 75 percent of the global warming potential for all pipe systems is from carbon dioxide from combustion of fossil fuels."	
Funder	Prepared for the Plastic Pipe and Fittings Association.	

[4] Notice the very different assumptions for recyclability of copper versus PEX. Copper is a highly valued material and is assumed to be far more likely to be recycled than the PEX material.

Below are two key tables pasted directly from Study #3. Copper K, L, and M refer to different industry standards for copper pipe, in which the thickness and weight of varies, with K being the thickest (and heaviest) per foot and M being the thinnest (and lightest) per foot.

Figure ES-6. Solid Waste for 1000 Feet of 3/4" HCWD Pipe by Solid Waste Category
(showing effects of various recovery levels)

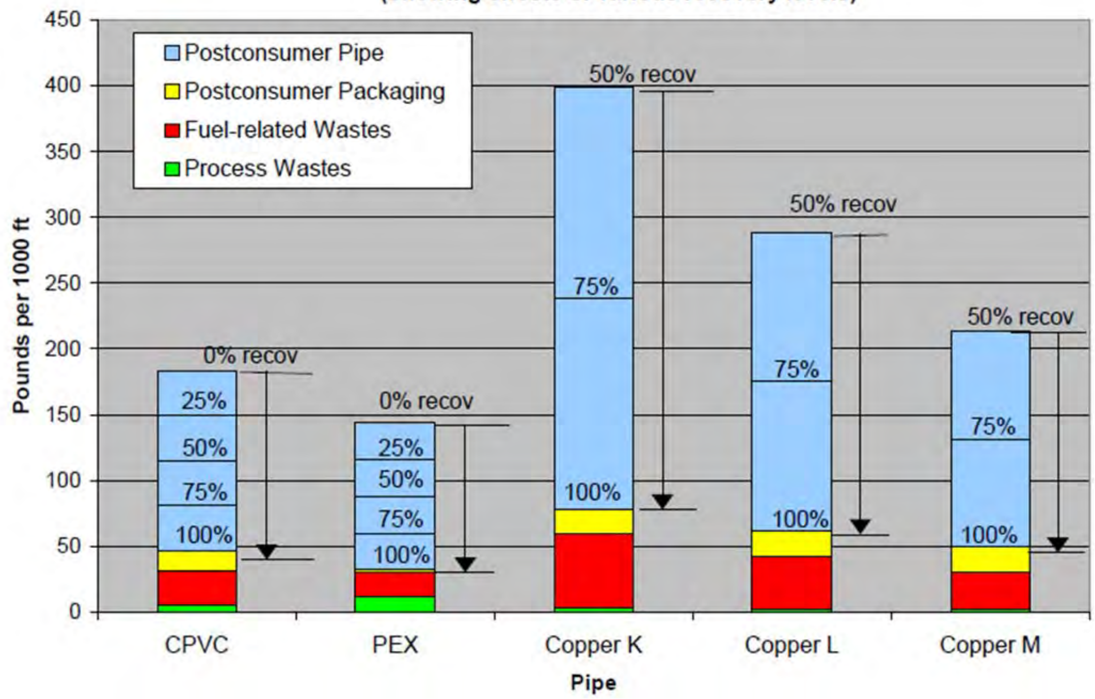
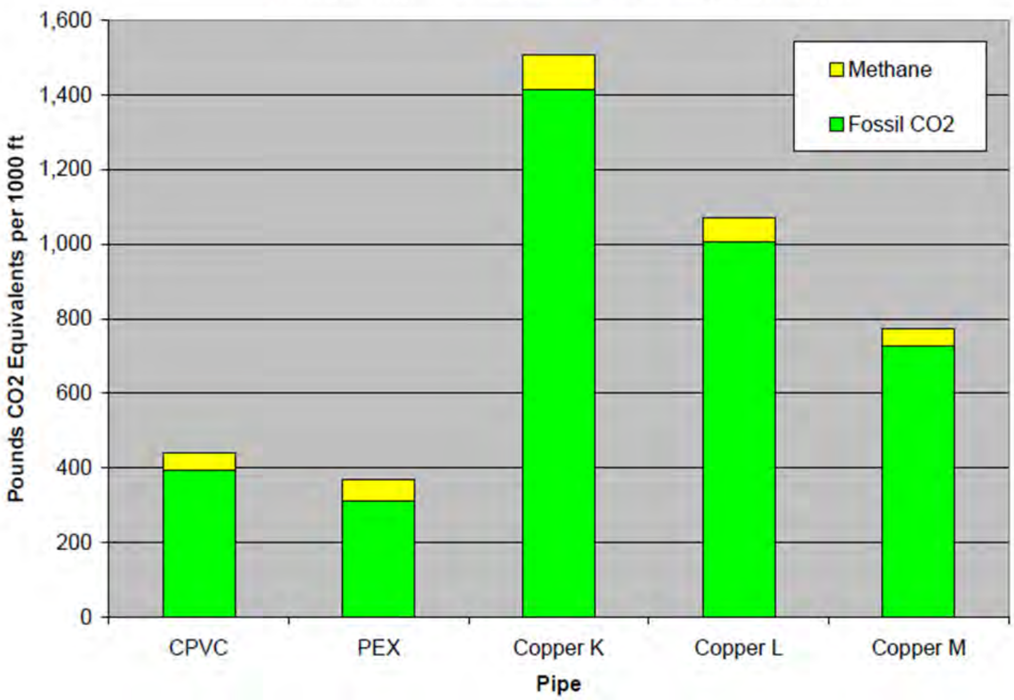


Figure ES-9. Global Warming Potential for Production of 1000 Feet of 3/4" HCWD Pipe

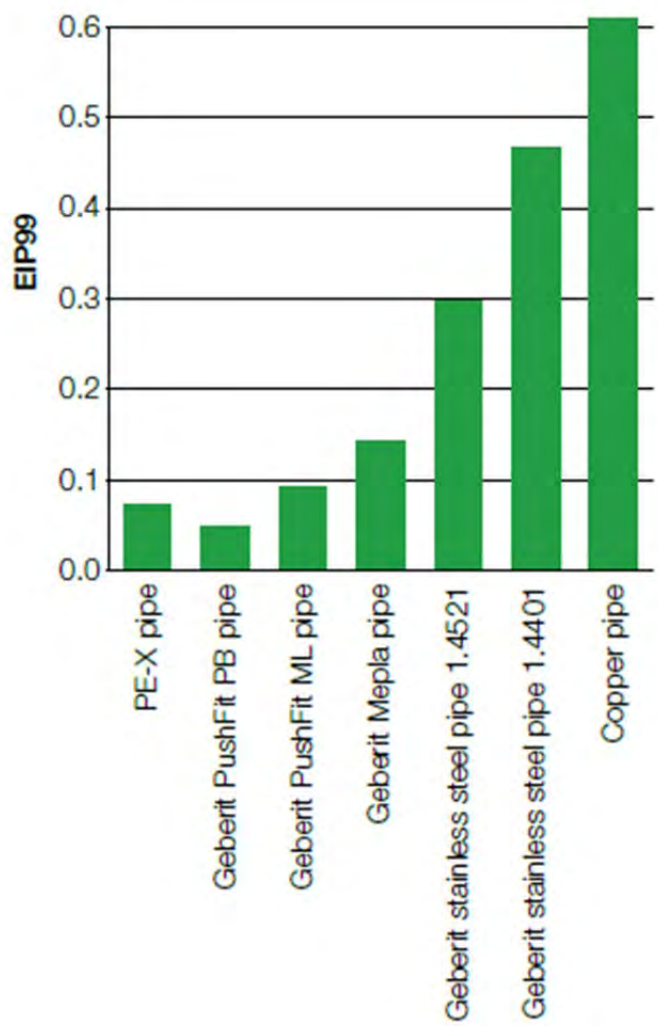


4. **"Life Cycle Assessment: Supply Pipes for Buildings," by Geberit, January 2009**		
Materials evaluated	Copper, PEX, and other supply pipe materials	
Boundary conditions	Mining to disposal (assuming incineration of PEX and recycling of copper), with a 50 year service life.	
Specific Findings	**Copper**	**PEX**
Overall Eco-Indicator Score (per a Dutch impact assessment method)[5]	Approx. 0.6 if 55% recycled Approx. 0.3 if 100% recycled The primary environmental impacts were mineral extraction and respiratory disease.	<0.1 This result was based on the assumption of 100% incineration for energy recovery (European analysis). As to the question of how the analysis would change if final disposal was a landfill, this is answered, in part by Study #2 that assumed 85% of the material was disposed in landfill and yet the disposal was the least impacting stage of the life cycle. The primary environmental impact was associated with the fossil fuel resource.
Conclusions	"From an ecological point of view, pure plastic drinking water pipes (PEX and PB[6]) have the best results. Plastic-aluminum multilayer pipes have a slightly higher environmental impact due to the additional aluminum layer." "The higher environmental impact of the copper and stainless steel pipes is due to the weight per meter, which is two to three times as high, and because extracting metal from metal ores is extensive and energy intensive"	
Funder	In-house project by Gerberit, a multinational plumbing part manufacturer and supplier, based in Switzerland.	

[5] The Eco-Indicator Score incorporates fossil fuel resources, climate change, acidification, eutrophication, respiratory diseases, fossil fuel combustion, mineral extraction, ozone depletion, land use, and ecotoxicity. The method aggregates all the impacts into a single score. The lower the score, the lower the environmental impact.

[6] polybutylene

Below is a key figure pasted directly from Study #4. This figure was included in Gerberit's English-language summary. The full report, available in German, provides additional documentation and graphics. The full report also parses out each of these results into the various environmental impacts (i.e., fossil fuel resources, climate change, acidification, eutrophication, respiratory diseases, fossil fuel combustion, mineral extraction, ozone depletion, land use, and ecotoxicity).



5. **Lee, Juneseok, and Easterling, Andrew, San Jose State University, "Application of the EIO-LCA and LCIA to Premise Plumbing Materials," World Environmental and Water Resources Congress 2012, ASCE.**	
Materials evaluated	Copper, PEX and CPVC
Boundary conditions	Cradle to gate, not including installation, use or end-of-life disposal.
Areas considered	Considered human health, ecosystem quality, climate change and resources using a computer model developed by Hewlett Packard. Based on a follow-up discussion with the HP model developer, standard model assumptions were used for this analysis, which may or may not have been the most appropriate assumptions for these materials.
Specific Findings	Given the wide range of impacts evaluated, the figure below best summarizes the results.
Conclusions	"The results revealed that for all midpoint and damage impact categories, PEX systems have less of an impact on the environment than either copper or CPVC." "Results… may be combined with economic, ergonomic, convenience, safety, and other relevant factors to produce a holistic decision model that can be used to optimize material selection."
Funder	Hewlett-Packard and San Jose State University

Below is a key figure pasted from Study #5.

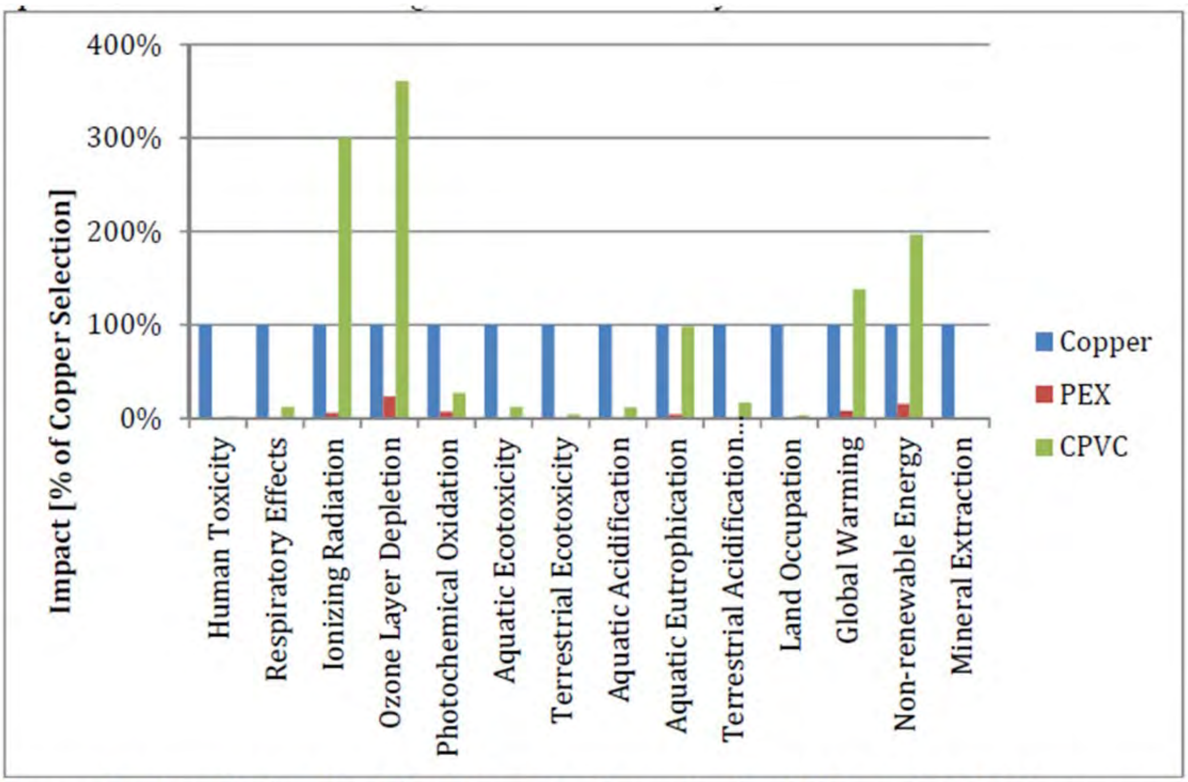


Figure 1: Results for the 14 midpoint categories for PEX and CPVC compared to copper.

2. Installer/Worker Safety

From a worker safety perspective, soldering of copper includes the use of solder and soldering flux. Note that the water-flushable flux (the one required for potable water pipe and recommended by BAPPG agencies) has a number of organic chemicals not included in the non-flushable flux. The ingredients in two typical fluxes on the market are presented below, along with a couple of findings about possible health concerns. In addition, I have received anecdotal complaints from Bay Area plumbers regarding the water flushable flux, contending that the fumes are more noxious than petrolatum-based flux.

Topic	Copper		PEX
Products used during installation	• Water flushable (ASTM B813) flux[7] • Solder	• Non-flushable (petrolatum based) flux[8] • Solder	PEX pipes are connected with brass fittings.
Ingredients	• Flux: o Ammonium chloride o Ethanolamine hydrochloride o Paraffic oil o Petroleum derivatives o Polyethylene-polypropylene glycol o Glycerine o Polyethylene glycol octylphenyl ether • Lead-free solder o Tin o Silver o Possibly antimony	• Flux: o Ammonium chloride o Petrolatum o Zinc chloride • Lead-free solder o Tin o Silver o Possibly antimony	Not applicable
Possible respiratory concerns	• Occupational asthma from ammonium chloride and zinc chloride[9] • "A qualitative assessment of organic vapors released during... soldering of copper plumbing systems. The organic vapors from three soldering paste fluxes and a solder paste flux...included a series of aliphatic hydrocarbons, aromatic and polyaromatic hydrocarbons, chlorinated benzenes, oxygenated aromatic materials, and several chlorinated phenols."[10] • Neither study evaluated the possible long-term exposure of heavy metals from the solder.		Not applicable

[7] Nokorode Aqua Flux MSDS

[8] Nokorode Regular Paste Flux MSDS (a common flux found in local plumbing supply shops)

[9] Weir, DC, Robertson, AS, Jones, S., Burge, PS, "Occupational Asthma due to Soft Corrosive Soldering Fluxes Containing Zinc Chloride and Ammonium Chloride," Thorax, Vol. 44, No 3, 1989. (Reviewed abstract only.)

[10] Nikora, JA, Olson, AJ, and Steele, WC, "Identification of Organic Vapors from Commercially Available Soldering Fluxes During Simulated Soldering of Copper Plumbing Systems," American Industrial Hygiene Association Journal, Vol 51, No. 7, pages A476-A477, 1990. (Reviewed abstract only.)

3. **Water Quality / Leachants**

I have previously conducted prior reviews of leaching from plastic pipes, including discussions of aquatic toxicity and human health concerns.[11] Below is a brief summary of likely leachants from copper, PEX, and CPVC.

Leachant	Copper	PEX	CPVC
Chemicals that may leach from the pipe material NOTE: Copper and PEX include brass fittings and fixtures which leach copper, led, nickel and zinc.[12]	Copper Flux residual (see section immediately above)	A number of volatile organic compounds may leach from PEX. For instance, in one study the following were the primary leachants:[13] • Methyl tert-butyl ether (MTBE) • Tertiary butanol • 4-Butoxy phenol • 5-Methyl-2-hexanone In that study, there were additional VOCs that were measured and there were unidentified VOCs that were not quantified. In another study, the following were the primary leachants:[14] • MTBE • 2,4-di-tert-butyl phenol	A number of volatile organic compounds may leach from CPVC. The following organotins appear to be of most concern from a health standpoint: • Monobutyltin • Dibutyltin • Tributyltin A review by the AWWA Research Foundation suggested that a number of additional chemicals could leach from PVC/CPVC water systems.[15] Some VOCs may be attributed to the cement solvents. Because CPVC formulations have changed over time, it is unclear whether these VOCs would be measured leaching from currently available CPVC pipe and associated solvents.
Timescale of chemical leaching	Copper will corrode most significantly in first years following installation (prior to a protective patina coating). It will continue to corrode at sites of turbulence, flux residual, or due to water chemistry or other physical/ chemical factors.	In both studies referenced above, the concentration of MTBE was originally greater than the US EPA MCL (maximum contaminant level) but decreased with time. In the 2011 study, the MTBE concentration decreased below this value in 5 months. That study concluded that the overall potential health concern was low, but that the odor could negatively affect drinking water for up to one year.	Based on available evidence, it appears that organotins are released from CPVC pipe and may do so for a number of days under typical use conditions. It is unclear the length of time over which this leaching would continue in a residential setting.[16]

[11] Hughes, Stephanie, "CPVC for Potable Water Piping: Review of Chemical Leaching Data and Related Toxicity Information" technical memorandum to the PARWQCP, September 2008.
[12] Kimbrough, David, "Source Identification of Copper, Lead, Nickel and Zinc Loading in Wastewater Reclamation Plant Influents From Corrosion of Brass in Plumbing Fixtures," Environmental Pollution, Vol 157, 2009.
[13] Skjevrak, I., et al, Volatile Organic Compounds Migrating from Plastic Pipes (HDPE, PEX, and PVC) Into Drinking Water, Water Research (2003) 1912-1920.
[14] Lund, V, et al., "Long Term Study of Migration of Volatile Organic Compounds from Cross-linked Polyethylene (PEX) Pipes and Effects on Drinking Water Quality," Journal of Water and Health, Volume 9, 2011.
[15] Tomboulian, P., Schweitzer, L., Mullin, K., Wilson, J., & Khiari, D. (2004). Materials used in drinking water distribution systems: contribution to taste and odor. *Water Science and Technology* , 219-226.
[16] Hughes, Stephanie, "CPVC for Potable Water Piping: Review of Chemical Leaching Data and Related Toxicity Information" technical memorandum to the PARWQCP, September 2008.

4. Municipal Water Supply Material Choices

According to California regulations, PVC and HDPE are among the materials that may be used for drinking water mains. **The table below was pasted from "California Regulations Related to Drinking Water" as of July 1, 2103**.[17] While PEX is not on the list, the use of other plastics throughout water distribution systems does provide a context with which to consider consumer pipe choices.

Article 4. Materials and Installation of Water Mains and Appurtenances

§64570. Materials and Installation.

(a) All newly installed water mains shall comply with the materials and installation standards of the American Water Works Association pursuant to tables 64570-A and 64570-B. The standards are hereby incorporated by reference.

Table 64570-A
Materials Standards for Water Mains

Type of Material	*Diameter of Main*	*Applicable Standard*
PVC	4 in. through 12 in.	C900-97
PVC	14 in. through 48 in.	C905-97
Polyethylene (HDPE)	4 in. through 63 in.	C906-99
Fiberglass	All sizes	C950-01
Ductile Iron	All sizes	C150/A21.50-02
Ductile Iron, Centrifugally cast	All sizes	C151/A21.51-02
Steel	6 inches and larger	C200-97
Copper	All sizes	C800-05
Concrete		
Reinforced steel-cylinder	All sizes	C300-04
Prestressed steel-cylinder	All sizes	C301-99, C304-99
Reinforced noncylinder	All sizes	C302-04
Bar wrapped/steel cylinder	All sizes	C303-02
PVC, Molecularly oriented polyvinyl chloride – All sizes		C909-02

5. Consumer Choice

Dr. Juneseok Lee, a professor at San Jose State University (and author of Study #5) has been reviewing consumer decision making with regard to plumbing materials. He has estimated that in the USA, about 90% of home plumbing systems are copper pipe, and that pinhole leaks have become a concern due to property damage, property values, and insurance concerns.[18] He studies consumer preferences and decisions, and in particular has conducted surveys in a region prone to pinhole leaks in copper pipe. While surveyed homeowners indicated that health, taste, and odor were dominant considerations, they sometimes stated preferences to a survey that differed from their real-life choices. **On the following page are a table and two pie charts pasted from Dr. Lee's research, summarizing parameters that impact consumer choice and the plumbing selections made by households that replumbed their homes.[19]** Dr. Lee concluded that "*the choice of plumbing materials is inevitably subjective and, in real life, numerous factors influence the selection of a particular pipe material*."

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[17] Available from www.cdph.**ca**.gov.

[18] Lee, et al., "Case Study: Preference Trade-Offs Toward Home Plumbing Attributes and Materials," Journal of Water Resources Planning and Management, ASCE, July/August 2009.

[19] Lee et al., "Homeowners' decision-making in a premise plumbing failure prone area," Journal AWWA, Vol 105:5, May 2013.

The following figures are directly from: Lee et al., "Homeowners' decision-making in a premise plumbing failure prone area," Journal AWWA, Vol 105:5, May 2013. NOTE: the surveyed community was in a region that was prone to pinhole leaks in copper pipe.

TABLE 1 Alternative information matrix used for survey

Parameters	Pipe Material: Copper	Pipe Material: Cross-linked Polyethylene	Pipe Material: Epoxy Coating
Corrosion resistance	Some risk of corrosion exists.	Material is corrosion-proof.	Material is corrosion-proof.
Taste/odor	Compounds released may give a bitter or metallic taste or odor to the water.	Compounds released may give a chemical or solvent taste or odor to the water.	Compounds released may give a chemical or solvent taste or odor to the water.
Health effects	Material meets USEPA standards. There is a very small chance that compounds released into drinking water may cause vomiting, diarrhea, stomach cramps, and nausea.	Material meets USEPA standards. There is a very small chance that compounds released into drinking water may lead to microbial growth, potentially causing severe illness.	Material meets USEPA standards. There is a very small chance that compounds released into drinking water may lead to microbial growth, potentially causing severe illness.
Convenience of installation	Penetration of walls and/or floors to replace existing system. Installation takes 7–9 days.	Some sections of wall penetrated for installation. Installation takes 5–6 days.	No penetration of walls and/or floors. Installation takes ~ 4 days.
Market history	Product has been on the market for more than 50 years.	Product has been on the market for less than 20 years.	Product has been on the market for less than 10 years.
Cost (labor+ material)	Costs range approximately from $9,000 to $16,000, depending on the size of the house.	Costs range approximately from $6,500 to $13,000, depending on the size of the house.	Costs range approximately from $9,000 to $14,000, depending on the size of the house.
Warranty	Product carries a 50-year manufacturer's warranty with some exceptions; reduces to one year if compounds in the water corrode pipes.	Warranty term is 10 years for the material.	Warranty term is 15 years for the material.

USEPA—US Environmental Protection Agency

FIGURE 3 Importance of attributes from analytical hierarchical process (stated preferences for 133 respondents)

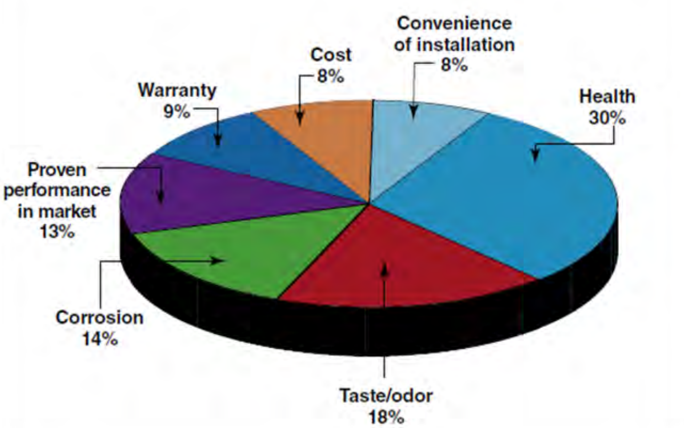
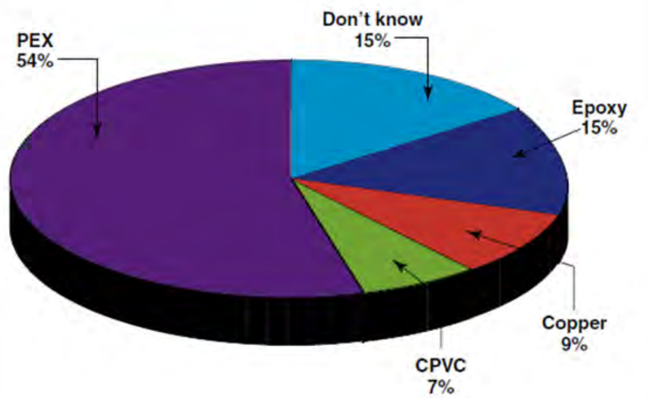


FIGURE 4 Preferences for those who replumbed (out of 59 households)



CPVC—chlorinated polyvinyl chloride, PEX—cross-linked polyethylene

Endnotes

This concludes the summary of my initial findings. BAPPG may want to use this information to conduct follow-up analysis and/or to update messages with respect to potable plumbing alternatives. I intend to summarize this information at the August 2014 BAPPG meeting to initiate a discussion about next steps, if any.