[A Few] Emerging Issues for Plastics with Infrastructure Rehabilitation & New Construction:
Pipes, Coatings, Liners and Composites

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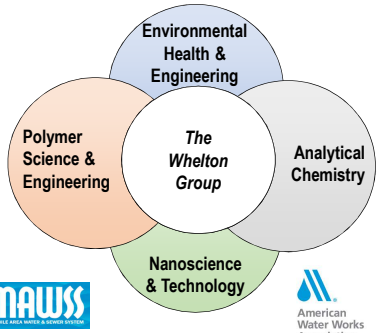
November 16, 2016

PURDUE UNIVERSITY

Water 2.0 – Indianapolis, IN

Mission: Develop the next generation of scientists and engineers knowledgeable to solve the growing number of complex infrastructure, public health, and environmental challenges



Partners

MAWSS, American Water Works Association, WV TAP, United States Environmental Protection Agency, Southern Company, NSF, USAPHC, NIST, VDOT, FDA, Water Research Foundation

Education Actions

Polymers in Infrastructure & Environ.
Fund. Environ. Eng. & Design
FASTCE
NESCC and ILSI Expert Panels
Industrial workshops & conferences

Research

Infrastructure materials
Polymer degradation
Aquatic chemistry
Water distribution
Water quality & treatment

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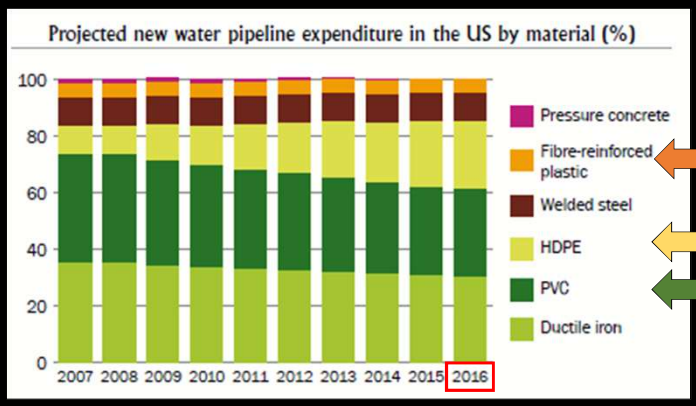
Why Care About Plastics?

$200.8 billion required by 2027 for water distribution and transmission pipelines just to continue to provide clean and safe drinking water to consumers [EPA 2007 – 9 years ago]



Up to 70% of new building construction utilizing crosslinked polyethylene (PEX) pipe

50% of all water pipes in the U.S. repaired by cured-in-place-pipe (CIPP)

And more…

Which plastics are in your home or utility?

Or are you considering?

INORGANIC PIPES AND COATINGS

AC	Asbestos Cement
CI	Cast Iron
CML	Cement Mortar Lining
Cu	Copper
DI	Ductile Iron
GI	Galvanized Iron
GS	Galvanized Steel
-	Lead
PECM	Polymer Enhanced Cement Mortar
PCCP	Prestressed Concrete Cylinder Pipe
SS	Stainless Steel
-	Wood

PLASTIC GASKETS

EPDM	Ethylene Propylene Diene Monomer
EPDM-P	Ethylene Propylene Diene Monomer – Peroxide Crosslinked
EPDM-S	Ethylene Propylene Diene Monomer – Sulfur Crosslinked
FKM	Fluorocarbon
NBR	Nitrile Butadiene Rubber
NEO	Neoprene Rubber
NR	Natural Rubber
PTFE	Polytetrafluoroethylene
PVAc	Polyvinyl Acetate
SBR	Styrene Butadiene Rubber
SR	Silicone Rubber

PLASTIC PIPES, COATINGS, AND LINERS

ABS	Acrylonitrile-Butadiene-Styrene
CIPP	Cured-in-Place Pipe
CNFRP	Carbon Nanofiber Reinforced Plastic
cPVC	Chlorinated Polyvinyl Chloride
EP	Epoxy
fPVC	Fusible Polyvinyl Chloride
FRP	Fiber Reinforced Plastic
HDPE	High-Density Polyethylene
HDPE-RC	High-Density Polyethylene – Resistance to Crack
LDPE	Low-Density Polyethylene
MDPE	Medium-Density Polyethylene
mPVC	Modified Polyvinyl Chloride
oPVC	Oriented Polyvinyl Chloride
PB	Polybutylene
PERT	Polyethylene Raised Temperature
PEUU	Polyurea
PEX	Crosslinked Polyethylene
PEX-a	Crosslinked Polyethylene manufactured by a Peroxide Method
PEX-b	Crosslinked Polyethylene manufactured by a Silane Method
PEX-c	Crosslinked Polyethylene manufactured by a Irradiation Method
PP	Polypropylene
PSf	Polysulfone
PU	Polyurethane
PVC	Polyvinyl Chloride
uPVC	Unplasticized Polyvinyl Chloride

OTHER MATERIALS

Multilayer pipe consists of an layer of plastic, a layer of adhesive, a layer of either aluminum or ethylene vinyl alcohol, another layer of adhesive, and an outer later of plastic. The plastics may or may not be similar in type.

Plastic Water Infrastructure Materials can be Much Less Expensive than Metallic Materials

Material Application and Name	Cost, $ USD	
	per 100 feet	per foot
Hot and Cold Use		
Copper (Type L)	$255.10	$2.55
Polypropylene (PP)	$94.10	$0.94
Chlorinated PVC (cPVC)	$53.80	$0.53
Crosslinked Polyethylene (PEX)	**$48.69**	**$0.48**
Cold Use Only		
Galvanized Iron	$174.20	$1.74
High Density Polyethylene (HDPE)	$23.98	$0.23
Polyvinylchloride (PVC)	$21.80	$0.21

Connell et al. (2013)

2013 Estimate for 4 Bedroom 2.5 Bath Residential Replumb on Slab in Alabama
$ 11,000+ Copper $ 8,000 cPVC $ 4,000 PEX

The Literature is Dominated by Deficient Material Testing Standards and Poorly Designed Studies

PB pipe failures (1980s-Pres)

Class Action
$300 million

Whelton House (2010)

HDPE pipe ClO_2 failures (2002-Pres)

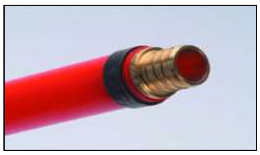
Water

Hypochlorite

Chlorine Dioxide

PEX fitting failures (2010-Pres)

Class Action
200 million fittings sold



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2000s: **Widespread EPDM failures** due to chloramines

2003-2016: **Odors from PEX pipe systems, replumbs sometimes needed**

2008-2016: **More than 35 CIPP incidents** of fish kills, activated sludge inhibition, facility evacuations, inhalation chemical exposures

2010: **EPDM gaskets linked to nitrosamine** contamination

2010–2012: "**Tens of thousands"** of HDPE water pipe failures costing $1,800/repair

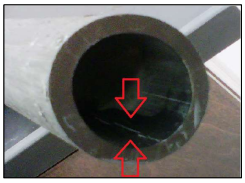
2012: **Premature PP water pipe failures** in presence of copper

2014: PEX pipe causes **"gasoline" odors**, but water is safe

2015: **Only 7 year HDPE water pipe life** (American Samoa, some Western US states)

2016: **Premature PEX water pipe failures**

"Approved" Technologies Keep Entering the Marketplace and Fail Unexpectedly



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Cause or Contributor to Failed Performance	Plastic Product User Contributing Factors
Product not manufactured appropriately	User didn't know or require certain quality
Impact of production variation on product performance not understood	User didn't know or require certain quality
Variation between product batches not minimized or understood	User didn't know or require certain quality
Installers inappropriately handle/damage materials	User didn't know or require certain quality
Impact of condition variation during installation not minimized or understood	User didn't know or require certain quality
Others…	User didn't know or require certain quality

But Why?

Education: Many Utility and Building Construction Professionals Lack a Basic Understanding of Plastics

Typical University Degree Courses

Water and wastewater treatment
Water chemistry
Environmental science
Hydraulics
Timber, concrete, asphault, steel
Statics, Dynamics, Deforms
Construction management

What They Need:

Polymer Chemistry
Polymer Engineering
Surface Science

We Teach Plastics. Plastics are Polymers!

Poly- (multiple) + **-mer** (part) = "chain" of compounds

Structure of compound affects material performance factors:
- Thermoplastic (can melt)/Thermoset (crosslinking)
- Crystallization/Glass-Transition/Melting Temperatures (T_c/T_g/T_m)
- Amorphous-Crystalline Spectrum

Within the polymer matrix, additives, including antioxidants, plasticizers, crosslinking agents, etc., can affect material performance:
- Resistance to oxidation and mechanical failure
- Chemical diffusion coefficients
- Health considerations (voluntary NSFI 61 testing – no government testing)

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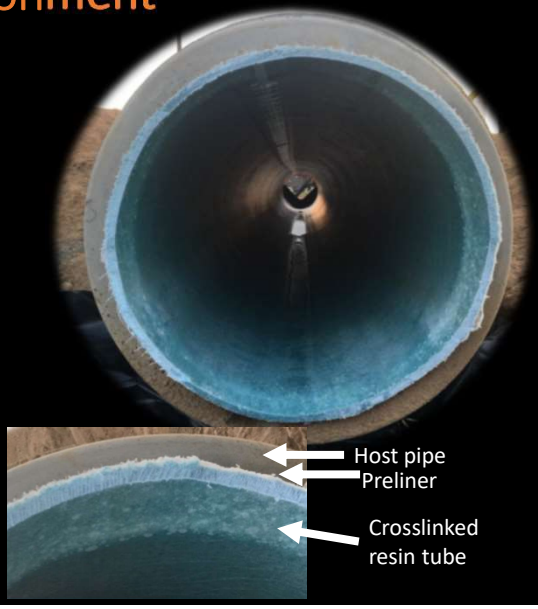
Emerging Issue #1: Cured-in-Place-Pipe (CIPP) Risks to Human Health and the Environment

Trenchless technology: "No Dig" "No Excavation"

Resin impregnated tube hardened in a broken pipe

Curing method: Hot water, Steam, UV light

Deliberate curing time: Hours to many days



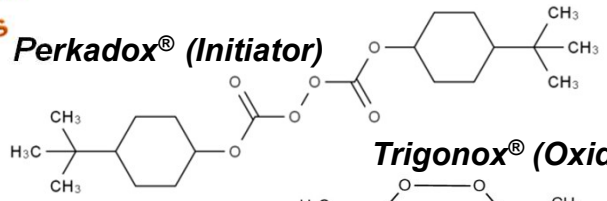
CIPP Is *Created* In the Field
Where Chemicals are Mixed and Reacted

Resin + Hardener + Initiators + Plasticizers

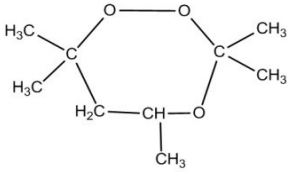
Initiation can be hot water, steam, or UV light

Some Listed CIPP Formulation Ingredients

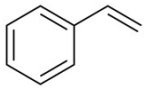
Perkadox® (Initiator)

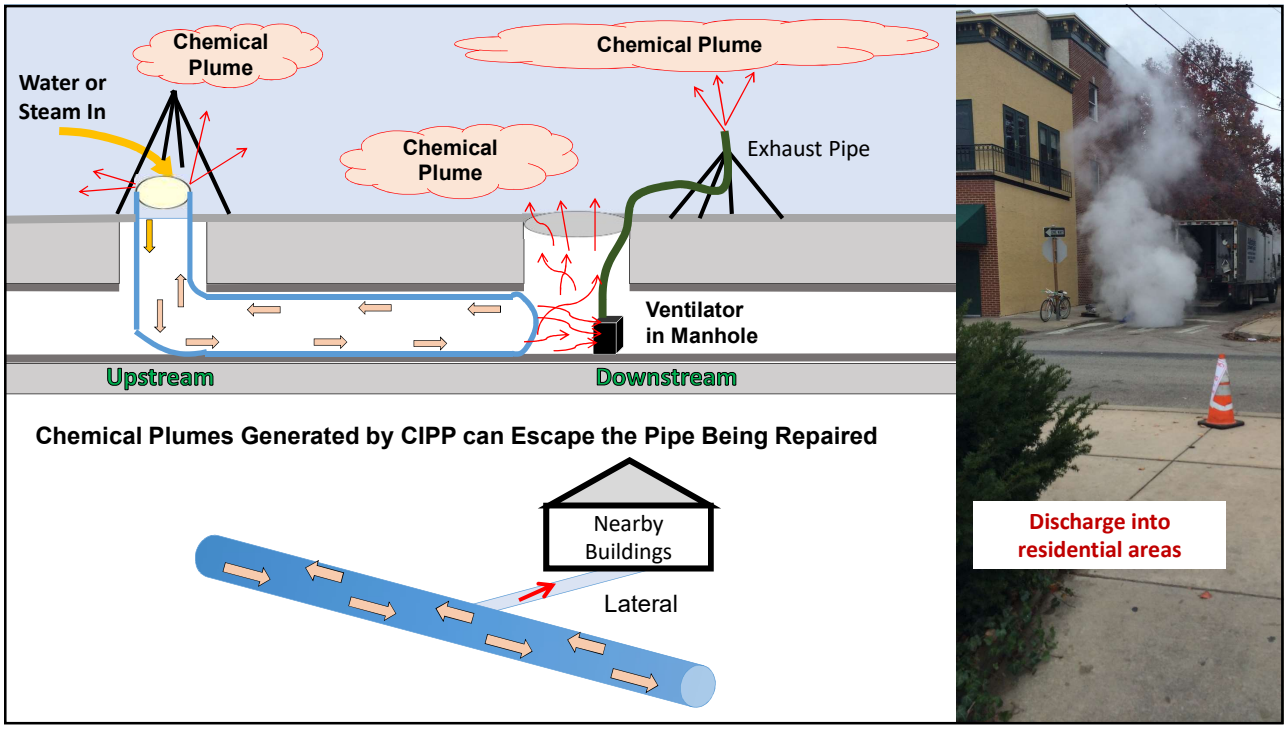


Trigonox® (Oxidizer)



Styrene (Reactive Dilutent)





Incident Location	Styrene	Description of Events from Reference
West Lafayette, IN (Whelton 2016)	nr	Fumes entered campus building through floor drains; doors opened to ventilate; no fire department called; contractor said just odor, not harmful
Good Hope, IL (Langhout 2016)	nr	Steam filled the post office 4 different times; no fire department called; lateral not plugged allowed chemical plume to enter building; blew off toilet
Montreal, Québec (Gagnon 2015)	nr	Fumes stayed in building for 1 month. Installers claimed styrene trapped underground and drifted into house. Installers installed blowers. After the 2nd month (1 month of ventilation) odor went away.
Buffalo Grove, IL (Andrews & Johnson 2015)	nr	Neighbors reported that they became nauseated and dizzy from chemical smell in their homes. One resident reported short of breath and headache. Another resident went to hotel due to the severe smell in their homes. They were repulsed, groggy, and confused.
Lincoln, NB (Fili 2015)	nr	Several homes evacuated; fire department called
Antigo, WI (Linder 2015)	nr	Illness symptoms reported; Whistling heard in drain inside building
Rensselaer, NY (Gagnon 2015)	nr	Chemical seeped to residential homes from sewer CIPP lining neighborhood displaced, residents reported that styrene permeated the clothing in their drawers, closets, and couches
Prairie Village, KS (Braun 2014)	nr	Smell of superglue in house, headaches and nostrils burning; utility contacted and told resident vapors nontoxic. Windows and doors opened for ventilation, but odor remained. County did not investigate and told resident chemicals were nontoxic.
Baltimore, MD (Ashton 2014)	nr	Resident evacuated house after detecting odor and experiencing chemical exposure symptoms; sought medical attention; Odors got stronger when it rained.
Ottawa, CN (Bauer 2012)	nr	Odors detected kilometers from worksite
Fayetteville, NY(Doran 2012)	nr	Odors permeated into nearby residences; residents complained and evacuated their homes
Brisbane, AUS (Woods 2012)	nr	Odors detected and exposure lasted 5 days in home; Health department investigated and demanded home be decontaminated; Pets died.
Birmingham, UK (Brody 2011)	nr	Six people and five students and a staff from high school were taken to hospital after the smell from sewer repair work made them sick.
Worcester, MA (Dayal 2011)	60 - 70	Fumes caused daycare center evacuation; headaches reported; emergency responders called to site
Minnesota (Marohn 2011)	nr	Odor caused building evacuations
Southfield, MI (Banovic 2011)	nr	Hazardous materials response team (HAZMAT) responded; vapors from nearby CIPP operation entered school ventilation system; building evacuated; children transported to hospital for chemical exposure symptoms
Saugus, MA (Tempesta 2011)	nr	Firefighters ordered evacuation of elementary school because of strong odor; dizzy and light-headed symptoms reported
Pittsburgh, PA (Hayes & Biedka 2011)	nr	Elementary and high school students were evacuated for fear of gas leak; odors from nearby CIPP operation were the cause
Birmingham, UK (Pub. Health England 2011)	20 - 200	Odor detected. Residences evacuated at contractors recommendation. Contractor did not disclose styrene present in homes above health limits until days after health agency involved.
Helena, MT (Banks 2010)	nr	Fire department evacuated affected building because of complaints of strong odors, nausea, and headaches
Arlington, VA (ARLnow.com 2010)	nr	Nearby CIPP installation caused odor; fire department responded
Pittsburgh, PA (WPXI-TV 2009)	nr	Firefighters evacuated apartment buildings; initially suspected cyanide gas, but styrene was ultimately detected from nearby CIPP
Somerset, United Kingdom (Wills 2007)	nr	Foul CIPP styrene odor permeated into residence through drain because of nearby installation
Brooklyn, NY (Lysiak 2007)	nr	Foul CIPP styrene odor permeated into buildings through drain because of nearby installations
Ottawa, CN (Bauer & McCartney 2004)	20, 115	Venting determined to be necessary to prevent air backup into nearby residences/ buildings
Alexandria, VA (Gowen 2004)	500	HAZMAT team responded because of styrene vapor backup into nearby buildings; illness symptoms reported
Milwaukee, WI (ATSDR 2004)	0.01 - 0.32	An office building that a large diameter sewer line was located under an old brewery building. All occupant complained about the strong odor. US federal health agency investigated. At least 11 employees were away from their work location for some portion of 17 days.
Toronto, CN (City of Toronto, 2001)	3.2	Eight houses were investigated but only two houses showed styrene due to traps engineered to be dry

In 2001 & 2004, Styrene Testing Results were Reported from Two CIPP Chemical Air Emission Studies

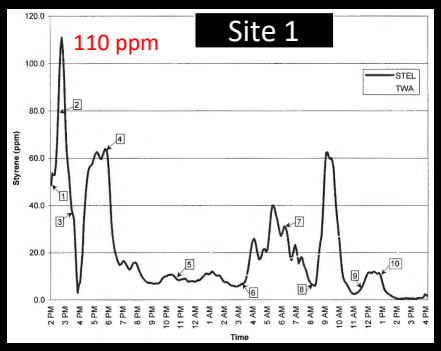
AirZone, Inc. (2001)

A Report on the Monitoring of Styrene in Toronto Homes During the Cured in Place Pipe (CIPP) Process for Sewer Pipe Rehabilitation by Insituform

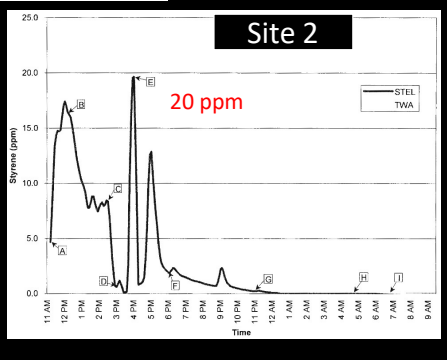
PROJECT NO. 041-6742

3.2 ppm

Prepared for
Toronto Works & Emergency Services
2700 Eglinton Avenue West
Toronto, Ontario
M6M 1V1



Bauer & McCartney. 2004. Proc. No-Dig.



In 2005, ATSDR Found CIPP Styrene and Other VOCs Entered Office Building through the Foundation, Chemicals Lingered for Months

ATSDR. 2005.

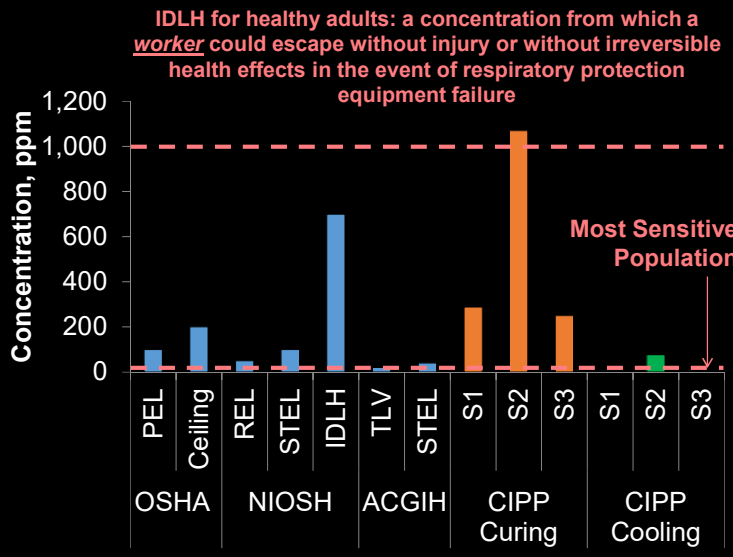
Date	Total VOC, ppm	Styrene, ppm
12/10	Evacuation	Evacuation
12/13	Evacuation	Evacuation
12/13-22	nd – 1.45	Not tested
12/22	nd – 199.0	Not tested
1/12	0.5 – 30.0+	Not tested
1/13	nd – 1.77	nd – 0.30
1/18	nd – 1.60	Not tested
1/21	nd – 0.86	nd – 0.22
2/4	nd – 0.21	nd – 0.15
2/7	nd – 0.57	nd – 0.04
3/28	nd – 0.22	nd – 0.01

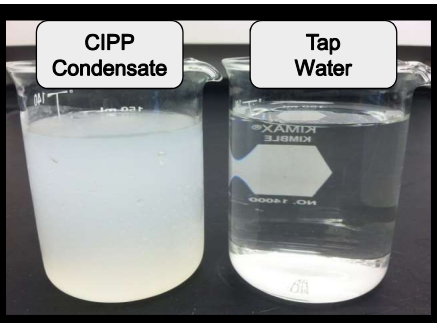
"…past conditions at the site are classified as a public health hazard."

Styrene odor threshold < 0.1 ppm

2015, CIPP Styrene Exited Sewer Manhole and Exceeded the NIOSH IDLH

Adjari (2016)





Tabor et al. 2013. *Environ. Sci. Technol.*

Carcinogens
Styrene
Benzene
Methyl ethyl ketone (MEK)
1,3,5-Trimethylbenzene (TMB)
1,2,4-Trimethylbenzene (TMB)

Endocrine disruptors
Diisooctyl phthalate (DOOP)
Dibutyl phthalate (DBP)
Diethyl phthalate (DEP)

Other chemicals detected, not shown here
Condensate COD 35,000 mg/L; dissolved organisms 24 hr

Prior studies have shown CIPP released more than just styrene into condensate waste/water

2012: Ontario WWTPs impacted by CIPP wastewater
2010: Some New York WWTPs ban CIPP wastewater
2009: Nevada WWTP required GAC treatment of CIPP wastewater to styrene < 2 mg/L before sanitary sewer discharge
2008: Massachusetts WWTP cease-desist order issued to CIPP contractor
2008: California WWTP processes upset by CIPP wastewater
2001: Germany researchers recommended 0.4 mg/L max. styrene sewer discharge limit

We are currently working to investigate CIPP Air and Water Emissions

Emerging Issue #2: Drinking Water Quality Changes Caused by Plastic Water Pipes, Coatings, and Liners

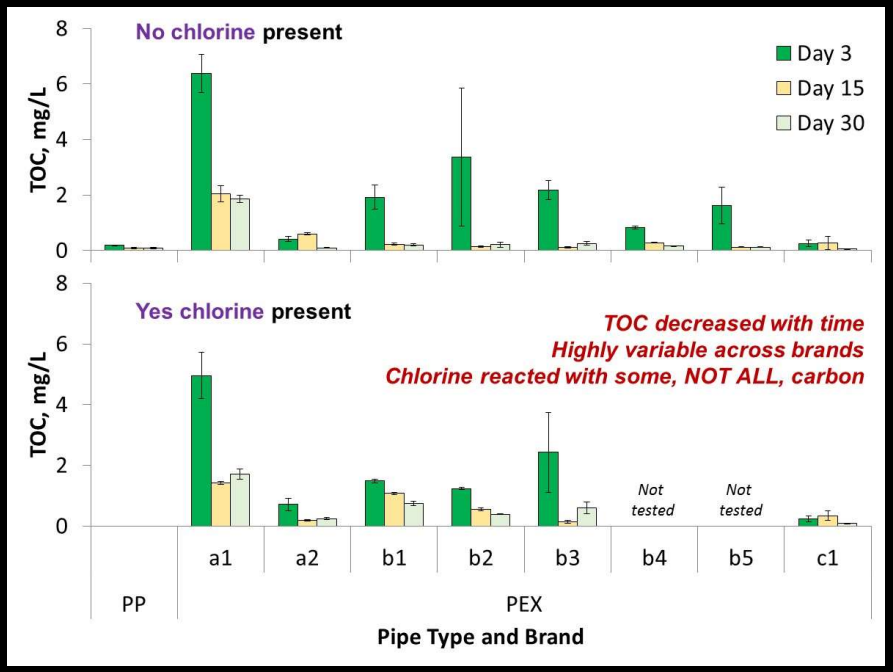
Cold water: HDPE v. PVC

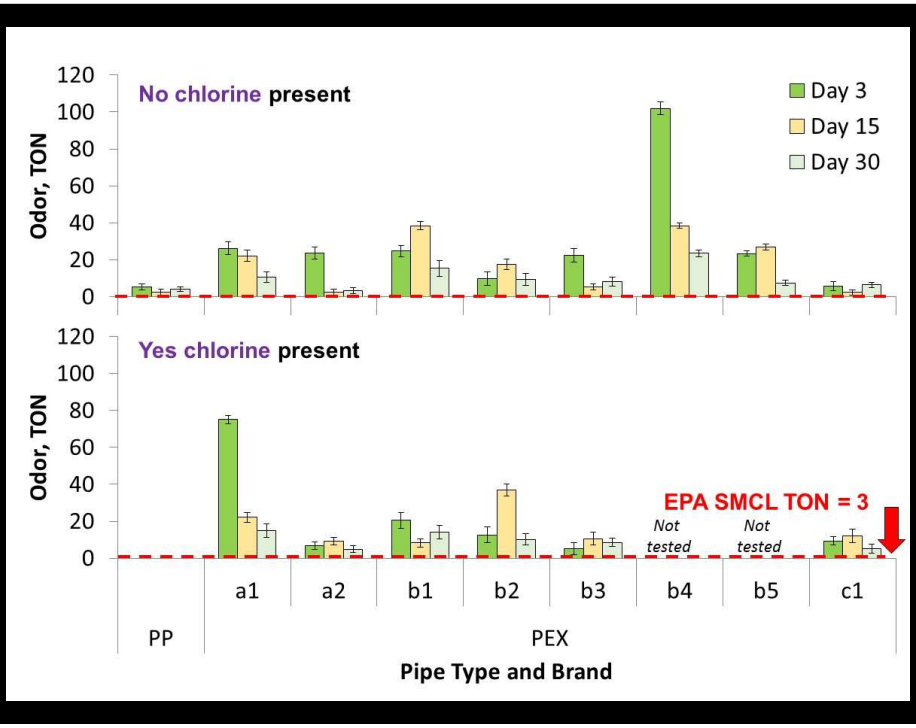
Hot water: PP vs. PEX vs. cPVC

NSFI Standard 61 certification

Water mains *Service lines* *Building plumbing*

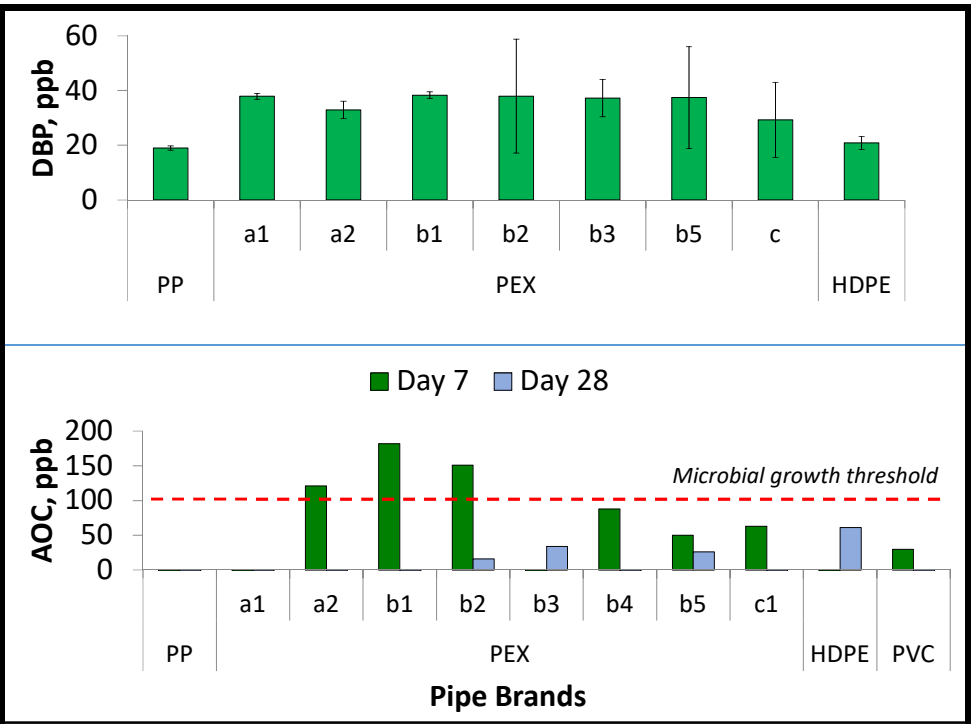
Chemical leaching from new plastic water pipe can be significant





Drinking water odor was highly variable across brands

Chlorine sometimes, not always, affected odor



Plastics can leach chemicals that can be transformed into DBPs

Plastics can leach chemicals that can be used by microorganisms to grow

Significant leaching differences between PEX pipe batches (SINGLE BRAND)

Material Type	Exposure Duration, days	2014, Alabama *[Kelley et al.]*	2015, Indiana *[This study]*
PEX-a	3	6.38 ± 0.69	13.09 ± 7.43
	15	2.04 ± 0.28	3.33 ± 0.11
	30	1.86 ± 0.13	5.07 ± 0.51
PEX-b	3	1.92 ± 0.44	16.66 ± 11.21
	15	0.23 ± 0.04	0.89 ± 0.13
	30	0.21 ± 0.03	1.08 ± 0.21

Other discoveries:

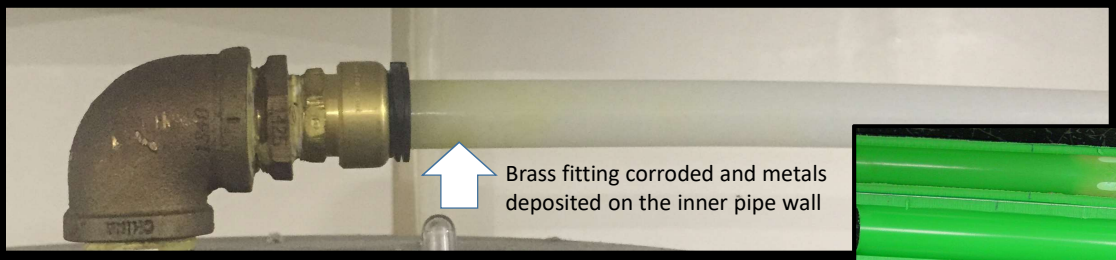
Significant leaching differences down the length of a SINGLE ROLL of PEX

Higher water pH, greater chemical leaching from PEX

The disinfection method you use for new PEX pipe can influence its leaching

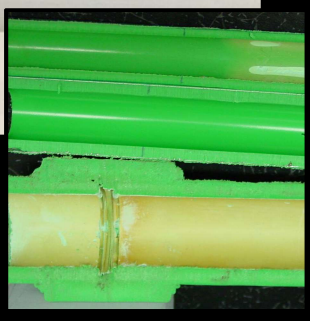
HDPE Pipe (Iron coated)

HDPE Pipe (Manganese coated)

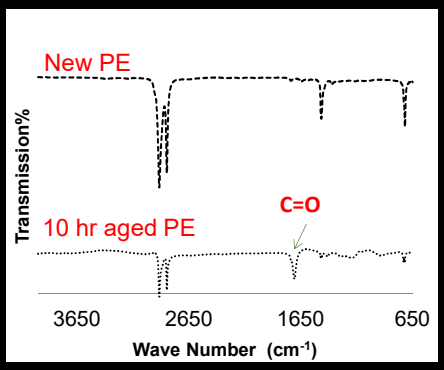


Metals can deposit on plastic pipes

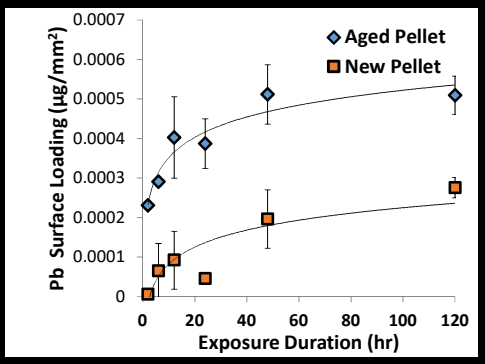
Polypropylene Pipe (Copper coated)



Material Aging Can Cause Plastic to Act as a Better Deposition Site for Heavy Metals



Example: pH 7.8, Pb 300 µg/L; 23 °C



Emerging Issue #3: Safe Cleaning Methods for Removing Inorganics and Organics from Pipe Surfaces

Large-scale, acute contamination

Backflow, acute contamination

Pb/ Cu/ As, chronic contamination

Q: *How long is needed to leach all the sorbed chemicals out?*

Q: *Will water flushing or surfactants remove sorbed chemicals?*

Q: *Will surfactant solutions damage the pipe?*

PURDUE UNIVERSITY

Water Infrastructure and Testing & Evaluation Facility for Renewal (Purdue WATER)

Recreate field conditions, Evaluate system design and contamination scenarios, Explore material-contaminant interactions, Challenge decontamination aide effectiveness

Actions in Progress

Plastic Water Contact Material Specifications

Pipe shall not cause water to exceed 0.5 mg TOC/L after 72 hr stagnation (pH 6 and 9), 23˚C and 0.5 mg/L after 72 hr

Pipe shall not cause water to exceed a TON value of 3 after 72 hr stagnation at 23˚C for pH 6 and 9

Plastics Education & Training

1 & 2 Day workshops

Cured-in-Place-Pipe (CIPP) Specifications

All laterals should be plugged air-tight to not allow chemicals to migrate to buildings

Contractor shall use equipment for removing and capturing chemical emissions into air

Setback distance from all sites where uncured resin or emissions enter air shall be at least 20 ft with proper safety fencing and warning signage

All complaints shall be reported to the utility and documented, NOT the contractor

A qualified 3rd party shall investigate complaints

Contractors shall conduct real-time air monitoring at the (1) upstream manhole, (2) downstream manhole before, during, and after their installation. Any level that exceeds 5 ppm shall be reported immediately to the Utility and to the public.

Any level that exceeds 50 ppm should trigger grab sampling by qualified individuals to characterize chemical emissions

All condensate generated shall be captured and disposed of in accordance with the Clean Water Act and POTWs

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