

# New Research on Plastic Water Pipes: Water Quality and Air Quality Challenges

*Andrew J. Whelton*

November 2, 2016



Webinar: Florida AWWA Section

## Plastics are Being Used for Water Infrastructure

**Pipes:** HDPE, MDPE, PEX, PEX/AL/PEX, PP, PVC, cPVC, FRP, and more...

**Gaskets:** EPDM, SBR, nitrile, and more...

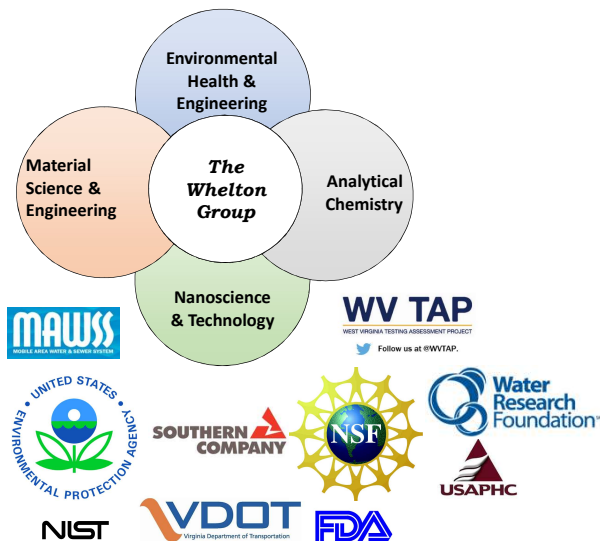
**In-situ:** Cured in place pipe (CIPP), epoxy, polyurethane, polyurea, PU/PEUU blends

**Overwraps:** HDPE, LDPE, PP

**Membranes:** Polyamide (PA), polysulfone (PSF), polycarbonate (PC), polyvinylidene fluoride (PVDF), and more...

**Tanks & chemical barrier:** HDPE, PET, PVC, and more...

## Our Team Operates at the Interface of the Environment-Infrastructure-Public Health



### Education Actions

Fund. Environ. Eng.  
 Polymer in Infrastructure & the Environ.  
 Environ. Eng. Design  
 NESCC and ILSI Expert Panels  
 Plastics training workshops  
 Industrial workshops & conferences

### Research

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

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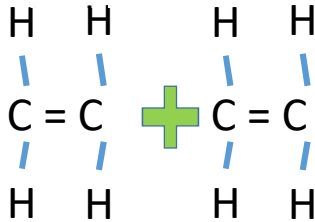
## Our Recent Projects Related to Plastics in Water and Energy Infrastructure

Degradation of HDPE pipes in nuclear and fossil power stations  
 Chemical release from CIPP, polyurethane and polymer enhanced cement mortar coatings  
 Chemical, microbiological, and aesthetic impacts of plastic piping for buried water service and plumbing  
 Contamination and decontamination issues associated with plastic water infrastructure components  
 Degradation and leaching of carbon nanofiber polyester composites  
 And others....

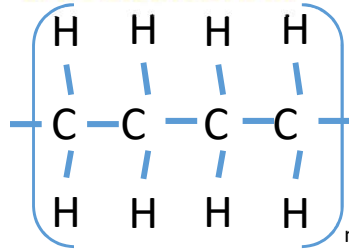
## Plastics are ....Polymers = *Many...Unit...compound*

Long-chain molecules of very high molecular weight ( $n$  = tens of thousands)

### MER UNITS



### POLYMERIZATION



### POLYMER CHAINS ... THINK SPAGHETTI !

#### Linear



#### Branched



#### Place of Manufacture

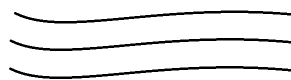
*Before onsite*  
HDPE, PVC, cPVC, PEX, etc.

*Inside the water system*  
Coatings and CIPP liners

## How to Make Plastics (*Think Spaghetti*)



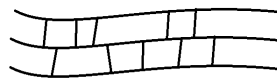
Straighten the spaghetti strands



Not crosslinked

HDPE,  
PVC, etc.

Bond the spaghetti strands



Crosslinked

CIPP,  
gaskets,  
coatings,  
PEX

Flexible: HDPE vs. LDPE (LDPE has more free volume/space between chains)

Flexible: HDPE vs. PEX (HDPE has greater chain mobility)

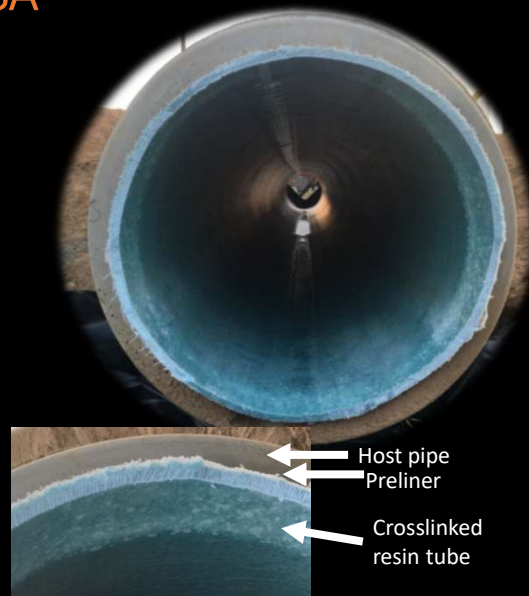
## Today, Cured-in-Place-Pipe (CIPP) is used to repair 50% of all water pipes in the USA

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

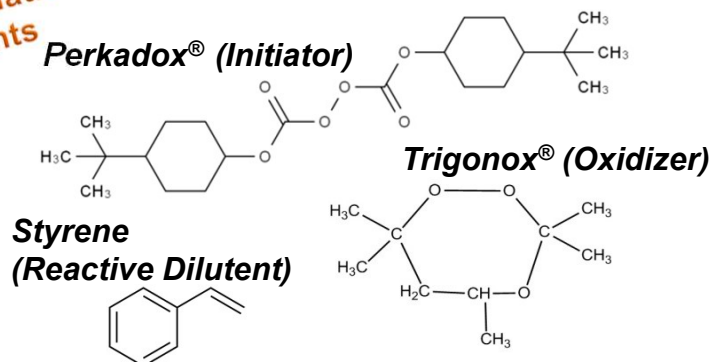


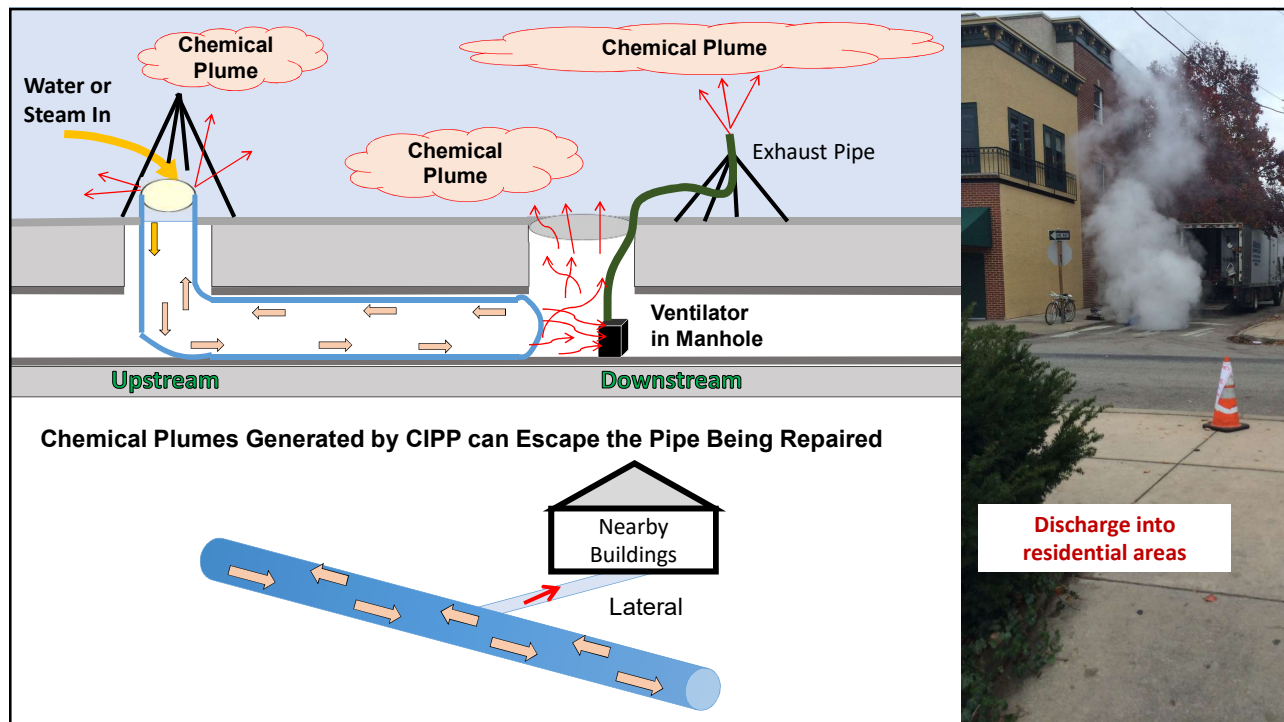
CIPP Is Created In the Field  
Where Chemicals are Mixed and Reacted

**Resin + Hardener + Initiators + Plasticizers**

*Initiation can be hot water, steam, or UV light*

**Some Listed  
CIPP Formulation  
Ingredients**





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	<b>Fumes stayed in building for 1 month. Installers claimed styrene trapped underground</b> and drifted into house. Installers installed blowers. After the 2 <sup>nd</sup> 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. <b>County did not investigate and told resident chemicals were nontoxic.</b>
Baltimore, MD (Ashton 2014)	nr	Resident evacuated house after detecting odor and experiencing chemical exposure symptoms; <b>sought medical attention; Odors got stronger when it rained.</b>
Ottawa, CN (Bauer 2012)	nr	<b>Odors detected kilometers from worksite</b>
Fayetteville, NY (Doran 2012)	nr	Odors permeated into nearby residences; residents complained and <b>evacuated their homes</b>
Brisbane, AUS (Woods 2012)	nr	Odors detected and exposure lasted 5 days in home; <b>Health department investigated and demanded home be decontaminated;</b> 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 <b>daycare center evacuation</b> ; 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; <b>vapors from nearby CIPP operation entered school ventilation system; building evacuated; children transported to hospital for chemical exposure symptoms</b>
Saugus, MA (Tempesta 2011)	nr	<b>Firefighters ordered evacuation of elementary school</b> because of strong odor; dizzy and light-headed symptoms reported
Pittsburgh, PA (Hayes & Biedka 2011)	nr	<b>Elementary and high school students were evacuated</b> for fear of gas leak; odors from nearby CIPP operation were the cause
Birmingham, UK (Pub. Health England 2011)	20 - 200	Odor detected. Residents evacuated at contractors recommendation. <b>Contractor did not disclose styrene present in homes above health limits until days after health agency involved.</b>
Helena, MT (Banks 2010)	nr	<b>Fire department evacuated affected building because of complaints of strong odors, nausea, and headaches</b>
Arlington, VA (ARLnow.com 2010)	nr	Nearby CIPP installation caused odor; <b>fire department responded</b>
Pittsburgh, PA (WPXI-TV 2009)	nr	<b>Firefighters evacuated apartment buildings</b> ; initially suspected cyanide gas, but styrene was ultimately detected from nearby CIPP
Somerset, United Kingdom (Wills 2007)	nr	Foul CIPP styrene odor <b>permeated into residence through drain</b> because of nearby installation
Brooklyn, NY (Lysiak 2007)	nr	Foul CIPP <b>styrene odor permeated into buildings through drain</b> 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	<b>HAZMAT team responded</b> 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. <b>US federal health agency investigated.</b> 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, Styrene was the Only Organic Chemical Detected from the CIPP Effort, Few ppm was the Highest Level

### 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

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

AirZone, Inc. (2001)

Buildings tested 7 (2000), 2 (2001)

Sewer pipe layout unclear

Manholes (Single 2-8 hr samples)

0.16 to 1.5 ppm with preliner

3.2 ppm maximum without preliner

Breathing zone (Single 4-9 hr samples)

0.08 to 0.5 ppm, workers

Indoors (Single ~24 hr samples)

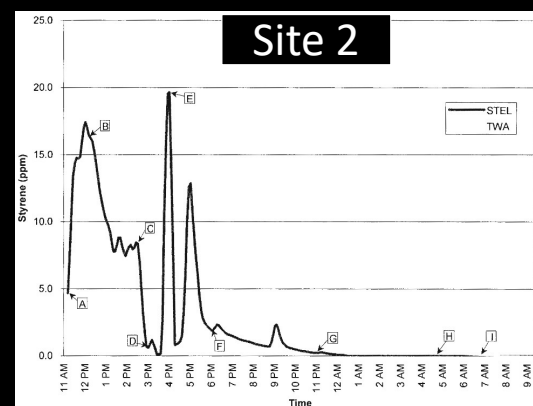
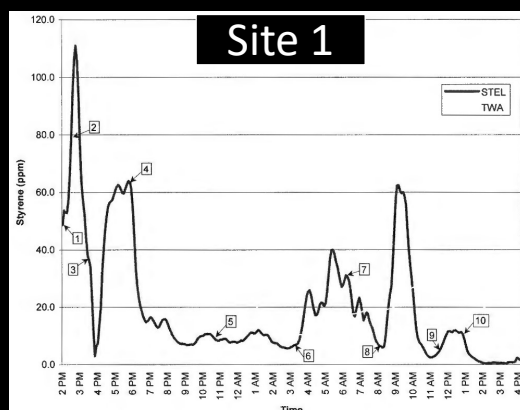
0.1 to 0.2 ppm, worst-case during the CIPP process

Highest concentrations, dry plumbing traps

*"...it does not appear that it is a significant source of any other VOCs...."*

## In 2004, CIPP PID Air Testing Study was conducted in Canada

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



### Observations:

PID set for styrene

One air sample collected every 15 minutes (4/hr)

Did not start monitoring until after CIPP installed



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

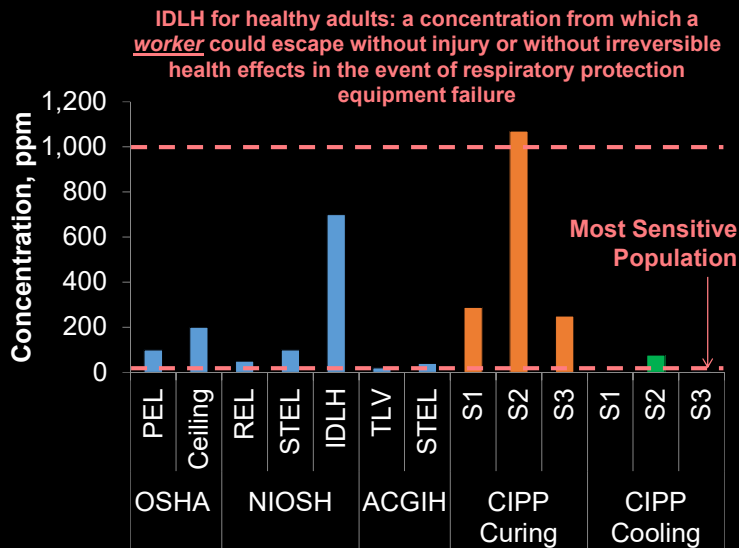
Date	Total VOC, ppm	Styrene, ppm
12/10	Evacuation	Evacuation
12/13	Evacuation	Evacuation
12/13-22	nd – 1.45	Not tested
12/22	nd – 199.0	Not tested
1/12	0.5 – 30.0 <sup>+</sup>	Not tested
1/13	nd – 1.77	nd – 0.30
1/18	nd – 1.60	Not tested
1/21	nd – 0.86	nd – 0.22
2/4	nd – 0.21	nd – 0.15
2/7	nd – 0.57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



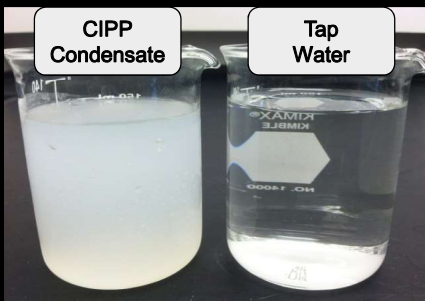
*"...past conditions at the site are classified as a public health hazard."*

Styrene odor threshold < 0.1 ppm

## 2015, Styrene Reported Exiting Sewer Manhole 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*

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

### **CIPP Condensate Waste after Steam Curing**

Property	Typ. Domestic Sewage	CIPP Condensate, 23°C
Water pH	6 to 8	6.2
COD, mg/L	10 to 30	35,666
Styrene, mg/L	< 0.001	> 310
Zinc, mg/L	< 0.20	1.20
Copper, mg/L	< 0.01	0.03
24-hr <i>Daphnid</i> Toxic	Not toxic	<b>Dissolved organisms</b>

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

### **Industry does not seem to understand the Clean Water Act or the toxicity of their generated waste**

Page 11: Recommends "release of process waters to ditches and/or waterways containing water and/or aquatic life ... should not create any environmental harm."  
"... the condensate may be released once it has cooled to near ambient temperature.."

*NASSCO GUIDELINE Report FOR CIPP Installation: 2009, Revised 2011*



## Some of the Environmental Impacts of CIPP Have Been Studied but Much Remains Unknown



## Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities

Matthew L. Tabor,<sup>†</sup> Derrick Newman,<sup>†</sup> and Andrew J. Whelton<sup>\*‡</sup>

<sup>1</sup>Department  
<sup>2</sup>Department  
Support.

## Impact of Infrastructure Coating Materials on Storm-Water Quality: Review and Experimental Study

Andrew J. Whelton, Ph.D., MASCE<sup>1</sup>; Maryam Salehi, Ph.D.<sup>2</sup>; Matthew Tabor, S.MASCE<sup>3</sup>; Bridget Donaldson<sup>4</sup>; and Jesus Estaba<sup>5</sup>

**Abstract:** A 15-day river and 30-day leaching tests were conducted to determine the extent that organic contaminants released from a polyethylene (PE) water pipe into water. Water quality was monitored. Newly installed polyethylene-coated mortar (PECM) and polyurethane (PU) (water-stop pipe coatings) were tested. The water quality was monitored during 10 three-day water immersion periods. For both materials, the greatest water quality changes occurred during the first three days of immersion. The water quality changes were related to the release of organic contaminants from the pipe from 7.1 to 10.3 ILD throughout the entire study. Organic contaminant release [total organic carbon (TOC) and  $\Sigma_{17}$ ] was also present during the first two water contact periods only. A leachability increased from 556 mg kg<sup>-1</sup> d in CaCl<sub>2</sub> to the first peak in PE at 18.50 mg kg<sup>-1</sup> d in CaCl<sub>2</sub> for each immersion period. Leachability from PU increased with water and reduced water leachability 1.0 to 1.5 mg kg<sup>-1</sup> d. The leachability from PU was not related to the water quality changes. The water quality changes were related to the leaching of organic contaminants from the PE water pipe. The organic contaminants were released from PU. A limited quantity of organic contaminants released by PU was biodegradable. Nitrogen compounds were detected only during the first PEU water contact period. DOI: 10.1002/acta.10001

CE Database subject headings: Coating; Leaching; Pipes; Infrastructure; Epoxy; Cement; Polyurethane; Water quality; Stormwater management; Experimentation.

**Author keywords:** Coating; Leaching; Pipe; Culvert; Polyurea; Epoxy; Cement; Polyurethane; CIPP.

## Introduction

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 Presidential Research Assistant, Dept. of Civil Engineering, 1468

Protection Agency (EPA) Office of Research, and Development; Kanchwala 2010; Ozam 2004; Talles et al. 2010]. Coatings are less costly than open-trench asset replacement, but they do not address the root cause of the material deterioration, sometimes provide structural protection, and extend infrastructure service life by 25–75 years (Ellis 2010). Coatings are generally prepared on site by mixing components followed by spray application. Popular coatings include cement mortar (CM), epoxy (EP), polyurethane (PU), (PELU), and PU/PELU blends.

An emerging concern regarding storm-water infrastructure rehabilitation is that some waters generated during and/or after the installation of storm-water infrastructure rehabilitation material installation can pose downstream water quality and toxicity hazards. For example, multiple fish kills, aquatic life inhibition, and air contamination incidents have been documented at several different cured-in-place pipe (CIPP) installations in the United States, Canada, and Europe (Table 1). Cured-in-place pipe is a popular rehabilitation technology that involves the

## Impact of Stormwater Pipe Lining Materials on Water Quality

Bridget M. Donaldson and Andrew J. Whelton

Many stormwater pipes and culverts have reached the end of their service lives, and their repair or replacement is a large maintenance concern. Many commonly used culvert rehabilitation techniques

maintaining their aging culverts, trenchless rehabilitation companies have expanded their focus from drinking water and sewer pipes to include roadway culverts. Unlike with rehabilitation materials used



## Standardized Test Method to Quantify Environmental Impacts of Stormwater Pipe Rehabilitation Materials

<http://www.virginia.gov/VirgOnline/reports/pdf/15-r11.pdf>

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cure rehabilitation techniques for material that cures in the field and is self-curing. In 2008, the Virginia Center for Transportation Research (VCTR), the Virginia Department of Transportation (DOT), and the Federal Highway Administration (FHWA) CIPF rehabilitation released a report that conveyed the rehabilitation techniques and proposed new specifications for the Federal Provision for Pipe Culvert Rehabilitation (FHWA, 2013). This new provision, 2013) and influenced by other state transportation departments in Nevada, and California. No studies were found in the literature that compared any trenchless techniques and conventional CIPF rehabilitation for road culverts, this study compares the techniques to release contaminants during installation.

infrastructure repair more than a multibillion-dollar industry in the most popular rehabilitation pipe industry (5), and it is an intricate culverts maintained by U.S. forces of this paper, three types: (a) conventional CIPP; (b) vinyl (UV) CIPP;

the most popular CIPT technique is to use a liner or sock saturated with a

### ***DOTs Recognized They Needed More Information to Design CIPP Culvert Rehab Construction Specifications to Best Protect the Environment***



## Contaminant Release from Storm Water Culvert Rehabilitation Technologies: Understanding Implications to the Environment and Long-Term Material Integrity

- (1) Survey state DOTs to determine (a) proportion of projects using technologies with polymer components (i.e., CIPP, coatings, liners, polymer-enhanced materials) and (a) document any specifications in place.
- (2) Conduct water quality testing from culvert rehabilitation sites in multiple states to determine implications to the aquatic environment and the effectiveness of any existing specifications.
- (3) Determine the relationship between chemical leaching, liner structural integrity, and longevity through accelerated aging tests and analyses of exhumed materials from the field.
- (4) Provide: (a) report that recommends construction specifications to minimize environmental impacts and maximize performance, and (b) Hands-on training workshop about current and emerging culvert rehabilitation technologies, specification considerations, and factors to consider for environmental and structural performance.

*FHWA Project Underway 2016 at Purdue: Whelton, Howarter, Jafvert, Youngblood, Zvyavkina*

## 2016 NSF RAPID Response Study Underway

*Andrew Whelton, Brandon Boor, Mabi Teimouri, Emily Conkling, Kyungyeon Ra, Nadya Zyaykina, John Howarter*

### Goal

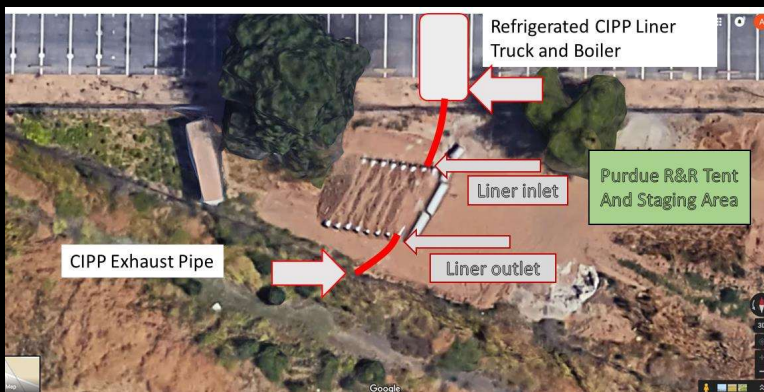
To better understand chemical emission from CIPP installations

### Objectives

- 1) Compare different air sampling strategies
- 2) Evaluate chemical air emissions under different installation conditions
- 3) Identify chemicals emitted and their magnitudes

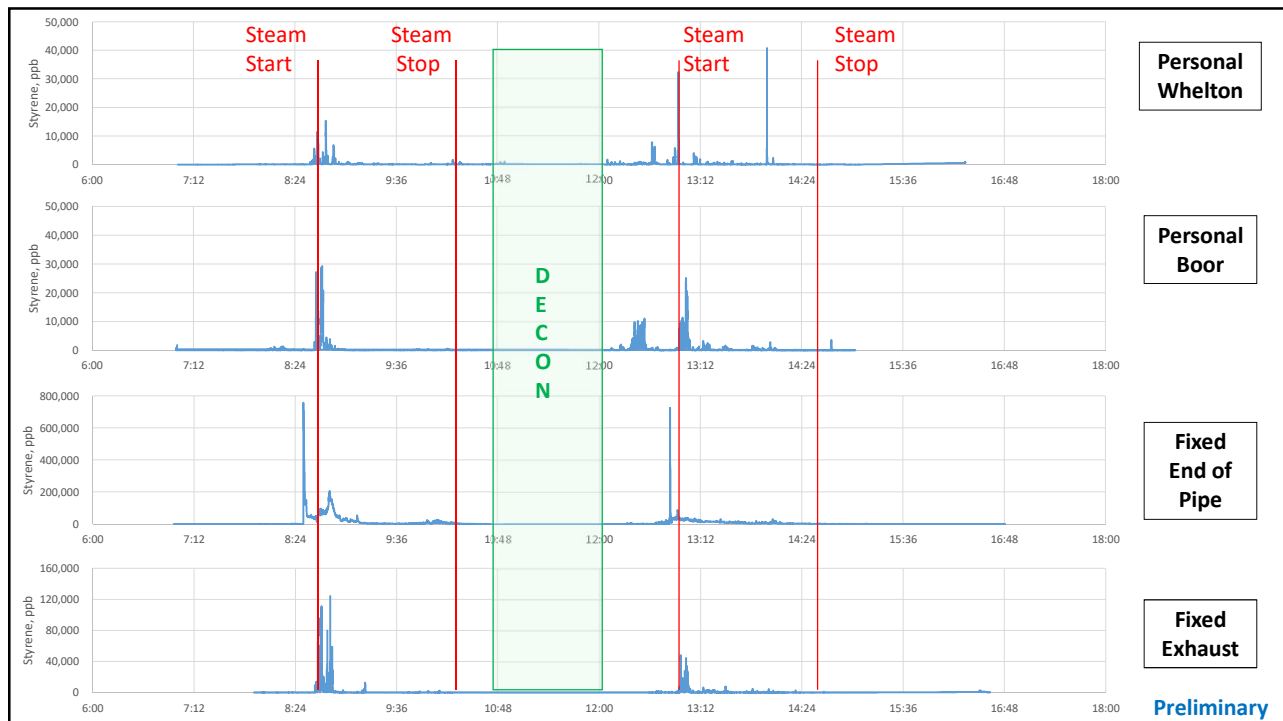
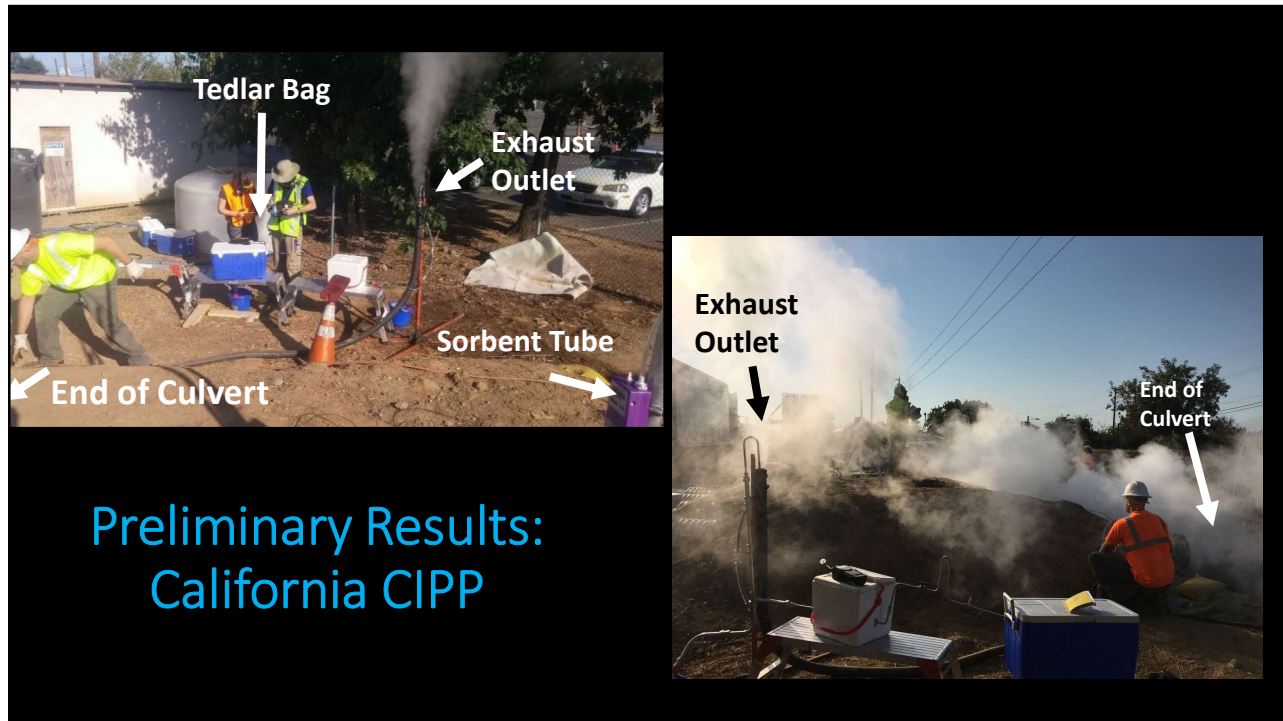


Crowdfunding



### Preliminary Results: California CIPP

Site	Host Pipe	Pulled Separate Preliner	Resin Type	Cooldown Method	Insertion Method
1	CSP	Yes, 1	A	Ambient air	Air inversion
2	CSP	No, 0	B	None	Air inversion
3	CSP	Yes, 2	A	Hot air	Air inversion
4	RCP	Yes, 1	A	None	Air inversion
5	CSP	No	A	None	Pull-in



We are still analyzing  
and interpreting CIPP air study data.

## A Few Preliminary CIPP Air Testing Observations

Independent air testing data is *extremely* limited

Air testing by CIPP contractors and pipe owners not routine

One contractor used wrong device to characterize styrene level in air

One contractor used wrong respirator for worker entry into manhole

Emissions were highly transient, high temperature, high flowrate

Different chemical safety postures applied by CIPP companies

Chemical plume and waste composition poorly understood

Myth: Plumbing traps are the only cause of indoor air contamination by CIPP

How you conduct air testing can strongly influence your results

### Preliminary CIPP Air Project Next Steps

We are looking for additional partners and CIPP sites

We will complete California data analysis and report

Controls and specification upgrades

Education



*Ajardi (2015)*



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[www.WheltonGroup.org](http://www.WheltonGroup.org)  
[@TheWheltonGroup](https://twitter.com/TheWheltonGroup)

CIPP air toxics RAPID response:  
<https://crowdfunding.purdue.edu/project/2768>

