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Note.

- 2002, Two CIPP workers died and five CIPP workers were hospitalized at a worksite in Iowa due to their exposure to “inhalation hazards such as hydrogen sulfide, unknown gases, and an oxygen-deficient atmosphere.” Workers were overcome by the hazardous atmosphere and were asphyxiated (Investigation 115096976). A CIPP company was issued multiple citations and penalties by Iowa OSHA.
- 2005, The ATSDR issued (Agency for Toxic Substances and Disease Registry, 2005) a health consultation report for a CIPP sewer pipe repair caused office building volatile organic compound (VOC) contamination incident in Milwaukee, Wisconsin. The incident caused multiple building evacuations and created a ‘public health hazard’ for the workers over several months after the CIPP project was completed.
- 2006, The Netherlands National Institute for Public Health and the Environment (RIVM, 2006) conducted air testing at a CIPP worksite and reported styrene emission.
- 2013, The Commonwealth Court of Pennsylvania (Commonwealth Court of Pennsylvania, 2018) records show that a CIPP worker lost consciousness inside an uncured resin tube, was exposed to the CIPP resin chemicals, and was pulled from the tube using a rope on his ankles. The claimant sought emergency medical care and worker’s compensation.
- 2013, The Public Health England (Public Health England, 2013) raised chemical hazards and poisons issue for CIPP
- 2014, A Purdue University and University of South Alabama team published (Tabor et al., 2014) a peer-reviewed field study showing that the condensed, concentrated liquid material (condensate) left behind after steam curing of a CIPP contained approximately 15,300 ppm styrene among other VOCs and SVOCs. Aquatic toxicity testing indicated that the liquid, at room temperature, dissolved *Daphnia magna* freshwater organisms in less than 24 hours. Since 2001, the CIPP industry group had recommended contractors dispose of this chemical waste into “streams and ditches”, though that action would seemingly violate the Clean Water Act.
- 2016, A University of New Orleans graduate student hired a commercial laboratory to conduct CIPP worksite air analysis as part of her dissertation research in Los Angeles (Ajdari, 2016). At the time she was also an engineering intern at the Bureau of Engineering, City of Los Angeles and her dissertation work focused on environmental impacts of CIPP technology. She found that during CIPP curing with steam and during the CIPP cool down process with

air, styrene vapor levels ranged from 3.62 to 76.7 ppm and 250 to 1,070 ppm, respectively. Some levels found exceeded the NIOSH immediately dangerous to life and health (IDLH) styrene limit of 700 ppm. Workers were also observed residing inside the exhaust waste chemical plumes without dermal or respiratory protection.

2016, In Kansas, a CIPP worker claimed he was injured during manual labor activities and sought worker's compensation (United States District Court, D. Kansas., 2018).

2017, The California Department of Health issued (California Department of Public Health, 2017) a statewide "Safety Alert" about the CIPP sewer pipe repair practice, identified concerns about chemical waste discharge, and human exposure and health impacts after a building chemical contamination incident. Their document was revised and reissued in 2020 (see below).

2017, A Purdue University team published (Teimouri Sendesi et al., 2017) a peer-reviewed field study showing what CIPP companies called "steam" was not steam, but instead a multi-phase mixture of partially cured resin, particulates, organic vapors, and water vapor. When the whole emission was captured and cooled to room temperature, the phases separated further showing the complexity of what workers were exposed to. This sampling approach was not possible with typical sorbent tubes, canisters, or Tedlar bags commonly used to look for "vapors" only. Also found was that more than styrene vapor was detected in multi-phase mixture to include benzaldehyde, dibutyl phthalate, phenol and other chemicals. Styrene levels ranged from 1,800 to 4,100 ppm in the multi-phase mixture samples. This multi-phase waste prompted death for acutely exposed mouse lung cells. Further, 59 chemical exposure events (Supporting Information file) were found reported for nearby office, restaurant, retail, school, daycare, university, and municipal buildings.

2017, The National Environmental Health Association (NEHA) hosted a webinar with the Purdue University team and NIOSH about CIPP chemical exposure risks and worker safety resources.

2018, The California Department of Public Health (California Department of Public Health, 2018) raised concerns about chemical intrusion into nearby residential buildings and issued issuing "CIPP Safety Alert"

2018, Toxicology researchers in France published (Persoons et al., 2018) a peer-reviewed field study showing that biomonitoring revealed elevated levels of styrene for CIPP workers.

2018, The Purdue University team published (Ra et al., 2018) a peer-reviewed study indicating

2019, The Purdue University team published (Kobos et al., 2019) a peer-reviewed study describing the inhalation toxicity of CIPP waste (captured at field sites) to mouse alveolar epithelial and alveolar macrophage cell lines. When styrene concentration was normalized across all exposures, cytotoxicity differences were observed between worksite samples. Protein changes were also related to pathways involved in cell damage, immune response, and cancer. Results demonstrated that exposure assessment of CIPP worksites should examine multiple chemical components beyond styrene, as many cellular responses were styrene-independent.

2019, The NIOSH published (National Institute for Occupational Safety and Health, 2019) their

in the composites. Further, some of the 19 newly reported chemical exposure events (Supporting Information file) were inside nearby schools affecting teachers, in a cancer care center, and bakery.

2020, A CIPP industry group representing several large CIPP companies and Louisiana Tech University presented (Matthews et al., 2020) results of their field CIPP air testing study. Results showed 10s to 100s of ppm styrene was discharged into air through exhaust pipes at multiple worksites. A styrene level of 1,824 ppm was found exiting the uncured resin tube truck, which is where CIPP workers obtain the uncured resin tube to insert it into the buried pipe.

2020, The California Department of Health revised and reissued (California Department of Public Health, 2018) their statewide “Safety Alert” about the CIPP practice, waste discharge, and human exposure and health concerns.

2020, The Virginia Department of Health reported (Virginia Department of Health, 2020) CIPP installation practice and an interpretation of styrene health risk.

2020, The Florida Department of Health issued (Florida Department of Health, 2020) a statewide factsheet about CIPP for health officials about chemicals emitted, health symptoms, recommended medical support actions.

2021, A \$3 million settlement was reached for a wrongful-death lawsuit brought on behalf of Brett Morrow’s family, the 21-year-old CIPP worker who died on a worksite in Streamwood, Illinois. The parties paying the settlement were Optimum Service Group Inc., Optimum Safety Management (Illinois-based company hired by Benchmark Construction to train its workers on safety procedures), Village of Streamwood [Infrastructure owner], JRG Materials, LLC [CIPP liner manufacturer], HR Green, Inc. [Engineering firm hired by Streamwood to consult on the project], and Benchmark Construction Company [CIPP installer].

2021, The NIOSH published (National Institute for Occupational Safety and Health, 2021) their first evaluation and recommendations about occupational chemical exposures during cured-in-place pipe liner preparation and during pipe repairs using hot water and steam curing practices. Results showed styrene exceeded worker safety thresholds.

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back of sink and toilet water nearby residential buildings. Indoor contamination/decontamination simulation, based on the field measured literatures and incident reports, predicted that indoor air styrene exposure could exceeded public health threshold of 4.9 ppm.

SI-2. Additional supporting results

Proposal, conduct, and oversight of CIPP construction projects

The cured in place-pipe (CIPP) repair projects are contracted out by the infrastructure owner (i.e., municipality) to a CIPP company or subsidiary. City, county, utility, or state Department of Transportation agencies often request companies submit a proposal or bid that meets their requirements (i.e., construction specifications). Within the bid, the contractor often explains their proposed CIPP design, expected material performance, as well as onsite and post-construction actions. The contractor ultimately selected manufactures the new CIPP at a temporary worksite over a period of a few hours to days, depending on CIPP size, methods, and local conditions. The most common pipe diameters are 10.16 to 180 cm.

Common problems for plumbing fixtures

Separate from CIPP, the migration of gases from sewers into homes and other buildings is

screening of readily accessible biological fluids for identification and quantification of exposure and toxicity biomarkers. For instance, these laboratory-based studies could examine specific composite manufacturing practices that modify emissions, as well as biological responses. These biomarkers then could be validated in biological samples from individuals exposed to CIPP emissions. Numerous factors require examination to understand human health impacts of CIPP emission exposures including: 1) worksite factors contributing to variability in exposure concentrations and health responses, 2) identification of susceptible groups (e.g., individuals with respiratory diseases, young children, elderly, individuals with heightened sensitivity to chemicals), 3) evaluation of secondary exposures (i.e., production of ozone), 4) acute vs chronic exposure risks, 5) evaluation of toxicity mechan

Example exposure scenarios that lack quantification evidence include: 1) uncured resin being removed from the delivery truck (National Institute for Occupational Safety and Health, 2021; Teimouri Sendesi et al., 2017); 2) uncured resin tube inserted and positioned inside the damaged pipe (Li et al., 2019); 3) excess resin seeping out of the CIPP into the sewer, does not harden (or cure) during CIPP manufacture and volatilizes into the air after contractors leave the worksite; 4) waste discharged into air and/or directed to an exhaust pipe(s) sometimes placed downstream (Matthews et al., 2020; National Institute for Occupational Safety and Health, 2019; National Institute for Occupational Safety and Health, 2021); 5) contractors cutting newly manufactured plastics (Li et al., 2019; National Institute for Occupational Safety and Health, 2019; National Institute for Occupational Safety and Health, 2021); 6) waste entering nearby buildings, and 7) after the new CIPP is placed into service.

Residential and community risks should be assessed in terms of the likelihood of exposure throughout the lifecycle of the CIPP installation and use. This action will require more data (i.e., breadth of emissions as well as understanding of vapor transport outdoors in sewers and plumbing). A better understanding of occupational risks could help understand public health risks by documenting direct emissions and material and operational conditions that prompt different chemical waste profiles. The same chemical analyses will be needed, but with specific concern of not incurring right-censored issues from the potentially higher concentrations that workers experience. While workers can move away from the waste exposure, publics inside buildings can be exposed when waste exhausts into buildings through drains, windows, doors mimicking confined spaces (i.e., small bathrooms, etc.).

as it occurs, while workers should be adept at preventing emergencies.

Table S2. Chemical compounds found in air during/after CIPP manufacture and their potential health impacts

Purpose	Chemicals involved	Potential health effects
Initiator degradation products	Acetic acid, acetone, acetophenone ^{HAP} , benzene ^{CAR, EDR, HAP} , benzoic acid, 4- <i>tert</i> -butylcyclohexanol; 2-butanone; cumene ^{CAR, HAP} ; 1-tetradecanol	Eyes, skin, nose, throat, mucous irritant; eye and skin burns; headaches; dizziness; nausea; skin sensitization; dental erosion; black skin; hyperkeratosis, conjunctivitis; blurred vision; lacrimation; pharyngeal edema; central nervous system depression; staggered gait; anorexia; lassitude; narcosis and coma; bone marrow and red blood cells decrease; hypnotic or sedative effects; hematological effects; weakened pulse; dermatitis; chronic bronchitis; some potential carcinogens
Monomer oxidation product	Benzaldehyde ^{EDR} ; ethyl benzene ^{EDR, HAP} ; phenylacetaldehyde; toluene ^{EDR, HAP}	Eyes, skin, nose, throat, mucous membrane, and respiratory system irritant; headache; dizziness and lightheadedness; tiredness and drowsiness; reduced alertness; loss of reflexes; slow reaction; difficulty sleeping; dermatitis; narcosis; lack of coordination and vertigo
Resin solvent	Carbon disulfide ^{EDR} ; cyclohexane; dimethyl acetamide ^{CAR*} ; dioxane ^{CAR, HAP} ; ethyl acetate; ethyl alcohol ^{CAR} ; n-hexane ^{EDR, HAP} ; isopentane; methylene chloride ^{CAR, EDR, HAP} ; 1,2,4-trimethylbenzene ^{EDR}	Eyes, skin, throat, nose, respiratory system irritant; cough; dizziness; drowsiness; confusion; headache; loss of muscle coordination; poor sleep; lassitude; anxiety; anorexia; nausea; vomiting; weight loss; anemia; depression; hallucinations; delusions; psychosis; giddiness; fainting; polyneuropathy; reproductive and teratogenic effects; Parkinson-like syndrome; dermatitis; ocular changes; coronary heart disease; gastritis; kidney and liver damage; jaundice; kidney failure; narcosis and coma; eye and skin burns; dermatitis; potential carcinogens
Plasticizers	Dibutyl phthalate ^{EDR, HAP} ; diethyl phthalate ^{EDR} ; isopropenyl benzene; naphthalene ^{CAR, EDR, HAP} ;	Eyes, skin, nose, throat, upper respiratory system, stomach irritant; headache; dizziness; confusion; lightheadedness; breathlessness; nausea; lacrimation; neurological damage; possible polyneuropathy and vestibular dysfunction; hemolytic anemia; liver damage; pain; numbness and lassitude
Unknown	Carbon tetrachloride ^{CAR, EDR, HAP} ; chloroform ^{CAR, EDR, HAP} ; nonanal; Isopropyl alcohol ^{CAR}	Eyes, nose, throat, skin irritant; central nervous system depression; nausea; vomiting; headache; lassitude; anesthesia; liver, kidney injury; enlarged liver; drowsiness; dizziness and dry cracking skin; mental dullness; loss of coordination; anticipated carcinogen
Antioxidant	2,6-Di- <i>tert</i> -butyl- <i>p</i> -cresol ^{EDR}	Eye, skin irritant
Lubricant	Isopropyl palmitate ^{EDR}	Eyes, skin irritant
Additives	1-pentanol; 1,3,5-trimethylbenzene ^{EDR}	Eyes, nose, skin, throat, respiratory system irritant; dizziness; headaches; confusion; lightheadedness; loss of muscle coordination; passing out
Monomers	Phenol ^{EDR, HAP} ; styrene ^{CAR, EDR, HAP} ; tripropylene glycol diacrylate; xylene ^{EDR, HAP}	Eyes, nose, throat, respiratory irritant; dizziness; confusion; skin sensitization; loss of muscle coordination; toxic if inhaled; suspected reproductive toxicity; suspected mutagenicity; damage to organs with prolonged exposure; anticipated carcinogen

Notes: Self-reported health symptoms from CIPP incidents are bolded for the chemicals confirmed present in CIPP air emissions. This health effects listed are from NIOSH (National Institute for Occupational Safety and Health,

2022)and CDC (Centers for Disease Control and Prevention, 2018), New Jersey Department of Health (New Jersey

Table S4. Workgroup feedback and questions were prioritized by public health associations by topic

Issues/ Gaps	Prioritized Questions Based on Public Health Associations Representatives Votes among the Entire Feedback of Participants
<i>Plastic CIPP Manufacture and Wastes</i>	
Curing Technology	<p>Will CIPP use increase with potential upcoming infrastructure spending?</p> <p>Does UV curing generate lower amounts of VOCs than steam/hot water?</p> <p>What is the source for 70% of CIPP installations having defects and how these defects can affect VOC concentrations, amount of uncured resin in the exhaust?</p> <p>Are there nonstyrene based products or alternatives for styrene products?</p>
Generated Wastes	<p>PRIORITY #2: Do employers maintain accurate safety data sheets health departments can refer to? If not, is there a collection of current safety data sheets to review?</p>
Measurement Technology	<p>If the photoionization detector (PID) does not give a good way to measure VOC concentration, then what would be a good way to collect/measure the concentration indoors?</p> <p>Have employers measured airborne contaminants like styrene, methylene chloride?</p>
Mitigation Technology	<p>PRIORITY #1: How can emissions be minimized?</p> <p>Can emissions be captured?</p> <p>If a GAC system is used to mitigate CIPP gas intrusion, how long would that need to be on site for a CIPP procedure?</p>
Utility Practice	<p>PRIORITY #3: What is the distribution of CIPP events across the country?</p> <p>Is there contract wording that utilities could use to minimize these issues?</p> <p>Is there any region where this process is more widely used?</p>
<i>Sewers and Buildings</i>	
Plumbing System	<p>PRIORITY #2: What kind of physical damage of plumbing do CIPP installation cause to?</p> <p>PRIORITY #3: Could the CIPP VOC emissions in urban areas contribute enough to impact the attainment and non-attainment status?</p>
VOC Pathways	<p>PRIORITY #1: How do vapors, including sewer gas and VOCs, move in sewer systems when not under pressure and during the CIPP process?</p> <p>PRIORITY #2: Most of utility pipes are running down the street. How can it happen even though the installation time is short? Is it because of disrupted pipe impact? Or the exhaust fan leads the air flow from a worksite (high concentration) to indoor (low concentration)?</p> <p>Should air districts be involved in CIPP projects?</p>
<i>Chemical Exposure and Health Effects</i>	
Public Exposure	<p>PRIORITY #1: How can estimate the health effect?</p> <p>PRIORITY #1: When CIPP is used to repair drinking water pipes, do chemicals leach out into the drinking water over time?</p> <p>PRIORITY #3: What is its impact on the residential air and the surrounding area?</p> <p>PRIORITY #3: What is the interaction and health impact between indoor air /air toxic and CIPP installation?</p>
Occupational Exposure	<p>PRIORITY #2: What data exist regarding occupational exposure?</p> <p>What are the acute versus chronic exposures?</p>

Toxicity/ Health Effects	<p>PRIORITY #2: What CIPP emission components drive toxicity, beyond styrene? Perhaps simple mixtures of these compounds could be used in toxicological studies.</p> <p>Can urinary styrene metabolites be monitored? Are there any other ways?</p> <p>Do we have a good understanding of the physiological half-life of styrene? And other chemicals?</p> <p>How would animal data vs. human data contribute to modeling?</p>
<i>Chemical Risk Assessment</i>	
Emergency Management	<p>PRIORITY #1: Are municipalities required to notify residents about their intent to use this technology? This could help residents be aware of what they're being exposed to when it happens, and therefore help the health department providing the most relevant and timely information possible. Of the complaints we've received from residents, they typically do not know what CIPP was or was being used.</p> <p>PRIORITY #2: What is the role of local emergency management in response?</p>
Risk Assessment	<p>PRIORITY #1: In one state, they have risk assessors which perform work as a part of the APPLETREE program (related to CERCLA) which falls under the purview of the ATSDR; however, regarding occupational exposures we would refer these exposure instances to NIOSH to perform site investigations and risk assessments.</p> <p>PRIORITY #2: In one state part of APPLETREE, they do risk assessments using ATSDR screening guidance and dose estimation. They do so for water and soil via drinking, showering, dermal contact for residents, leisure people, and workers. The model used is lacking air, but the state received guidance from ATSDR on how to evaluate air exposure. The state usually gets a request by any agency or county health department to do an assessment and needs to have environmental data provided to them.</p> <p>At one state's local level, they do not do risk assessments with private entities. They would direct the company to work with a consultant. The agency may help other local entities help implement suggestions/findings.</p>
<i>Risk Communication</i>	
Health Equity	<p>PRIORITY #3: Are there other health equity concerns?</p> <p>Can there be a checklist to ensure public safety?</p> <p>Is this practice used more frequently in certain socioeconomic level neighborhoods?</p> <p>Do more affluent/privileged communities voice concern and receive more costly repairs to prevent exposure?</p>
Incident Response	

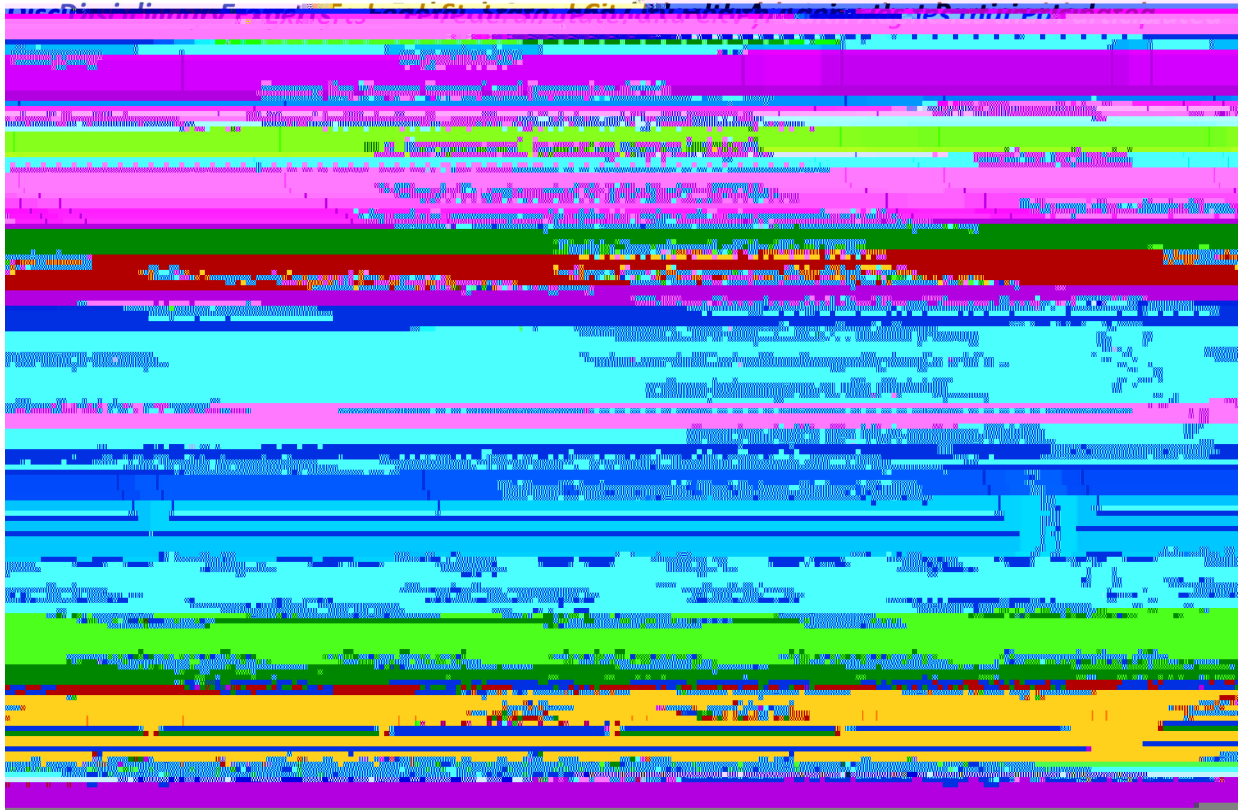


Figure S1. Diagram of workgroup formation and virtual activity organization



Figure S2. Risk communication frameworks can help diagnose communicative challenges, identify critical information needs, develop audience targeting strategies, and identify appropriate communication channels.

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