# Renewal Engineering Technologies for Drinking Water and Wastewater Pipeline Systems – A State of the Art Literature and Practice Review

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## ABSTRACT

Over the last few years, several advancements have been made in water and wastewater pipe renewal technologies that have allowed utilities to utilize innovative renewal techniques that decrease project costs, the impact of the project on the surrounding citizens and environment, and allow for expedited pipeline renewals compared to traditional open trench methods. The challenge now is in getting utilities to implement new innovative technologies within their system. This thesis provides background information on a number of the technologies available for the renewal of water and wastewater system pipelines. It then provides State of the Art Literature and State of the Art Practice Reviews based on technology use trends in literature and technology use trends in utility practice. The information from both reviews is then synthesized to provide a clear view of the state of the water and wastewater pipeline renewal technology industry, including the trends by pipe material, drivers for renewal, and technology type.

## Acknowledgements

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To my family, I do not even know where to begin. Their love and support means more than the world to me, and I can never thank them enough for putting up with me over the last 2 years in my volatile shifts between feeling caught up and stressing out over due dates that suddenly came out of nowhere. I always knew no matter where I was or what I had gotten myself into, my family would be there in a heartbeat to help however they could. My mom, dad, grandmother, granny, grandpa, and sister have all shaped the person that I am and will always remain the most important people in my life. I love them with my whole heart, and I am so proud to be part of such an amazing, loving, and supportive family. From the time I was born, my family has given me everything they possibly could to help me succeed, always sacrificing their own wants and needs to provide for me. I only hope to be half the parent, grandparent, and sister that mine were to me for the last 25 years.

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# CHAPTER 1. INTRODUCTION

## 1. Current State of Water and Wastewater Infrastructure in America

Over the last few years, the crumbling of American infrastructure has transitioned from a subject "out of sight and out of mind" to a subject receiving national attention, though the general public attitude toward underground systems has not changed. Water and wastewater utilities continue to struggle with the increasing needs of their infrastructure and the lack of citizen support for the tax or rate increases that would help meet infrastructure needs. The 2009 ASCE Infrastructure Report Card assigned a grade of D- to both water and wastewater infrastructure, meaning that both types of infrastructure systems are in poor, almost failing, conditions. (ASCE, 2009)

While the problem is well defined, the question of how to most appropriately address the dire situation is a subject of heavy debate. A large majority of water and wastewater pipelines were built within the same time period, well over 50 years ago, and thus, a large proportion of infrastructure is reaching or surpassing its useful life within a short period of time. The problem is exacerbated by the current economic situation since not only must utilities face the insurmountable challenges in identifying the most deficient pipelines, prioritizing renewal projects, and choosing the most appropriate renewal solution, the utilities must also be able to accomplish set goals with a limited budget that diminishes each fiscal year.

### 1.1. Need for New Pipeline Renewal Engineering Solutions

The infrastructure problem cannot be solved with a blanket solution in part because of the immense number of drinking water and wastewater utilities. There are over 156,000 drinking water utilities alone (EPA, 2008) in the United States, each with needs that are unique to their size, geographic location, and system characteristics. Larger utilities have more infrastructure to operate and maintain, but smaller utilities, especially those in remote locations, have much tighter budgets and generally have more limited access to advanced technologies. Small utilities are also less likely to have developed asset management plans, making it more difficult to determine the 'best' solutions to their infrastructure problems; detailed records of their infrastructure have not been created, and the specific problems are not well defined.

Another part of the problem lies in the tendencies utilities have developed to stick to what they know. Technologies are much slower to advance because infrastructure owners tend to turn to a "go-to" technology or product rather than opening the door to more innovative solutions. New technologies or products are not guaranteed to work, and therefore represent too large a risk for the utility to take. If a technology fails to work as planned, all of the time, investment, and effort that went into the initial installation would be for nothing, and the project would need to proceed with a different solution. Influxes in system demands and decreases in budget make efficient use of the allocated budget essential, and spending more (on open cut methods for example) on a project to use a well-developed technology and eliminate the risks associated with new technologies is often acceptable.

Utilities also tend to treat projects as if they were on a long checklist. Infrastructure projects cannot be completed as fast as more renewal needs are identified, and as a result, projects are simply checked off the "to-do" list at the time of completion. Experiences with more innovative technologies are not often shared unless the technology provider takes the time to publish a case study. Utilities do not have incentives as academics do to publish their experiences with the benefits, limitations, and costs of a technology, though sharing experiences among utilities would help ease the transition of promising technologies into the industry. Successful implementation of a technology makes it less risky for use by another utility, especially if circumstances are similar. Without an efficient means by which to share experiences and knowledge regarding renewal technologies and practices, the same mistakes are repeated by multiple utilities across the nation.

## 1.2. Thesis Purpose

The purpose of this research was to provide a State of the Art Literature Review and a State of the Art Practice Review for water and wastewater pipeline renewal engineering technologies, with the ultimate goal to compare the technologies commonly used according to literature with those commonly used in practice. The comparison between literature and practice will then be synthesized to provide a clear picture of the State of the Industry for water and wastewater pipeline renewal technology use. This synthesis will include observations regarding the trends in the industry related to pipe material, technology types, and drivers for technology use.

## 1.3. Approach

The very first step was a literature review which is captured in the "Water and Wastewater Technology Descriptions" as well as in the State of the Art Practice Reviews for water and wastewater system pipeline technology use included in each of the two manuscripts. The manuscript format was utilized for this thesis and includes two separate manuscripts to be submitted to journals for publication. Other papers on the research have already been written and accepted or already presented at conferences. These publications are shown in Table 1 below. Each publication built on the previous paper, leading up to the development of this thesis report and the two final journal paper submissions.

**Table 1. Publications**

| | Publication | Type | Status |
|---|---|---|---|
| 1 | K. Steiner, S. Sinha, G. Whittle, W. Graf (2011) *"Development of a National Web-Based Interactive Database of Renewal Technologies for Water and Wastewater Pipelines" Raleigh, NC. WEF Collections.* | Conference Paper (Full Review) | Alternate |
| 2 | K. Steiner, S. Sinha, J. Jung, G. Whittle, W. Graf (2011) *"Development of a Web-Based Interactive Database for Water and Wastewater Pipeline Renewal Engineering Technologies and Management Practices" Los Angeles, CA. WEFTEC.* | Conference Paper (Full Review) | Presented |
| 3 | K. Steiner, S. Sinha, J. Jung, W. Graf (2012) *"Proposed Guidance for Implementation of Renewal Engineering Technologies and Incorporation of Best Appropriate Management Practices for Water and Wastewater Pipelines" New Orleans, LA. WEFTEC.* | Conference Paper (Full Review) | Accepted |
| 4 | Steiner, K. and Sinha, S. (N/A) *"A State of the Art Literature and Practice Review for Wastewater System Pipeline Renewal Technologies"* ASCE Jounral of Infrastructure Systems (upcoming) | Journal Paper | Future Submittal |
| 5 | Steiner, K. and Sinha, S. (N/A) *"A State of the Art Literature and Practice Review for Wastewater System Pipeline Renewal Technologies"* Urban Water Journal (upcoming) | Journal Paper | Future Submittal |

The literature review identified both popular and innovative technologies available for pipeline renewal using major research reports, journal papers, and conference proceedings. To complete the state-of-the-art practice review, individual utilities were contacted, and after agreeing to supply data, they were sent the Guiding Questions document. The guiding questions were developed to help utilities understand the type and depth of information that their data would be mined for.

The overall approach for capturing utility technology usage began with the development of a set of "Guiding Questions" which were discussed with utilities in the initial interest meeting and used to help them understand the types of data and project documents that were most helpful for them to share. The Guiding Questions document was set up like a questionnaire, but utilities were instructed not to answer the questions directly. Instead they were asked to upload any available information or data in which the answers could be found and that they were willing to make available for use in case study development. The Guiding Questions are attached in Appendix B. Utilities uploaded raw data, technology information, and project documents to a secured FTP in bulk, and everything provided was "mined" for the essential information required for the development of a technology case study.

There were several reasons for this specific approach in utility contact and data mining. First, it was important for utilities to understand that their time was valued, and allowing them to upload any easily accessible data in raw form saved them the time of reading through old reports/project files to track down specific answers. Second, this approach provided insight into the types of technologies and practices used within the utility, even if there was not enough information from which to make a complete case study. When documents of too little information were received that were of particular interest, follow-up interviews were used to see if more information on that specific technology use could be shared. Follow-up interviews or emails were also used once all provided data had been mined so that additional questions could be answered or additional document requests made. The quality of information provided by each utility ranged significantly, and the information provided was supplemented with reviews of existing case studies completed by the utility and/or with technology provider information.

Development of comprehensive technology use case studies was the key step in creating the State of the Art Practice reviews found in each of the manuscripts. The goal was to capture as even a distribution as possible of utility experience by geographic location using EPA Regions. A second goal was to capture a representation of all technologies available for water and wastewater pipeline renewal. The difficulty in this was apparent almost immediately as the sheer number of technologies available to the industry were revealed, as well as the number of technology combinations and products available. To solve this, each type of renewal (repair, rehabilitation, and replacement) was broken down into broad technology categories that could represent the more specific technologies available. These broad technology categories are described below in the "Water and Wastewater Pipeline Renewal Engineering Technology Definitions" section of this report.

## 2. Renewal Engineering Technologies in WATER*i*D

Simultaneously with the research performed for this thesis, the living knowledge base, WATER*i*D, was being created. Much of the work for this thesis was used to populate WATER*i*D with renewal engineering technology information. Several informational technology profiles were written that provide readers with (1) general technology information, (2) technology cost considerations, (3) a summary of technology applicability, (3) commercial contacts and availability, (4) host pipe requirements, (5) site condition considerations, and (5) application considerations for phases of installation such as design, manufacturing, construction, QA/QC, and O&M. These profiles also contain technology datasheets, when available, that summarize the basic information for the technology in tabular form as well as case studies, where available, that document specific technology applications in utilities across North America.

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# CHAPTER 2.
## RENEWAL ENGINEERING BACKGROUND INFORMATION

### 2.1. Pipeline Renewal Engineering Defined

The United States Environmental Protection Agency (EPA) defines Pipeline Renewal to be "the application of infrastructure repair, rehabilitation, and replacement technologies to return functionality to a drinking-water distribution system or wastewater collection system." (EPA, 2010) The line between whether to repair, rehabilitate, or replace a pipeline is often a fine one, and each utility currently has its own protocol for making this decision. The EPA provides a few generalized guidelines and host pipe requirements that describe appropriate situations for application of each type of pipeline renewal as summarized in Table 2-1 below.

**Table 2-1. Renewal Engineering Components and Descriptions of Use (EPA, 2010)**

| Pipeline Renewal Component | Description of Applicable Uses |
|---|---|
| Repair | 1. Host pipe is structurally sound<br>2. Existing pipeline provides acceptable flow capacity<br>3. Host pipe can serve as support structure for applied technology |
| Rehabilitation | 1. Extends operational life of the pipeline, generally by at least 50 years<br>2. Completely or almost completely restores hydraulic and structural functionality of host pipe |
| Replacement | 1. Host pipe is severely deteriorated or collapsed and unable to provide the level of service in its current condition<br>2. Host pipe cannot support installation of repair or rehabilitation systems<br>3. Existing pipeline requires additional flow capacity |

To further complicate the decision to renew a pipeline, there are a number of different technologies available to complete each component of pipeline renewal and several products available to represent each technology. It is helpful to have each repair, rehabilitation, and replacement technologies classified into broader technology categories as was previously mentioned. These technology categories are defined in later sections of this report.

### 2.2. Water and Wastewater Pipeline Renewal Engineering Technology Definitions

The available technologies and products vary by system type (water versus wastewater) as reflected in minor differences in lower level technology types shown in the Figures below that outline the technology categories and types. The broad technology categories are described below, with further explanations and applications for use detailed in each of the State of the Art Literature and Practice Reviews for water and wastewater pipeline systems in the separate manuscripts.

The technology descriptions below are meant to provide general background information based on literature and thus address water and wastewater pipeline renewal technologies together, noting any important differences between technologies available for each system type. The technology types for water and wastewater systems share many of the same characteristics, making it redundant to address each system separately. If not specifically noted, the general technology is available for use in both water and wastewater systems.

### 2.3. Water and Wastewater Pipeline Repair Technologies

Water and wastewater pipeline repair technologies are used to restore normal pipeline operating conditions or repair small, localized leaks along the pipeline. The technologies are typically used where the defect is not severe enough to require renewal of the entire pipe segment or where deterioration is contained to a small area. Repair technologies can be used to enhance structural stability of the host pipe, but the repair mechanism still relies on the host pipe for structural soundness (EPA, 2010). As shown in Figures 2-1 and 2-2 below for water and wastewater systems respectively, pipe repair technologies have been broken into three major technology classes: (1) pipe joint and leak seals, (2) pipe point repairs, and (3) pipe coatings.

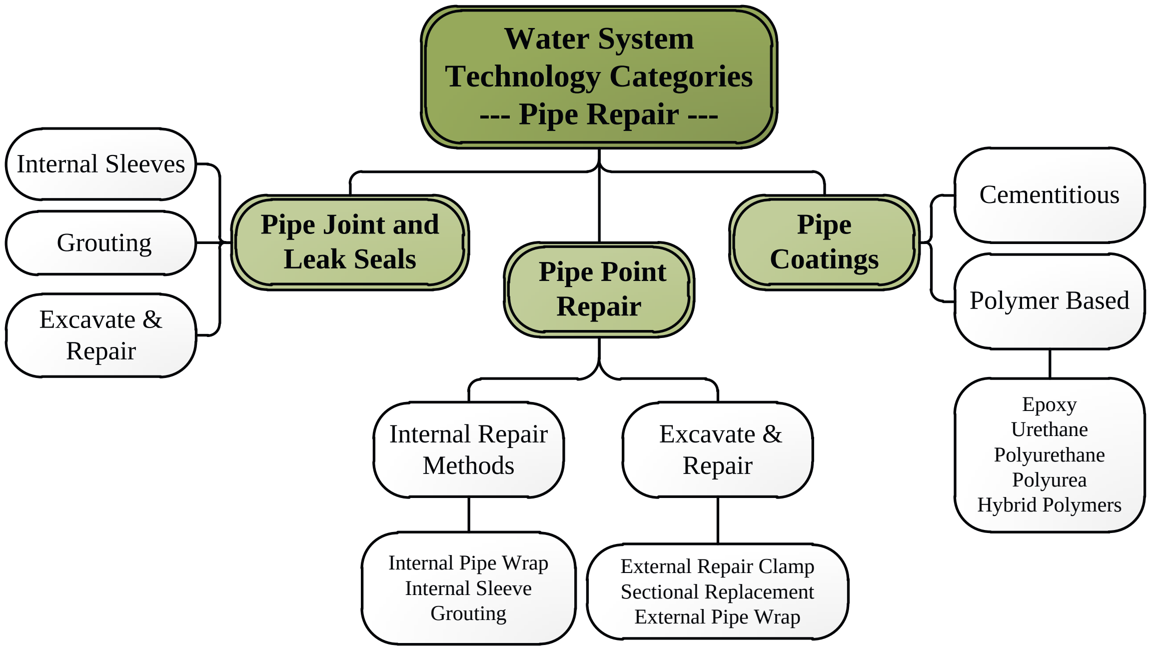


**Figure 2-1. Water Pipe Repair Technology Categories**

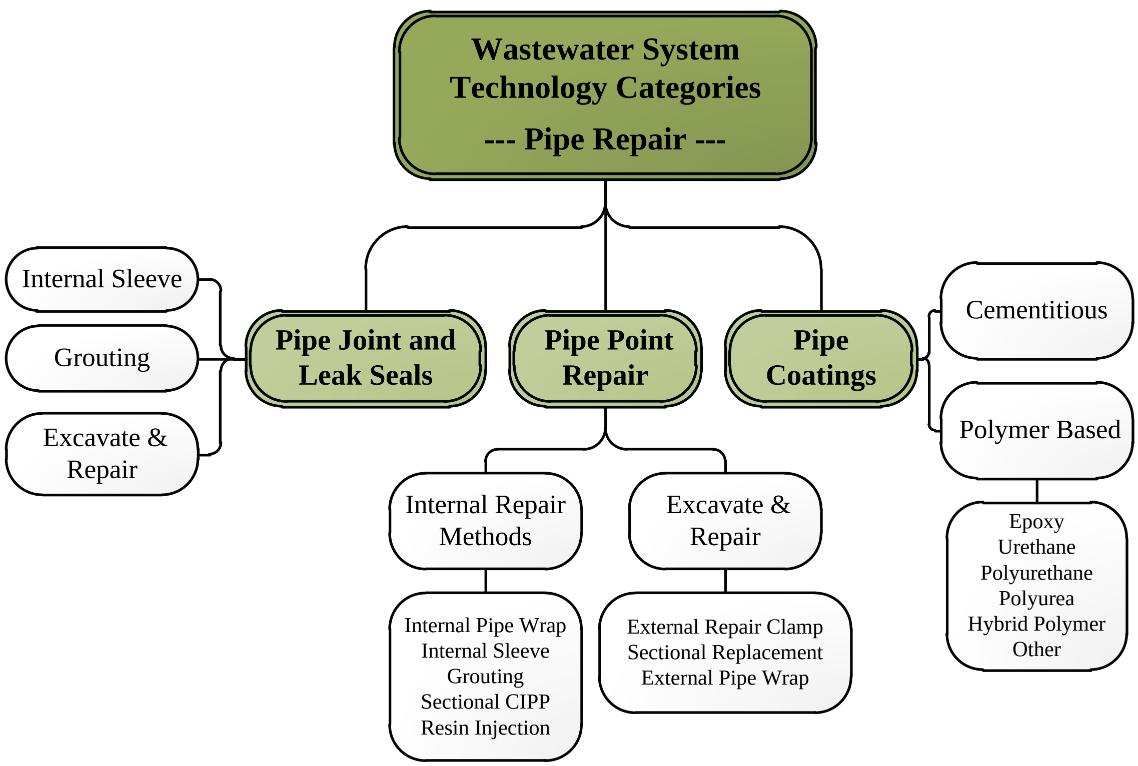


**Figure 2-2. Wastewater Pipe Repair Technology Categories**

### 2.3.1. Pipe Joint and Leak Seal Technologies

Pipe joint and leak seal technologies are typically installed by in-house operation and maintenance crews. These technologies are designed to repair leaking, cracked, or defective joints and require only localized excavations, if excavation is required at all. As shown in Figures 1 and 2, three primary pipe joint and leak seal methods have been identified, including (1) internal sleeves, (2) grouting, and (3) excavated repairs.

**Internal Sleeves**

Internal mechanical sleeves are typically made of an ethylene propylene diene M-class (EPDM) rubber with two stainless steel compression rings, one on each edge of the rubber seal (Robert Morrison, March 2010). The rubber seal is placed over the leaking joint or at the transition point between two different pipe materials, and the steel retaining bands are expanded to fit tightly against the pipe wall, sealing off the leaking joint. Before applying the internal sleeve it is important to make sure the surface of the pipeline has been adequately cleaned to ensure that a proper seal can be established between the rubber seal and the host pipe. Dirt and other debris can prevent a tight leak seal from being established and prevent the repair technology from adequately sealing the joint or cause failure. Examples of typical internal joint sleeves are shown below in Figure 2-3.

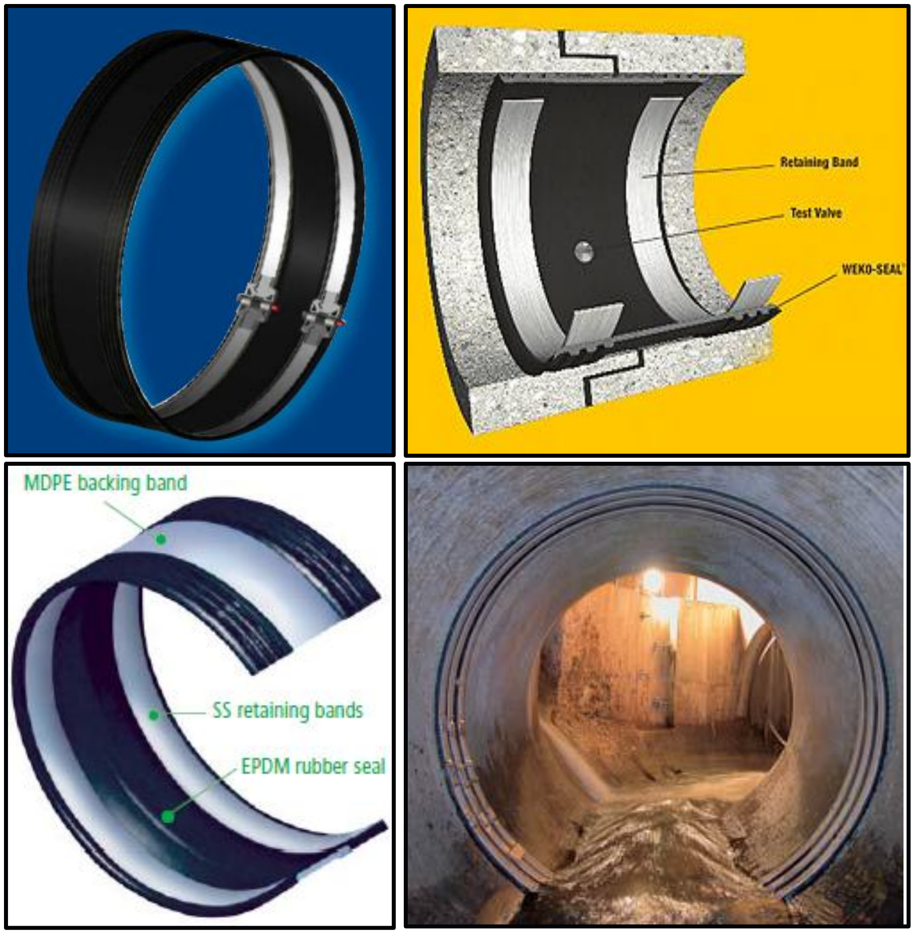


**Figure 2-3. Internal Joint Seals: NPC Internal Joint Seal (top left) (Trelleborg, 2009), Weko Seal (top right) (Sancon Engineering, Inc., 2008), AMEX-10 Seal (bottom left) and AMEX-10 Installed in Potable Water Pipe (bottom right) (AMEX GmbH, 2006)**

A second type of internal joint and leak sealing sleeve uses a resin saturated felt liner wrapped around a polyethylene foam layer and stainless steel core. Adequate cleaning is also an essential part of successful installation for this type of internal joint seal. The assembled components are carried into position within the pipeline on an inflatable rubber plug, and a CCTV camera is used to help the installer adjust the position of the repair sleeve within the pipeline. Once in position, the plug is pressurized, causing the sleeve to expand and lock into place when the full installation pressure is reached. The resin begins curing when the sleeve locks at which point air pressure can be released and the equipment removed. There is no need to maintain pressure on the sleeve as it cures, as the mechanical lock in the steel sleeve keeps the resin in place as it cures (Link-Pipe, 2010). Figure 2-4 below shows examples of this type of internal sleeve for both water and wastewater applications.

**Figure 2-4. Mechanical Sleeve (left), Cured in Place Internal Sleeve (center), and Installed Sleeve (right) (Link-Pipe, 2010)**

### Grouting

Joint grouting involves the application of grout material, typically mortar or polymer based, to seal leaking joints or repair cracked joints. There are different methods for grouting based on the severity of the leak or crack. For leaking joints, chemical grout can be applied via grout packing systems, while more severely cracked joints may require methods that essentially re-gasket the joint. All joints need to be properly prepared before repair, including removing any old joint sealing materials and debris that have collected over time.

For non-potable applications, grout packers, as shown in Figure 5 below, are often used to seal leaking joints. Packer systems work by isolating the joint from the rest of the pipeline and injecting a liquid resin and activator simultaneously into the defects. This technology essentially creates a waterproofing grout-collar external to the sewerline that seals the defect and all surrounding soil voids (Robert S. Amick, 2000). A CCTV camera is attached to the front of the inflatable packer to help the installer guide the packer into position centered over the leaking joint. The packer is then inflated to isolate the leaking joint from the rest of the sewerline, and the two grout components are pumped through the joint connection to form a rapid setting, hard gel and sand mass around the outside of the pipe joint. The resin and activator are pumped into the packer through separate tubes so that mixing occurs just before injection, preventing the grout from curing before it is allowed to infiltrate all the external voids. The grout packer is then deflated and pulled from the pipeline, and any excess grout is scraped off of the interior pipe wall to leave a smooth finish.

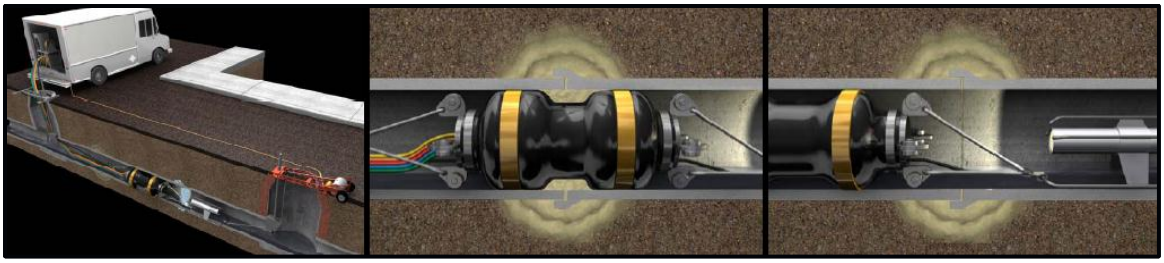

**Figure 2-5. Joint Sealing with Grout Packer (C. Vipulanandan, October 2004)**

Where the joints are cracked or opened in excess of 1-inch, repairs can be made through re-gasketing of the joint. One method makes use of special packing fibers that are saturated with a water-activated resin which are activated in a water bath packed into the joint cracks. The joints must be sprayed with water in preparation for packing so as to further activate the resin-saturated fibers once they are in place. With the new gasket in place, the top 1-inch of the crack is patched with rapid setting grout and smoothed to match the existing surface. As an alternate method, a rapid setting grout material can be applied and injection tubes encapsulated in the grout around the circumference of the joint. An elastomeric, water-activated resin is then injected into the tubes until the entirety of the open joint is filled. The rapid setting grout material originally applied acts to keep the injected resin within the bounds of the open joint until it is completely filled, at which point resin will begin seeping out of the top-most injection tubes. Figure 2-6 provides a snapshot of this grouting method. The two methods described above can be used in potable water applications, provided the materials are NSF 61 approved for such use.

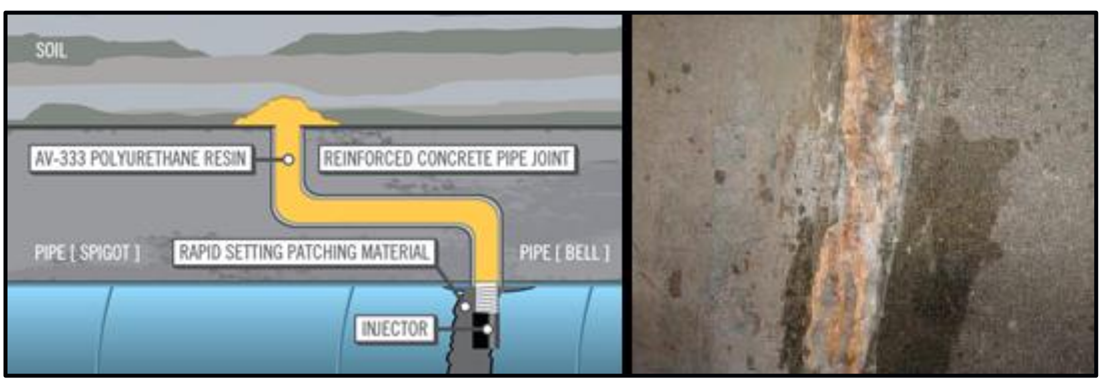


**Figure 2-6. Pipe Joint Crack Repair Diagrams (left) (Avanti International, 2009) and Post-Joint Repair (right) (Prime Practices, 2010)**

## Excavated Repairs

The most traditional form of pipeline joint and leak repair excavation of the defective joint. One of the most common excavate and repair methods is to install an external repair clamp. The clamps are specifically designed for different pipe materials, joint types, and pressure ratings. Many of the available repair clamps made specifically for joints are specified for bell joints and can be used on ductile iron, cast iron, certain types of PVC, and rubber ring and caulk joints. The working pressure allowance is dependent on the diameter of the pipeline and decreases as pipe diameter increases. Most of the external joint seals available are geared toward the repair of gravity pipe joints, but bell joint repair clamps are available for working pressures of up to around 150 – 200 psi Clamps are also available for leaking joints at junctions and service connections. The use of pipe joint repair clamps is limited in pressure system applications to pipelines with diameters less than 15-inches. An example of a bell joint and junction repair clamp is shown in Figure 2-7 below.

**Figure 2-7. Bell-Joint Leak Clamp for up to 150 psi (left) (Smith-Blair, 2011) and for Joints at Pipe Junctions (right) (Tyco Water, 2011)**

### 2.3.2. Pipe Point Repair Technologies

Pipe point repairs are designed to provide semi- or fully- structural repair solutions for short segments of the pipeline. Each technology differs in materials used and applicability and the technology provider should be consulted for questions regarding the capabilities of any specific technology or product. Point repair technologies can be divided into two primary categories: (1) Internal Point Repair Technologies and (2) Excavate and Repair Technologies. There are a number of more specific technologies that fall into each of these categories which are described below.

#### Internal Point Repair Methods

There are a number of alternatives for internal water and wastewater pipeline point repair technologies including: (1) Internal Pipe Wraps, (2) Internal Pipe Sleeves, (3) Sectional CIPP, (4) Resin Injection, (5) Welded Strips/Straps, (6) Patch Repairs, and (7) Grouting.

Only internal pipe wraps, internal pipe sleeves, and grouting are used for waterline repair; the other methods are only applicable to wastewater systems.

**<u>Internal Pipe Wraps</u>**

Internal pipe wraps are made out of materials such as fiberglass or carbon fiber and are available in a variety of widths and lengths depending on the specific application. Before installation, it is very important that the pipe wall be properly prepared by thorough cleaning, surface roughening with a method such as water blasting, and complete surface drying. These measures are necessary to ensure that a good bond between the cured pipe wrap and host pipe surface is achieved (Robert Morrison, March 2010). Pipe wraps are a common repair method for pressurized pipelines.

There are a couple of different types of pipe wrap, one that is pre-cured and one that is applied with a wet lay-up method. Both are fiber reinforced, transported to the job site on spools, and can be easily cut to any size in the field. The pre-cured laminate wrap, an example of which is shown in Figure 8 below, has an "elastic memory", creating the need for the spool of laminate to be restrained by string until in position within the pipeline. A tack coat is applied to the defective area, and once the string is cut, the wrap automatically expands outward to fit tightly against the host pipe. In drinking water applications, an epoxy paste is applied to the interior surface of the installed wrap as a protective and bonding seal. (Pipe Medic, LLC, 2012)

Another type of commonly used pipe wrap is fiber reinforced wrap that is applied with a wet lay-up method. An example of this is also shown in Figure 2-8 below. This type of pipe wrap also requires that the surface around the defect be properly prepared, meaning it needs to be meticulously cleaned and the surface repaired to be completely even. A tack coat is applied to the prepared pipe surface once it is completely dry, the resin-saturated fabric applied by hand with a roller, and a final epoxy coat applied over the fabric layer as a sealant. There are NSF 61 certified top-coats for use in potable water systems. (Fyfe Co, LLC, 2009)

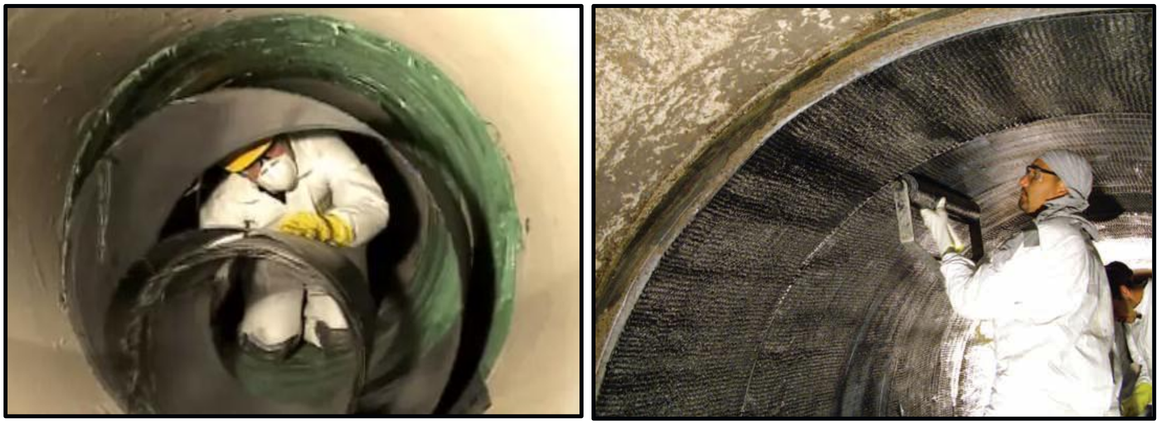

**Figure 2-8. Fiber Reinforced Internal Pipe Wrap – Pre-Cured Laminate (left) (Pipe Medic, LLC, 2012) and Wet-Lay Up Applied (right) (Fyfe Co, LLC, 2009)**

**<u>Internal Repair Sleeves</u>**

Internal mechanical sleeves are typically made of steel or plastics such as PVC (EPA, 2010), depending on their application to water or wastewater systems. Before applying the internal sleeve it is important to make sure the surface of the pipeline has been adequately cleaned to ensure that a leak-proof seal can be established between the rubber seal and the host pipe. Dirt and other debris can prevent a tight leak seal from being established and prevent the repair technology from adequately sealing the defect or cause failure.

A factory manufactured, mechanical sleeve is used to position and permanently secure a resin-impregnated fabric liner or collar of grout inside of a pipe, again depending on the type of pipeline to which the technology is being applied. The metal or plastic sleeve structurally reinforces the pipe system, while the cured liner or grout provides a seal against leaks. The Mechanical Sleeves can be used to repair longitudinal and circumferential cracks, and can span multiple cracks. The grouting collar is wet-out and wrapped around the sleeve. The sleeve is positioned around an inflatable bladder and then inserted into the host pipe. The Grouting Sleeve is positioned with the help of CCTV equipment at the location of the required point repair. The bladder is inflated and the sleeve radially expands locking out tightly against the host pipe. For experienced maintenance personnel, an internal point repair with a Grouting Sleeve can be accomplished in 20 minutes. The sleeves can be overlapped for lining longer lengths. An example of a typical internal joint sleeve that utilizes grout is shown below in Figure 2-9 and is applicable only to wastewater systems. The mechanical sleeves for potable water applications are the same sleeves as those used to seal leaking joints as was shown previously in Figure 2-4.

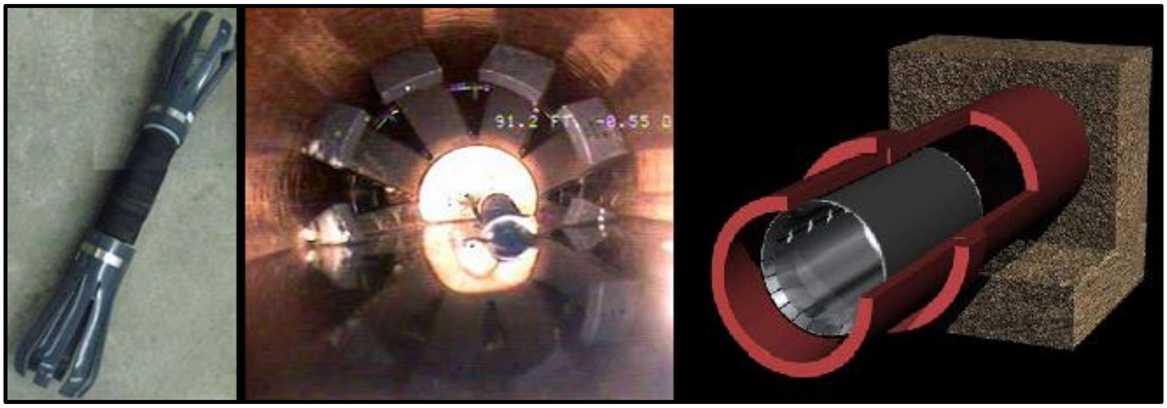


**Figure 2-9. Internal Mechanical Sleeve (Link-Pipe, 2010)**

## Sectional CIPP Liner

CIPP Liners are one of the oldest forms of pipeline rehabilitation, and a similar technology, often called CIPP sectional or short liners, is available to repair localized defects. CIPP short liners utilize CIPP liners that are attached to a specialized bladder and pulled, rather than inverted, into place within the pipeline. Resin is applied to the CIPP liner before it is attached to the bladder, and once in position, the liner is inflated to fit tightly against the host pipe. Short liners are designed to span only short lengths of pipeline whereas traditional CIPP liners are used to rehabilitate pipe segments from manhole to manhole. If necessary, more than one short liner can be used within the same pipe segment, but typically after about two liners it becomes more reasonable to reline the entire segment. CIPP short liners (shown in Figure 2-10 below) are only used in wastewater applications due to the increased access issues and inconveniences that would be faced with their use in water systems.

**Figure 2-10. CIPP Short Liner Material (top left), Mixing of Resins A and B (top right), Resin Application (bottom left), Liner Secured to Carrier Tube (bottom right) (Steiner, 2012)**

**Resin Injection**

Resin injection works by injecting a specially designed resin, typically composed of either epoxy or mortar, into the crack, hole, or fracture in the pipe wall to provide a water tight seal. There are a couple of different methods for injection of resin into the defect. Some technologies utilize a grout packing system that is winched into place within the pipeline and inflated to fit against the host pipe wall. The quick-set resin is then injected into the defect, and the packer is left in place until the resin is cured. A protective coating remains over the crack around the injection site, providing some support for the pipeline and preventing defect propagation.

Another injection method requires that a series of holes of specified diameter are drilled along-side the defect, and individual packers are inserted into the drill holes to inject resin into the defect. The installer moves from drill hole to drill hole, injecting resin until the entire crack has been filled. There are two primary types of resins: hydrophilic and hydrophobic. Hydrophilic resins are activated by water whereas hydrophobic resins repel water. (Prime Resins, 2012) An example of a resin injection system is shown in Figure 2-11 below.

**Figure 2-11. Resin Injection (Heenan, 2010)**

**Patch Repair**

Patch repair methods include those technologies used to perform spot repairs on localized defects by welding a patch of new material over the defect. Typically spot repairs are performed with plastic or metal sheets on pipelines that have been lined with or are composed of the respective material. Plastic liner patches utilize a virgin sheet of PVC that is applied to the PVC-lined pipe surface, and the sheeting is fused to the host pipe lining with welding strips that are backed with a special adhesive of molten material to facilitate hot air welding of the weld strip. The resulting liner is a continuous, impermeable PVC membrane that protects the pipe from the harmful chemicals and abrasive particles that exist in sewage flows. Small repairs of cuts, nail holes, or other minor defects can be repaired with the weld strips alone, but larger defects require a piece of virgin PVC sheeting so that adequate overlap of material, typically about 1-inch, can be made on all sides of the new liner patch (Ameron International, 2005). In a similar manner, patch repair is also an option for steel pipelines. Any existing defects must be repaired and areas of pitting or corrosion removed to create a smooth interior wall surface. A patch of new steel material can then be welded over the defect area using weld strips on each edge of the liner patch to join the host pipe and new steel material. Figure 2-12 below shows examples of a small and large PVC liner patch repair.

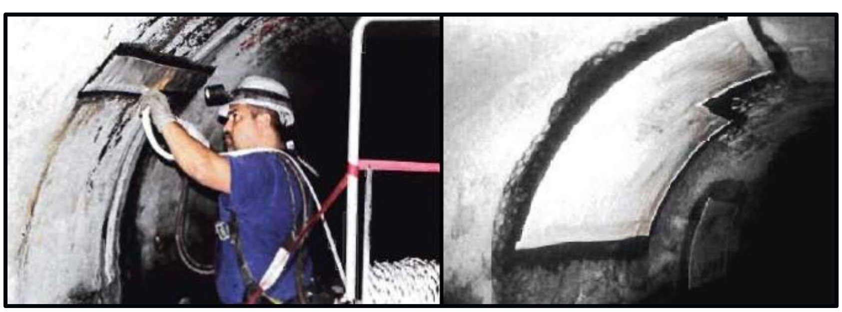

**Figure 2-12. Small Patch Repair (left) and Larger Liner Patch Repair (right) (Project Engineering Consultants, LTD. , August 31, 2005)**

## <u>Grouting</u>

Grouting of individual defects is performed in much the same manner as grouting of leaking joints when using grout packing systems and injection grouting methods. For information on these grouting methods, please refer to the "Pipe Joint and Leak Seal Technology" section above.

Flood grouting is another method for grouting of point defects that is frequently used in Europe. For this method, the leaky sewer section between two manholes is cleaned and isolated using plugs at both ends, and it is then filled with two different chemicals grouts, one resin and one activator. Chemical grout component A is injected through the end plug until it fills the entire volume of the isolated pipe segment. Component A is left in the pipe segment for a pre-determined amount of time, allowing it to enter all defects in the pipe walls. After some time, any excess grout is pumped out of the pipe segment back to the truck for disposal. The line is flushed with water to remove any remnants of component A, and the second chemical compound is then injected through the end plug until the entire volume of the isolated segment is filled. The second compound reacts with the first to form a hardened grout that seals off any defects in the pipe wall. The excess second chemical is then pumped back into the second truck for disposal. This method can be very effective for reducing inflow, infiltration, and exfiltration. The process usually involves the use of silicate-based grout materials. The volume of surplus chemicals is measured and utilized to estimate the effectiveness of the procedure. (Downey, 2012)

### Excavated Point Repair Methods

Excavated repairs are used when a short segment of pipeline becomes weakened or deteriorated to the extent that external reinforcement or repair of the pipeline is required. The pipeline must be excavated at the defect location, and sometimes a section of pipe must be cut out to be replaced with a new segment of pipe that is reconnected with external couplings. Repair clamps, external pipe wraps, and sectional replacement are all examples of excavated point repair methods.

## <u>Repair Clamps</u>

Repair Clamps are a common form of pipe point repair and come in a multitude of different diameters and widths. The repair clamp must be wide enough to attach to areas of structurally sound pipe wall adjacent to the defective area; if this is not possible, replacement is the only option. Clamps are also available that come in multiple pieces for assembly around the damaged pipe without having to completely remove it. Repair clamps have been designed for use on a vast number of pipeline types including those that operate by both gravity and pressurization.

After exaction, the first step to application of the repair clamp is to completely clean the surface of the pipe so that it is free of all soil, mud, scale, etc.  A clean surface is imperative to creating a tight seal between the repair clamp and host pipe. Once the pipe surface is cleaned, the repair clamp is held up against the pipeline, and left-end and right-end clamp locator marks are drawn on the pipe. All nuts can then be loosened, but not removed, to the end of their studs, but care should be taken not to flatten or crease the metal bands. Lubricant is applied to the clamp and pipe surface, and the clamp is then wrapped around the prepared host pipe and moved into position between the left and right clamp locator marks. It is important to keep all gaskets and studs free of any dirt, debris, or other foreign material. The repair clamp should be tightened per manufacturer directions, making sure that the gasket mat is not wrinkled or twisted anywhere around the pipe. Studs should be re-tensioned after about 30 minutes to account for tension losses caused by gasket relaxation. Once all components of the repair clamp have been tightened securely and re-tensioned, the excavation pit can be backfilled per specifications and the site restored.  Figure 2-13 below shows two different types of repair clamp.

**Figure 2-13. Pipe Repair Clamps (left) and Kwik Clamps (right)**

**<u>External Pipe Wraps</u>**

Much like internal pipe wraps, external pipe wraps are made out of materials such as fiberglass or carbon fiber-reinforced polymers and are available in a variety of widths and lengths depending on the specific application.  Before application, it is very important that the pipe area to which the wrap will be applied be properly cleaned, the surface roughened with a method such as disc grinding, and the surface allowed to completely dry.  These measures are necessary to ensure that a good bond between the cured pipe wrap and host pipe surface is achieved (Robert Morrison, March 2010).  External pipe repair wraps are commonly used for structural strengthening of both gravity and pressure pipelines.

The primary type of pipe wrap externally applied is with a wet lay-up method. The FRP wrap is transported to the job site on spools and can be easily cut to any size in the field. Examples of external pipe wraps for small and large diameter pipelines are shown in Figure 2-14 below. A tack coat is applied to the prepared pipe surface once it is completely dry, the resin-saturated fabric is applied by hand with a roller, and a final epoxy coat is applied over the fabric layer as a sealant. (Fyfe Co, LLC, 2009)

**Figure 2-14. External Pipe Wrap Applications on Small Diameter (left) (EA Services, 2011) and large diameter (right) (Fyfe Co, LLC, 2009)**

**Sectional Replacement**

The most traditional way for external repairs is through excavation and replacement of a short section of pipeline. The exact alignment of the pipeline is located with subsurface utility locating technologies, and a trench is excavated surrounding the section of pipeline to be removed. The defective area is then removed from the pipeline and a new pipe segment put in its place. This method is especially common in water or wastewater pipelines where there are too many defects in one localized section to make point repair methods cost effective or where the defects in one particular section are too severe to warrant individual repairs or rehabilitation.

**Pipe Coatings**

Pipe coatings can either be cementitious or polymer-based and are non-structural in nature. Coatings are mostly used to repair the pipeline when it has had issues with corrosion or pitting but can also be used to span small pinholes or leaks. Before the coating can be applied, the pipeline must be taken out of service and a temporary bypass pumping system installed where necessary. The pipe must then be cleaned with appropriate methods to facilitate a long-term bond between the coating and host pipe. CCTV inspections are used to verify cleaning, and the coating can then be applied. Coatings are typically centrifugally cast through a specially designed spray head attached to a hose that is winched through pipe. Mixing of the polymer and thickness of the applied coating are monitored and controlled by computerized equipment. The pipe is inspected at both ends and sealed to facilitate the curing process. After curing, an inspection is performed to verify that the lining has been applied properly, the pipe is disinfected and flushed according to specifications, and it is then put back in service. (Ed Kampbell, February 2011)

### *Cementitious Coatings*

Cement-mortar lining is a mixture of cement, sand, and water that forms a chemically hardened cementitious material installed onto the interior wall of the host pipe. Cement-mortar can be applied by hand with trowels or a spray nozzle or centrifugally cast onto the surface by machine. Cement linings have been used for decades to act as a barrier to corrosion, to increase fluid flow, and in the case of potable water lines to address color and odor issues. Hardened cement mortar does not possess significant tensile strength and therefore cannot provide the host pipe with additional internal pressure capacity or compensate for lost internal pressure capacity due to substantial wall thickness loss (Ed Kampbell, February 2011). Figure 2-15 below shows an example of an applied cementitious coating.

**Figure 2-15. Cementitious Coating (left) (Cement Lining Corporation International, 2008) and Epoxy Coating (right) (Craftsman Pipe Lining, Inc., 2012)**

### *Polymer-Based Coatings*

**Epoxy.** Epoxy Coatings are spray on pipe coatings applied to the interior of a pipeline to protect it from corrosion, stop leaks, prevent future leaks, and improve water quality. It is especially popular for use in potable water service lines because the lining can be installed and cured and the pipe put back into service within one business day. The lining is very thin and hard, though not necessarily strong enough for load bearing applications. Epoxy coatings are mostly used for small diameter waterlines and are not as commonly used in sewer applications (Robert Morrison, March 2010). An example of an applied epoxy coating can be seen in Figure 15 above, which also shows the build-up of tuberculation in pipelines that pipe coatings prevent.

**Urethane.** Urethane Pipe Coatings are applied to the internal or external surface of a pipeline, primarily to protect it from abrasive materials and corrosion. Urethane coatings are typically spray-applied in thicknesses that vary based on design requirements. Urethane coatings are made up of two components, a base and an activator, which combine to create a strong, corrosion resistant barrier for steel or concrete surfaces. Application is quick with minimal disruption to the surrounding public and service can generally be reinstated the same day where the coating is applied to the internal pipe surface. Urethane coatings are more popular for use in oil and gas pipelines as external protective coatings.

**Polyurethane and Polyurea.** Polyurethane and Polyurea Coatings are also two-component, spray-applied systems composed of 100% solids. The primary benefits of polyurethane and polyurea coatings over epoxy are their faster curing time, wider application window, and increased durability (flexibility, abrasion resistance, adhesion, and elongation). The primary disadvantages are the higher material costs, increased surface preparation requirements, and the tendency of the coating to adhere to surface debris rather than pipe wall, increasing the possibility for premature lining failure. The differences between polyuria and polyurethane lie primarily in the newness of the polyurethane linings as well as in the fact that the approximate service life for polyuria is estimated to be 20 years, 5 years longer than that of polyurethane.

### 2.4. Water and Wastewater Pipeline Rehabilitation Technologies

Water and wastewater pipeline rehabilitation technologies are used where the existing host pipe is structurally sound enough to at least partially support the use of the renewal technology. These technologies are aimed at restoring the capacity of a defective pipeline, but slight increases in capacity are sometimes possible, primarily due to reductions in surface friction that results from technology applications. Rehabilitation technologies also restore the structural integrity of the pipeline system, though still may rely on the host pipe for some support, and also extend the life expectancy of the pipeline, typically by at least 50 years. (EPA, 2010) Rehabilitation technologies are used where the defects are too numerous or severe for repair options to be feasible. As shown in Figures 16 and 17 below for water and wastewater systems respectively, pipe rehabilitation technologies have been broken into six major technology classes: (1) Cured-in-Place Pipe (CIPP) Liners, (2) Fold and Form Pipe (FFP) Liners, (3) Grout-in-Place Pipe (GIPP) Liners, (4) Spray-in-Place Pipe (SIPP) Liners, (5) Sliplining, and (6) Modified Sliplining.

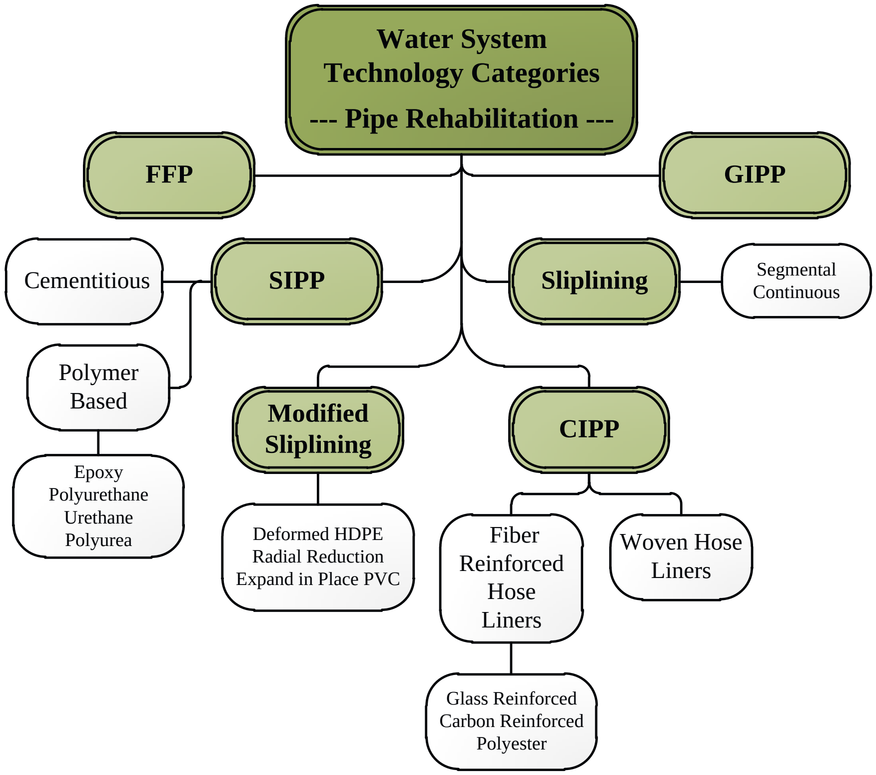


**Figure 2-16. Broad DW Pipe Rehabilitation Categories**

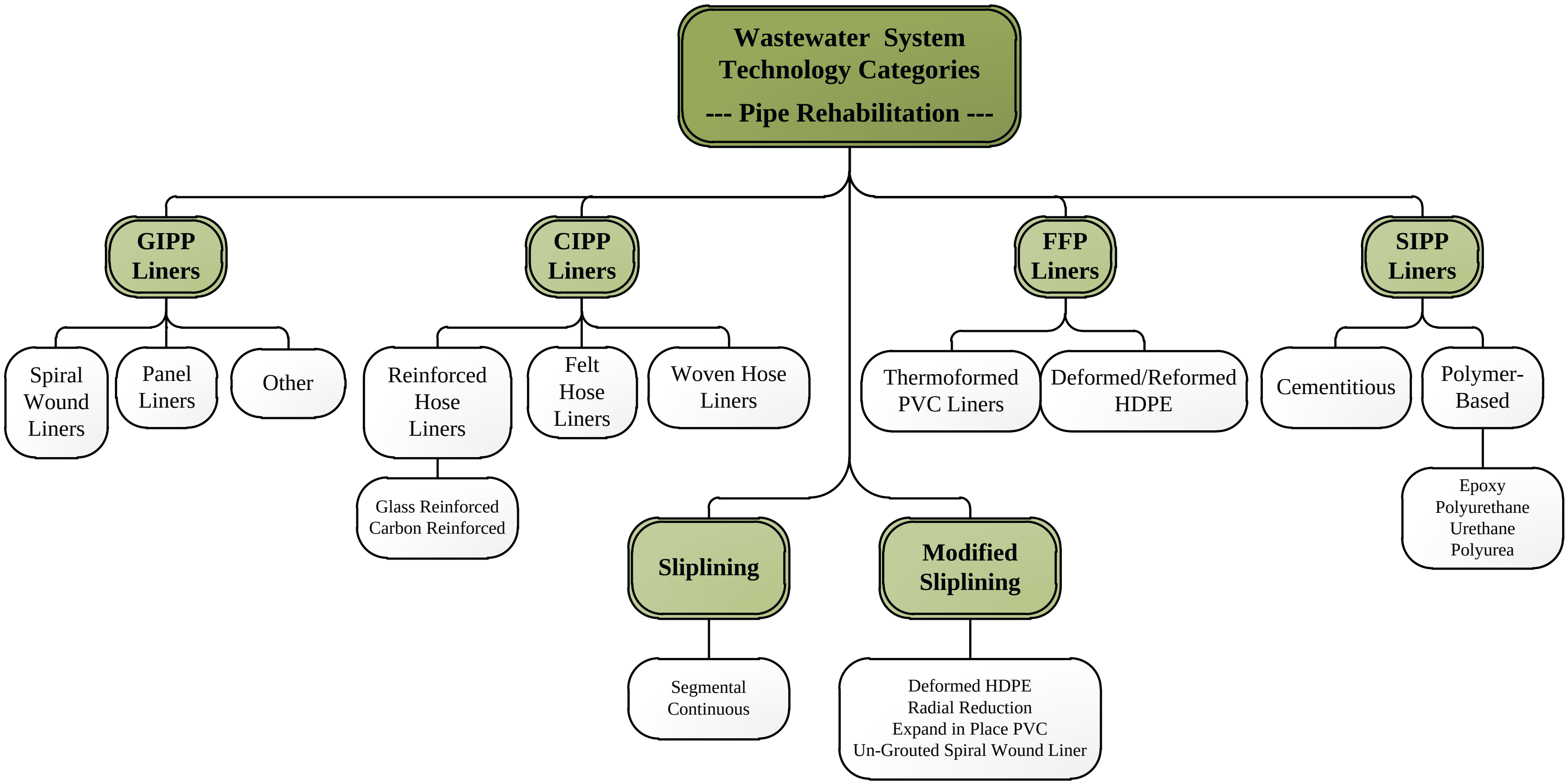


**Figure 2-17. Broad DW Pipe Rehabilitation Categories**

### 2.4.1. Cured-in-Place Pipe (CIPP) Liners

Cured-in-Place Pipe (CIPP) Liners are the oldest and most popular rehabilitation solution used in the industry today. The liner tube is wet-out with a special resin and is pulled or inverted into the deficient host pipe. Hot water or steam is then used to cure the impregnated liner until it has achieved a smooth, hard finish and has adhered to the host pipe. The three primary types of CIPP liners are discussed below.

**Felt Hose Liners**

The most traditional CIPP liners incorporate a felt tube with an outer coating, usually polyurethane or polyproplene, to resist hydrolysis and chemical attack. The felt tube is then impregnated with a process such as vacuum impregnation if completed in the factory or by hand if completed in the field. If resin impregnation is done at the factory, the setting is more controlled, but the resin impregnated liner must be used within two weeks and kept in a controlled temperature low enough to prevent premature liner curing since resin is heat activated. Resins applied in the field must be carefully applied so as to thoroughly and evenly coat the felt liner. The traditional CIPP liners are either hot water cured or steam cured once in place. Hot water was more prominent in earlier techniques, but steam has been found to be more effective in many installations at reducing cure times. Figure 18 includes an example of a felt hose CIPP liner.

**Woven Hose Liners**

Woven Hose CIPP Liners are fully structural liners designed mostly for pressure pipe applications. Woven hose liners utilize layers of woven fiber, typically polyester, that is resin impregnated much in the same way as a felt tube liner. The inner surface is a polymer based membrane that creates a smooth, protective interior coating. Depending on the individual product, installation of the woven hose liner is achieved through either inversion or pushing a pig through the liner with water pressure. Curing is carried out using either circulated steam or hot water. Service connections are plugged prior to lining to prevent blockage with resin slugs and are robotically reinstated once curing has been completed. Figure 2-18 includes two examples of woven hose CIPP liners.

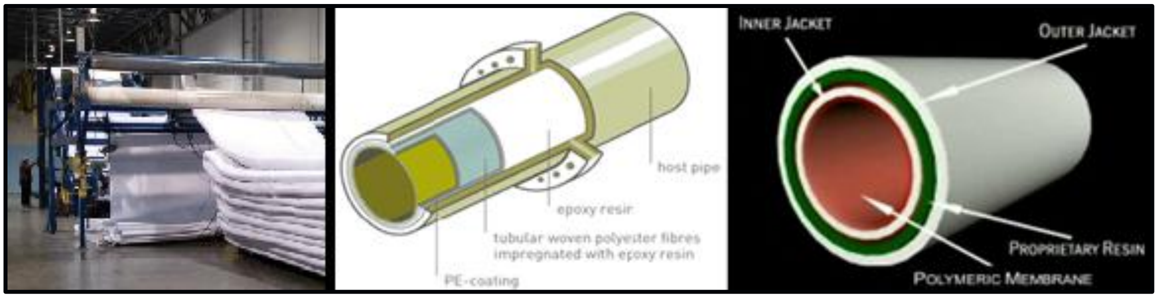


**Figure 2-18. Felt Liner in Factory (left) (Insituform Technologies, Inc., 2012), Woven Hose Liners with One Woven Layer (center) (Sekisui SPR Europe GmbH, 2012) and with Two Woven Jackets (right) (Sanexen Environmental Services, Inc., 2012)**

**Reinforced Hose Liners**

Fiber-Reinforced Hose CIPP liners are designed with single or multiple fiber-reinforcing layers, in some cases sandwiched between layers of the more traditional needled felt material. The most common reinforcing fiber materials are glass, polyester, and carbon, with the number of required reinforcing layers dependent on the project requirements, especially internal and external loadings. Reinforced hose liners can be cured with hot water or steam whereas products that use only layers of fiber reinforcement rely on UV technology for curing. UV technology involves pulling a string of UV lamps through the installed liner for curing rather than circulating hot water or steam. Reinforced hose liners can be designed as semi- or fully-structural rehabilitation solutions and are available for both water and wastewater applications. Figure 2-19 shows examples of reinforced hose CIPP liners and a UV lamp string.

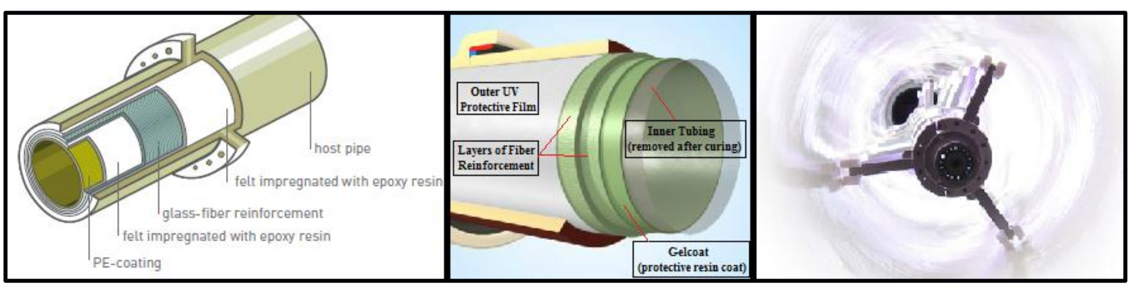


**Figure 2-19. Reinforced Hose Liner with Reinforced and Felt Layers (left) (Sekisui SPR Europe GmbH, 2012), Reinforced Hose Liner with Reinforced Layers Only (center) (BKP-Berolina Polyester GmbH & Co., 2010), UV Curing for Reinforced Hose Liners (right) (Pleasants Construction, Inc., 2010)**

## 2.4.2. Fold and Form Pipe (FFP) Liners

Fold and Form Pipe (FFP) Liners are often confused with modified sliplining technologies, with the primary differences being that FFP Liners can be inserted through an existing manhole (in the case of sewer applications) and do not require individual excavations at connections since they can be reinstated remotely. The capabilities and applicability of FFP are more like technologies such as CIPP Liners and are classified into two primary liner types including Thermoformed PVC Liners and Deformed/Reformed PE Liners.

**Thermoformed PVC Liners**

Thermoformed PVC Liners are collapsed into a shape such as a "C" that effectively reduces its cross section. It is then put onto large spools in continuous lengths at the manufacturing facility for transportation to the project site. Once the liner has been pulled off of the spool and winched into position within the host pipe, the PVC liner is expanded with hot water or steam until it fits tightly against the host pipe wall. Once fully cured, the tight fit of the liner eliminates the need for grouting since no annular space exists. Diameters are available from 3- to 30-inches and in lengths up to 1000 LF. PVC liners provide full, independent structural solutions, and are used for structural renewal as well as for infiltration and root control. There are products available that have received the NSF 61 approval for use with potable water, and they have also been used in pressure applications. Figure 20 below shows an example of a Thermoformed PVC Liner.

**Deformed/Reformed Liners**

Deformed/Reformed FFP Liners are available for both water and wastewater applications. The liner is composed of some form of Polyethylene (PE) material such as HDPE or FRPE and is folded into a "U" shape at the factory before being coiled onto a spool for transportation to the project site. The liner is winched into place within the host pipe, and heat and pressure are used to reform the liner to its natural shape until it fits tightly against the host pipe. Because it is a tight-fitting liner system, no grouting is required, and services can be reinstated robotically. Figure 2-20 below shows an example of a Deformed/Reformed HDPE Liner.

**Figure 2-20. Thermoformed PVC Liner Insertion (left) (Miller Pipeline, 2012) and Deformed/Reformed Liner Exiting Pipeline (right) (HydroTech Inc., 2012)**

### 2.4.3. Grout-in-Place Pipe (GIPP) Liners

GIPP Liners involve the insertion of a thin, thermoplastic material extruded with a stiffening profile within the deficient host pipe. There are several different types of GIPP Liners including spiral wound liners and panel liners. The one common factor between all forms of GIPP Liners is the requirement for grouting of the annular space between the host pipe and installed technology to lock the liner into place and provide additional structural support.

**Spiral Wound Liners**

There are two materials available for Spiral Wound Liners including PVC and HDPE. Both HDPE and PVC can be installed robotically with a winding machine and are designed to be a structural liner that uses grout to fill the annular space between host pipe and liner for added structural integrity. The machine wound liners are metal-reinforced to give them adequate stiffness, and various strengths of grout are available to fill the annular space based on project requirements. The winding machine winds from within the pipe, so no trenches are necessary. An internal bracing system is sometimes required for structural support until the grouting process has been completed.

Some PVC Spiral Wound liners have to be installed by hand, meaning that the pipe diameter must be greater than 36-inches. The liner is spooled at the manufacturing factory for transportation to the project site, and the spool is kept on the surface as the liner is manually pulled into position within the host pipe. The liner has a ribbed outer wall that faces the host pipe and a smooth inner wall that results in reduced friction for pipe flows. The liner edges lock together with male-female double locking mechanisms, and once all liner edges have been locked, a cementitious grout with structural capabilities ranging from filler-foam to high-strength, is injected into the annular space. The PVC liner grooves lock into the grout to form a stabilized, continuous tunnel. Similarly to machine wound liners, an internal bracing system is sometimes required for structural support until the grouting process has been completed.

**Panel Liners**

There are a number of different types of GIPP liners, some requiring man-entry for welding, and others that are welded together prior to insertion to avoid the need for man-entry. For hand-applied panels, the segments are carried or pulled into the host pipe and joined by extrusion welding. Once all panels are welded together to form one continuous liner, an internal support structure is constructed to keep the panels in place while non-expansive grout is injected into the annular space between the liner and host pipe. The grout provides structural stability for the pipe-liner system, but it also acts to anchor the panels in place against the host pipe. The support structure must be kept in place until the grout is cured and the panels are securely formed to the host pipe.

Another type of panel liner is a Jointed Rigid Panel which can be made from Fiberglass, Reinforced Polymer Mortar, or PVC. Some or all of the panels are joined together via jointing or bolting prior to insertion which simplifies the positioning and handling of the numerous panel liners that will be used to rehabilitate the pipeline. The ability to connect sections of panel liners at a time enables even large diameter pipes to be rehabilitated from relatively small access chambers. Line and grade can be adjusted with the use of shims during the installation of each segment, and once the Panels are in place, the annular space is grouted.

A more flexible form of GIPP Liner consists of sheets that are pulled into place within the pipeline. The joints are welded once the liner sheet is inside the pipeline, and the sheets are inflated to a specified air pressure at which point the annular space is filled with grout. Like rigid GIPP panels, the sheets typically have studs that anchor it into the grout, holding it firmly in position within the host pipe once the grout has cured. Flexible sheet liners are the only form of GIPP Liner currently used for potable water and pressure applications. Spiral wound liners and rigid panels do not have sufficient pressure ratings, and panel liners become more difficult to install when access pits (manholes) do not already exist.

### 2.4.4. Spray-in-Place Pipe (SIPP) Liners

SIPP Liners are composed of either cementitious or polymer-based materials. Traditionally, these materials have been used in a non-structural manner to span small holes and act as a barrier to corrosion or harsh water conditions. Cement mortar and polymer based SIPP linings are available for more structural applications by increasing the lining thickness, which, in turn increases the strength of the lining. Increasing the lining strength makes the lining harder, more brittle, and less flexible.

**Cementitious Linings**

Reinforced Cement lining is the most common form of cementitious SIPP Lining, but it is limited in its structural capabilities due to its lack of adequate tensile strength. At best, metal pipes such as ductile iron or steel have nearly 100 times the tensile strength of concrete, and at the cracks that inevitably occur in the lining over time, the tensile strength is essentially zero. The cementitious material is sometimes reinforced with fibers such as steel for added structural integrity or is sprayed into a metal reinforcing cage-like structure which provides a structural rehabilitation solution. Figure 2-21 below shows an example of a spray applied cementitious material.

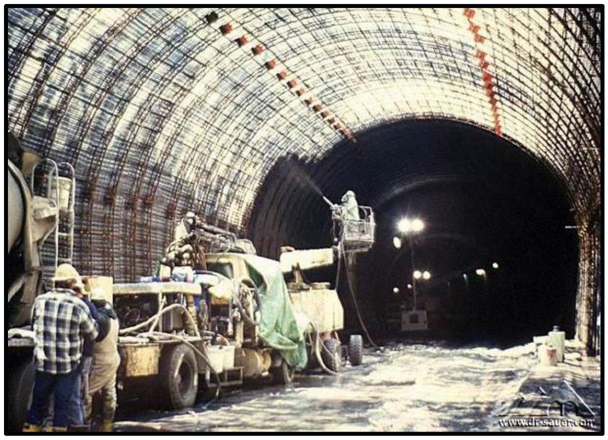

**Figure 2-21. Shotcrete Application (Dr. Sauer Group, 2012)**

**Polymer-Based Linings**

**<u>Epoxy</u>**

High-Build Epoxy Linings are applied to the interior of a pipeline to protect it from corrosion, stop leaks, prevent future leaks, and improve water quality. It is especially popular for use in potable water service lines because the lining can be installed and cured and the pipe put back into service within one business day. The lining is typically applied in thin layers which are not necessarily strong enough for load bearing applications. Though high-build epoxies have promise for applications further than non-structural only, it is most commonly used as a coating.

**<u>Urethane</u>**

High-Build Urethane Pipe Linings are applied to the internal surface of a pipeline, primarily to protect it from abrasive materials and corrosion. Urethane linings are typically spray-applied in thicknesses based on design requirements and have two components, a base and an activator, which combine to create a strong, corrosion resistant barrier for steel or concrete surfaces. Application is quick with minimal disruption to the surrounding public, and service can generally be reinstated the same day when the lining is applied to the internal pipe surface.

**<u>Polyurea and Polyurethane</u>**

High-Build Polyurethane and Polyurea Linings are also two-component, spray-applied systems composed of 100% solids. The primary benefits of polyurethane and polyurea linings over epoxy are their faster curing time, wider application window, and increased durability (flexibility, abrasion resistance, adhesion, and elongation). These linings are much more promising for structural solutions. The primary disadvantages are the higher material costs, increased surface preparation requirements, and the tendency of the material to adhere to surface debris rather than the pipe wall, increasing the possibility for premature lining failure. The differences between polyuria and polyurethane lie primarily in the newness of the polyurethane linings as well as in the fact that the approximate service life for polyuria is estimated to be 20 years, 5 years longer than that of polyurethane. Polyurea is applicable for pipes up to 36-inches in diameter, whereas polyurethane can be applied to pipes with diameters up to 48-inches. Both types can be applied to pipe lengths up to 1,000 LF.

### 2.4.5. Sliplining

Sliplining is a method of pipe rehabilitation in which a new pipe of smaller diameter is inserted directly into the deteriorated pipe by pulling or pushing. Any type of pipe used for direct burial can be used for sliplining, but the preferred pipe materials include: HDPE, PVC, glass reinforced mortar, and DI. Utilizing push-in-place methods, segmental pipe sections with traditional joints can be used. Pull-in-Place installation is possible with fused, welded, or restrained joint pipes. The two drawbacks to sliplining are the reductions in pipe diameter which often decrease the hydraulic capacity of the pipeline, and the requirements for excavation at service connections, valves, and fittings. There are two different methods for sliplining, segmental sliplining and continuous sliplining.

**Segmental Sliplining**

In segmental sliplining, the liner is assembled one pipe segment at a time, each being lowered into alignment at the insertion pit where the it is pulled or pushed into the existing pipe nearly all the way, leaving one end exposed for joining to the next segment. The next segment is then lowered into the insertion pit, joined to the previous segment, and pulled or pushed into the existing pipe nearly all the way, leaving one end exposed for joining to the next segment. This process continuous until the entire liner is in place within the host pipe. With the liner in place, the annular space between the host pipe and new pipe is grouted. Compared to continuous sliplining, segmental sliplining generally reduces the construction site footprint as well as the size requirements of the insertion pit. Figure 2-22 below shows the various stages of segmental sliplining.

**Figure 2-22. Loading of Pipe Segment into Fusion Pit (left), Fusion (center), and Insertion (right) (Underground Solutions, Inc., 2011)**

### Continuous Sliplining

In continuous sliplining, the liner is manufactured as a continuous pipe or is assembled in the field prior to insertion to match the entire length of the existing pipe. Joints can either be fused or restrained type joints. Continuous Sliplining often uses HDPE or fusible PVC pressure pipe. The length of the insertion pit is determined by the allowable radius of curvature of the pipe and is also influenced by host pipe depth. The length of the pipe string can lead to large construction footprints and generate substantial site disruption as compared to many alternative pipe rehabilitation technologies. Figure 2-23 below shows the various steps and components of continuous sliplining.

**Figure 2-23. Insertion (left), Fusion (left-center), Lay-Down Area (right-center), Exit Pit (right) (Underground Solutions, Inc., 2011)**

### 2.4.6. Modified Sliplining

Modified Sliplining refers to close-fit and deformed lining techniques that insert a new thermoformed pipe within the host pipe. Modified sliplining differs from traditional sliplining in that it provides a close-fit between the host pipe and new liner pipe, eliminating the annular space and therefore any grouting requirements. Additionally, modified sliplining techniques cause minimal diameter loss compared to sliplining and typically increase flow capacities. Though not always used, thermoformed pipes can provide a smooth, jointless interior surface which is beneficial since joints are the weakest points on a pipeline. Modified sliplining technologies also have the flexibility to be designed as either a semi-structural (Class II/III) if the condition of the host pipe allows, or fully structural (Class IV) solution.  There are four primary methods for modified sliplining including: (1) Deformed HDPE, (2) Expand-in-Place PVC, (3) Radial Reduction, and (4) Un-Grouted Spiral Wound Liners.

**Deformed HDPE**

Deformed HDPE Pipe is pulled through a die to deform it into a shape with a cross section small enough to be pulled easily into the host pipe. Deformation can either be performed on-site as shown in Figure 2-24 below, or it can be done by the manufacturer so that it arrives to the project site ready for pull-in.  Straps are typically wrapped around the circumference of the deformed pipe to restrain it until it is safely in place within the host pipe.  A cable is strung through the host pipe from an access pit or existing manhole and attached to the liner at a second manhole or access pit. The liner is then carefully pulled through the host pipe using sleeves or rollers to protect it from damage. Once in place, the liner is cut and end seals attached that allow for monitoring of pressure and temperature during the reforming and curing processes. An alternate method for reforming the HDPE pipe is to run a rounding device through the deformed pipe to re-round it to its natural shape. Steam is injected into the new liner until it is reformed and fits tightly against the host pipe wall.  Once this curing process is complete, the liner is allowed to cool to below 100°F before equipment can be disconnected and service connections reinstated via a robotic cutter device.  Once the deformed pipe has been reformed within the host pipe, it becomes a structural pipe within the host pipe.  There are Deformed HDPE products available for both water and wastewater applications.


**Figure 2-24. On-Site Deformation of Deformed HDPE Pipe Liner Pull-In (left) and Close-Up of Deforming Machine (right) (Insituform Technologies, Inc., 2012)**

### Expand-in-Place PVC

Expand-in-Place PVC liners begin with a diameter smaller than that of the host pipe to facilitate easy insertion. The pipe segments are fused in the field and inserted just as they would be for a continuous sliplining technology. Once in position within the host pipe, the pipeline is heated and pressurized until the new PVC pipe is fully cured and expanded to fit tightly against the host pipe. Once the curing process is complete, the liner provides a fully independent, structural solution. This technology is available for application to both water and wastewater pipelines and is shown in Figure 2-25 below.

**Figure 2-25. Expand-in-Place PVC Entering Host Pipe (left) and After Expansion (right) (Underground Solutions, 2012)**

### Radial Reduction

Radial Reduction installations are either mechanically or thermally induced. For mechanically induced reductions, the diameter of the new pipe is reduced by up to 20% after it is put through a machine such as a rolling machine. The pipe is hydraulically pushed through a series of compression rollers to reduce its diameter. With the pipe under compression rather than tension, there is little change in pipe length. There is, however, a corresponding increase in the pipe wall thickness. The pipe diameter does not immediately try to recover its original shape, so pressurization is used to help the pipe recover its original diameter after it has been pulled into place within the host pipe. To mechanically reduce the new pipe diameter by tension, the pipe is pulled through a swage die just before it enters the host pipe as shown in Figure 2-26 below. With the pipe under tension, there is some change in pipe length, so after pull in is completed, the winch is disconnected and the liner allowed to visco-elastically recover towards its original diameter until it fits tightly against the host pipe wall. Technologies that utilize radial reduction are available for both water and wastewater applications.

**Figure 2-26. Mechanical Radial Reduction by Compression (left) (Insituform Technologies, Inc., 2012) and Tension (right) (Swagelining, 2011)**

### Un-Grouted Spiral Wound Liners

Un-Grouted Spiral Liners are not used very often and are only available for wastewater system applications. Liners are made of HDPE, PVC, or steel reinforced materials based on the unique needs of the individual project. A specially designed spiral winding machine winds the liner into place within the deteriorated host pipe at a diameter smaller than that of the host pipe. A secondary locking mechanism is used to hold the liner at the reduced diameter until it reaches the upstream access point. At this point, the liner is torsionally restrained as the cutting wire is pulled to release the secondary locking mechanism. When the cutting wire is removed, the liner is allowed to expand in place and adjacent profile wraps are joined automatically by the primary lock upon expansion. Once the liner is expanded to fit tightly against the host pipe and the primary locking mechanism has allowed the joining of all profiles, the ends of the liner are cut at the manhole chambers to achieve a perfect fit. The locking mechanisms and wound liner are shown in Figure 2-27 below. The smooth liner can be designed as a fully structural solution, but it is not able to withstand the loadings of a pressurized pipeline.

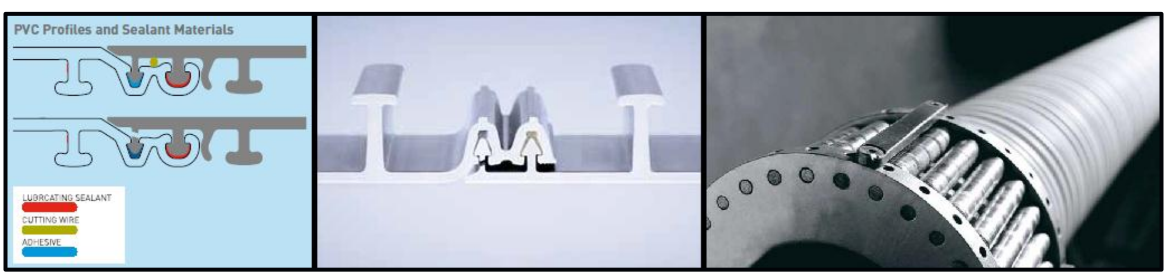


**Figure 2-27. Un-Grouted Spiral Wound Profiles (left and center) and Wound Liner (right) (Sekisui SPR , 2011)**

### 2.5. Water and Wastewater Pipeline Replacement Technologies

Water and wastewater pipeline replacement technologies are used where the existing host pipe is no longer structurally sound enough to support repair or rehabilitation technologies or where the existing host pipe is severely deteriorated or collapsed. These technologies are designed to completely restore or increase capacity and structural integrity of a defective pipeline, and the old pipe is either abandoned in place or removed in some manner from its existing alignment (EPA, 2010) . Replacement technologies re-start the life expectancy of the pipeline rather than just extend it, so that the new life expectancy is heavily dependent on the type of pipe chosen for installation. As shown in Figures 2-28 and 2-29 below for water and wastewater systems respectively, pipe replacement technologies have been broken into two major technology categories: (1) In-Line Replacement Methods and (2) Off-Line Replacement Methods.

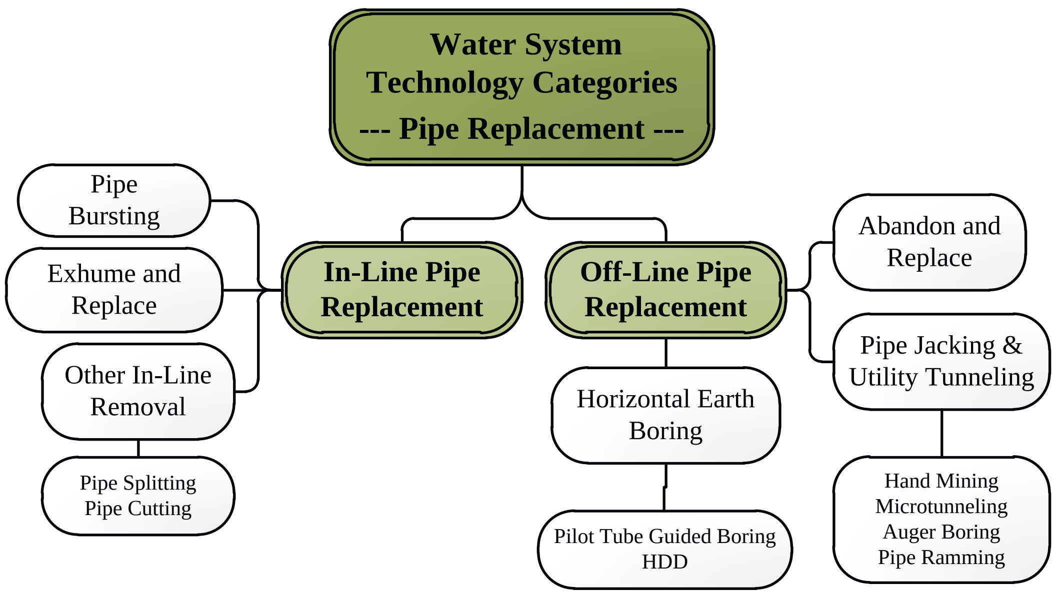


**Figure 2-28. Drinking Water System Technology Categories**

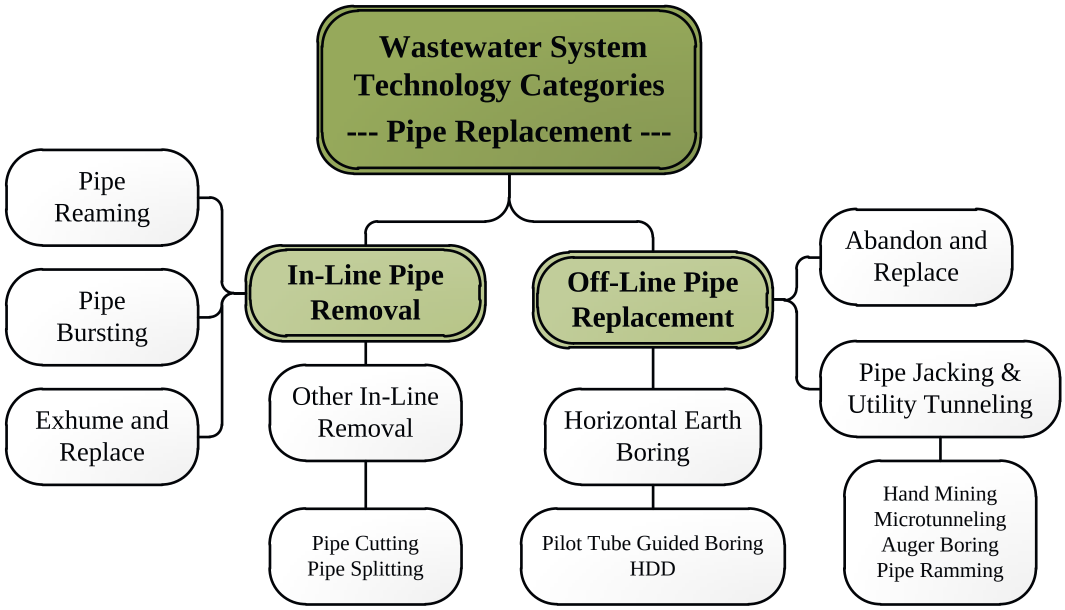


**Figure 2-29. Wastewater System Technology Categories**

### 2.5.1. In-Line Pipe Replacement

In-Line Pipe Replacement includes those technologies that install the replacement pipe on the same alignment as the original host pipe. The original host pipe is removed completely in all of these methods, but only the Exhume and Replace method requires full excavation of the original host pipe. The alternate, "trenchless", forms of pipe replacement remove the pipe in place, disbursing the pieces into the surrounding soil or drawing it back out in small pieces for disposal. There are three primary methods for in-line pipe replacement including (1) pipe bursting, (2) pipe reaming, and (3) exhume and replace. There are certainly other methods for in-line pipe removal and replacement; only the most common technologies are discussed in detail since alternative methods for in-line pipe removal tend to only slightly vary from the primary methods.

**Pipe Bursting**

Pipe Bursting uses a specialized bursting tool to shatter the host pipe into small fragments that are forced into the surrounding soil by an expander head. The bursting tool itself typically has a conical shaped tip with a base larger in diameter than the host pipe, making it possible to increase the diameter of the pipeline, though there are restrictions on the degree of upsizing that can be performed. The new pipeline is installed along the same flow line as the host pipe, so upsizing will result in a slight decrease in the depth of the pipe crown.

Pipe bursting can be used on almost any type of existing pipe, but some pipe materials such as ductile iron, heavily reinforced concrete, and corrugated metal are certainly more challenging to effectively fracture. Bursting of ductile pipes is often called pipe cutting because specialized cutting wheels and expansion heads are required to cut through the ductile material. Figure 2-30 below shows an example of a pipe bursting and pipe cutting.

**Figure 2-30. Cutter Head at Coupling (left), Expanded Steel Pipe (center), Bursting Head (right) (Underground Solutions, Inc., 2011)**

Segmental replacement pipe can be used in lieu of fused pipe, but aside from a few types of restrained joint segmental pipes, jacking equipment is required to force the new pipe in behind the bursting unit. Currently the applicable diameter range for pipe bursting is between 2- and 54-inches, with larger units becoming available. There are three primary types of pipe bursting: pneumatic, static, and hydraulic as described in the sections below.

**Pneumatic Pipe Bursting**

The pneumatic pipe bursting method uses air pressure to drive a bullet shaped hammer through the existing pipe. The front of the bullet hammer has knife blades that cut or fracture the existing pipe with each blow. The pneumatic pipe bursting head is considerably longer than the head used in the hydraulic pipe bursting method, thus requiring longer launching and receiving pits. The replacement pipe is attached to the back of the bursting head, pulling the replacement pipe into place as the head progresses. If the pipe material and soil conditions are suitable, the pneumatic method is capable of faster rates of installation than the hydraulic method because the hydraulic method must cycle the head of the machine opened and closed regardless of the pipe type or soil conditions. (TT Technologies, Inc., 2006) Figure 2-31 below shows a pneumatic pipe bursting head and an assembly entering the host pipe.

**Figure 2-31. Pneumatic Bursting Head (TT Technologies, Inc., 2012)**

## Hydraulic Pipe Bursting

The hydraulic pipe bursting process uses a bullet shaped head driven by a hydraulic power supply. The bursting head is attached to the front of a cable that is used to pull it through the existing host pipe, and the hydraulic power is used to open and close the bursting head, the action of which breaks up the existing pipe. The head, attached to a constant-tension winch cable, is used to break one section of the pipe, and the assembly is then pulled forward to break the next, unbroken section of pipe. The primary function of the winch cable is to prevent the bursting head from shifting off of alignment as it opens and closes. It is not for pulling the cone-shaped head forward to break the pipe. This process repeats itself until the entire pipeline has been replaced. (Jadranka Simicevic, 2001) Figure 2-32 below shows a hydraulic pipe bursting head and winching machine.

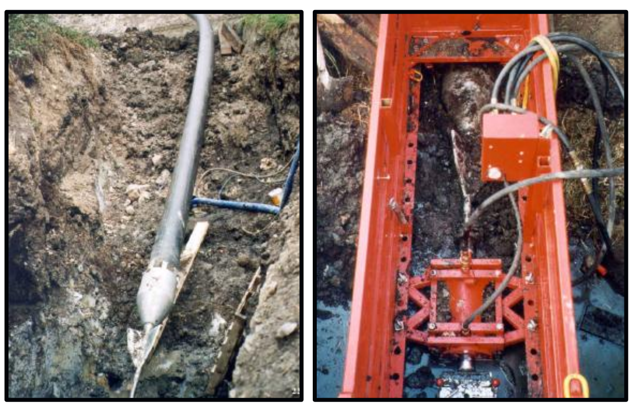

**Figure 2-32. Hydraulic Bursting Head (left) and Winching Machine (right) (Terra Systems for Trenchless Pipe Installation, 2011)**

## Static Pipe Bursting

Static Pipe Bursting does not use any hammering action but instead applies a large tensile force to the cone-shaped expander head with a pulling rod assembly or cable (winch) inserted through the existing pipe. The cone transfers the horizontal pulling force into a radial force, breaking up the existing pipe and expanding the cavity to a diameter large enough for the new pipe. The individual steel bursting rods are connected and inserted into the existing pipe from the pulling shaft. When the rods reach the insertion shaft, the bursting head is attached, and the new pipe is connected to the rear of the head. The head is then pulled by either a pulling rod assembly (TRS system) or a winch cable, which, like the rods, would also be inserted through the existing pipe and attached to the front of the bursting head. The bursting head and new pipe are pulled by the rods or winching cable, fracturing the existing pipe and pushing the debris into the surrounding soil. The process continues until the bursting head reaches the pulling shaft, where it is separated from the new pipe. If a cable or winch is used instead of a rod assembly, the pulling process continues with minimum interruption, but the force available for the operation is less. Roller blade cutting wheel assemblies allow bursting of pipe types such as steel and ductile iron as well as ductile iron repair clamps which are more difficult to burst. (Jadranka Simicevic, 2001) Figure 2-33 below shows a static pipe bursting head and machine.

**Figure 2-33. Static Pipe Bursting Head (left) and Bursting Machine (right) (TT Technologies, Inc., 2012)**

## Pipe Reaming

Pipe Reaming is a replacement technology that grinds the existing host pipe up into smaller pieces that are mixed with drilling fluid and flushed back through to the extraction point. The new pipe is pulled into place simultaneously as the backreaming head cuts up the old pipe and expands the soil tunnel, if necessary, to the appropriate diameter. Pipe reaming is often compared to pipe bursting, but there are actually a number of important differences between the two trenchless installation methods. While pipe bursting installs the new pipe at the same invert as the original host pipe so that the elevation of the original flowline is maintained, pipe reaming installs the new pipe on the same centerline. Where pipe reaming is used to upsize a pipeline, the new pipe remains on the same centerline creating a flowline in the new pipe that is lower than that of the original host pipe.

Pipe reaming typically requires a horizontal directional drilling machine and a specially designed backreaming tool which can be made from a compaction reamer modified by a shop or manufacturer. Figure 2-34 shows the reaming head recommended for use when hard pipe materials such as VCP need to be replaced. A minimum of two excavation pits are required for installation: one acting as an insertion pit and one as a retrieval pit. (Nowak Pipe Reaming, Inc., 2011) The insertion pit is, on average, somewhere around 30 feet long, but this figure varies heavily based on the depth of the pipe being replaced. The retrieval pit also acts as a pit for the excess particles, ground up host pipe, and drilling fluids that are pushed through the alignment of the existing host pipe. The number of access pits required will increase with the length of pipeline being replaced. Pipe reaming can be used with waterlines, but it is not a common practice.

**Figure 2-34. Reaming Head Recommended for Use with VCP (Nowak Pipe Reaming, Inc., 2011)**

### Exhume and Replace

The in-line form of open-trench replacement, Exhume and Replace, entails the excavation and removal of the existing pipeline so that a new pipeline can be installed in the same location. Open trench excavation has historically been the most common form of pipeline replacement, and despite the new focus on other forms of pipeline renewal, it remains the standard replacement method for most water and wastewater utilities. Open trench installations involve the excavation of the trench, in this case on a pre-determined alignment; installation of trench wall stabilization for placement of the bedding and new pipeline; placement and compaction of the backfill; reinstatement of the service connections or laterals; and restoration of the site to its pre-construction state. If open trench installation is chosen as the most appropriate method for renewal, the exhume and replace method is especially good where there are a lot of service connections or laterals or where the density of existing underground infrastructure makes installation on a parallel alignment difficult. It is beneficial to install a pipeline along the same alignment when there are numerous connections because the connections can remain in their current locations rather than be moved or extended to facilitate connection to the parallel line. Figure 2-35 shows an old pipe being removed from the existing alignment.

**Figure 2-35. Exhume and Replace Pipe Removal (Wake Forest, 2011)**

### 2.5.2. Off-Line Pipe Replacement

Off-Line Pipe Replacement Technologies refer to technologies used to replace the pipeline on a different alignment than the original host pipe. When the host pipe is to be taken out of service and abandoned in place, it is filled with grout. In some cases, especially where the primary project driver is increased capacity, the original host pipe will remain in service, acting as an overflow pipeline or back-up pipeline should the new pipe need to be taken out of service at any point in the future. There are three primary methods for off-line pipe replacement including (1) abandon and replace, (2) pipe jacking & utility tunneling, and (3) horizontal earth boring.

#### Abandon and Replace

The off-line form of open-trench replacement, Abandon and Replace, entails the filling of the existing pipeline with grout and the installation of a new pipeline on a different alignment, typically parallel to the existing. Open trench excavation has historically been the most common form of pipeline replacement, and despite the new focus on other forms of pipeline renewal, it remains the standard replacement method for most water and wastewater utilities. Open trench installations for Abandon and Replace involve the excavation of the trench, in this case on a pre-determined alignment; installation of trench wall stabilization for placement of the bedding and new pipeline; placement and compaction of the backfill; reinstatement of the service connections or laterals; and restoration of the site to its pre-construction state. If open trench installation is chosen as the most appropriate method for renewal, the abandon and replace method is useful where the old pipe is difficult to access, making maintenance and repair as well as replacement on the same alignment difficult. As mentioned above, if capacity issues exist or are expected to exist in the future it may be beneficial to repair the existing pipeline and install a new parallel line so that the old pipeline can be used for additional capacity. The utility may also choose to keep the original pipeline in service as a bypass line when the new pipeline requires maintenance or repair.

**Pipe Jacking & Utility Tunneling**

Pipe Jacking & Utility Tunneling refers to technologies that require workers to enter the bore hole. The term Horizontal Earth Boring has come to be used where borehole excavation is accomplished entirely by mechanical equipment. Pipe Jacking is also frequently distinguished from Utility Tunneling, which also requires man-entry; with Pipe Jacking the excavation and pipe installation occur simultaneously whereas in Utility Tunneling where a temporary ground support system is installed during excavation for subsequent pipe insertion.

**Hand Mining**

Hand mining is a simple, yet effective method for utility tunneling in many situations, where access issues or soil composition prevents other tunneling techniques. The tunnel opening is advanced by hydraulic jacks or by traditional blasting techniques in predetermined increments, and the tunnel face is cleared of material and debris by hand or with the aid of a small excavator. (NYC Comptroller, 2001) Figure 2-32 shows an example of a tunnel being created by traditional drill and blast where hand mining with rail carts was used to remove blasted rocks and debris.

**Figure 2-36. Back Dump Mucker to Remove Debris (left) and Dumping of Spoil into Much Car (right) (Steiner, Sewer Interceptor Installation Using Traditional Drill and Blast Tunneling Techniques in Howard County, MD, 2012)**

**Microtunneling**

Microtunneling is essentially a remote controlled, guided Pipe Jacking process that provides continuous support to the excavation face (unlike auger boring). It allows for installation of pipes in a wide range of soil conditions and is capable of maintaining tight line and grade tolerances along the entire alignment. Microtunneling systems utilize five independent systems: microtunneling boring machine, jacking or propulsion system, spoil removal system, laser guidance and remote control system, and pipe lubrication system. The most common pipe materials used for Microtunneling are RCP, DI, welded steel, and FRP Concrete, or reinforced polymer concrete. Microtunneling can be used to install pipelines ranging in diameter 12- to 144-inches, but it is most commonly used for pipes with diameters between 24- and 48-inches. Figure 2-37 shows a large diameter Microtunneling Machine and access shaft.


**Figure 2-37. Microtunneling Machine (left) and Access Shaft (right) (SAK Construction, 2012)**

## Auger Boring

Auger Boring, also referred to sometimes as Jack and Bore, is a process by which new pipes can be installed underground with minimal excavation. A rotating cutter head is used to drill a borehole from the entrance pit to the exit pit. Spoils are transported back to the drive shaft by helical wound auger flights rotating inside of the steel casing pipe which is jacked into place simultaneously. There are two separate installations in an auger boring project. The first is a steel casing, and the second is the actual pipelines that are housed within the casing. Auger boring is particularly common where new pipelines need to be installed under embankments or railroads where the casing is required to aid the carrier pipe in handling external loads. It is also used in locations where some flexibility of the final steel casing alignment is necessary since the carrier pipes can be adjusted to exact grade within the carrier pipe. Auger boring technologies offer only a limited amount of tracking and steering, and following installation, any service connections have to be excavated for reinstatement.

## **Pipe Ramming**

Pipe Ramming is a trenchless installation method where a pneumatic tool is used to pound the new pipe into its proper alignment. The front edge of the pipe is left open so that the spoils are pushed inside the pipe rather than compacted around the external surface of the pipe. If the installation is long so that the pipe gets too heavy to move forward with the installation, the process may need to be completed in multiple segments so that spoils can be removed at an intermediate point.

## Horizontal Earth Boring

Horizontal Earth Boring technologies are used to create new bore holes through the existing earth along the design alignment. There are a number of different methods for horizontal earth boring, including but certainly not limited to horizontal directional drilling, auger boring, and pilot tube guided boring.

### **Horizontal Directional Drilling**

Horizontal Directional Drilling is a form of renewal that allows a water or wastewater pipe to be installed through hard rock or beneath environmental features such as lakes/rivers with minimal disturbance. The technique requires two excavation pits, an entrance pit and a receiving pit, and a small diameter pilot hole is first drilled along the proposed pipe alignment. The operator has steering capabilities, though limited, to ensure that the pilot hole is drilled along the correct alignment. A series of back-reamers, progressively larger in size, are then used to expand the pilot hole to the diameter required for host pipe insertion. Once the soil tunnel has been expanded to the proper diameter, the new pipe is pulled back through from the receiving pit to the insertion pit by the reaming machine, and service connections are reinstated robotically or by hand, depending on the pipe type and diameter. Figure 2-38 below shows the various components of the HDD process.

**Figure 2-38. Drilling Rods and Rig (top left), Pipe Fusion (top right), Pipe Pull-In (bottom left), Exit Pit (bottom right) (Underground Solutions, Inc., 2011)**

**<u>Pilot Tube Guided Boring</u>**

Pilot Tube Guided Boring, also referred to sometimes as Pilot Tube Microtunneling (PTMT), installs small diameter tubes (pilot tubes) by way of slanted-face cutting heads fitted with a target containing light emitting diodes (LEDs) and a camera mounted theodolite in the shaft. The LEDs and camera allow the pipeline to be installed on alignment with great precision. With the pilot tubes in place, the hole is enlarged gradually to the same outside diameter of the new pipe, and the new pipe is either jacked or pulled into place within the newly established soil tunnel.

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# CHAPTER 3.
## STATE OF THE ART LITERATURE AND PRACTICE REVIEW FOR WATER SYSTEM PIPELINES

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Over the last few years, several advancements have been made in water pipe renewal technologies that have allowed utilities to utilize innovative renewal techniques that decrease project costs, the impact of the project on the surrounding citizens and environment, and allow for expedited pipeline renewals compared to traditional open trench methods. The challenge now is in getting utilities to implement new innovative technologies within their system. This paper provides background information for the technologies available for the renewal of water system pipelines and then provides State of the Art Literature and State of the Art Practice Reviews based on technology use trends in literature and technology use trends practiced by utilities. The information from both reviews is then synthesized to provide a clear view of the state of the water pipeline renewal technology industry, including the trends by pipe material, technology type, and drivers for renewal projects.

**Keywords:** drinking water pipe; renewal; repair; rehabilitation; replacement; pipe renewal technologies

### 3.1. Introduction

There are over 156,000 public water systems in the United States (EPA, March 2008), each with needs that are unique to their size, geographic location, and system characteristics. Drinking water utilities face a unique set of challenges associated with buried pipeline renewal for a number of reasons such as increased consequences of failure compared to gravity pipelines, increased risks associated with new or un-proven technologies, limited access, level of service responsibilities to customers, etc. With the increased awareness of the severity of underground infrastructure deterioration, paired with the decreasing budgets available to utilities to renew their municipal infrastructure, strategies for pipeline renewal have become a major focus for utilities across the nation. This is especially true for water pipelines which have limited options for cost effective renewal.

## 3.2. Pipeline Renewal Technology Background Information

The United States Environmental Protection Agency (EPA) defines Pipeline Renewal to be "the application of infrastructure repair, rehabilitation, and replacement technologies to return functionality to a drinking-water distribution system or wastewater collection system." (EPA, 2010) The line between whether to repair, rehabilitate, or replace a pipeline is often a fine one, and each utility currently has its own protocol for making this decision. The EPA provides a few generalized guidelines and host pipe requirements describing appropriate situations for the application of each type of pipeline renewal as summarized in Table 3-1 below.

To further complicate the decision to renew a pipeline, there are a number of different technologies available to complete each type of pipeline renewal and several products available to represent each technology. The technologies discussed in this paper have been broken down by type of renewal and are then further broken down into more specific technology categories. It was necessary to define these technology categories to encompass the more specific products and technologies due to the number of technologies currently on the market. The technology descriptions that follow are meant to provide a general definition for each type of renewal and technology category in an effort to help the reader understand the technologies and their general applicability to drinking water pipelines

**Table 3-1. Renewal Engineering Components and Descriptions of Use (EPA, 2010)**

| Pipe Repair Technologies | |
|---|---|
| Pipe Joint & Leak Seals | Pipe joint and leak seal technologies can typically be installed by in-house operation and maintenance crews and are designed to repair leaking, cracked, or defective joints. Joints are commonly the weakest part of a pipeline, and these technologies are designed to seal leaking joints and prevent inflow and infiltration. There are three primary types of pipeline joint and leak seal technologies: (1) internal sleeves, (2) grouting, and (3) excavated repairs. |
| Pipe Point Repairs | Pipe point repair technologies are those technologies used to fix short sections of pipeline with a range of structural solutions and are designed to repair sections of pipeline with semi- or fully- structural repair options. There are two primary forms of point repair technologies: (1) Internal Point Repair Technologies and (2) Excavate and Repair Technologies. Examples of internal point repair technologies include internal pipe wraps, internal sleeves, and grouting. Examples of Excavate and Repair Technologies include exteral repair clamps, sectional replacement methods, and external pipe wraps. |
| Pipe Coatings | Pipe coatings are applied by hand or robotically to span small defects in the pipe wall or provide protection from degradation mechanisms such as corrosion. These linings are not considered stand-alone repair technologies and provide very little to no added structural integrity to the pipeline. There are two types of coating available: (1) cementitious and (2) polymer-based. |

### 3.2.1. Drinking Water Pipeline Repair Technologies

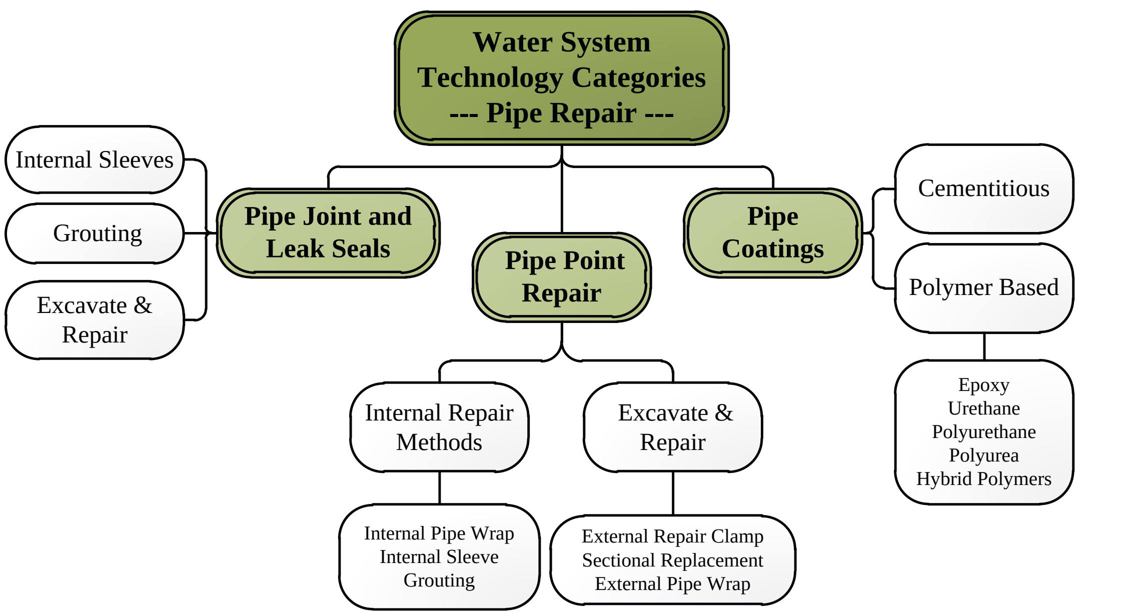


**Figure 3-1. Water Pipe Repair Technologies**

Pipeline repair technologies are used to restore normal pipeline operating conditions or repair small, localized leaks along the pipeline. The drinking water pipeline repair technology categories are shown in Figure 3-1 above. The technologies are typically used where the defect is not severe enough to require renewal of the entire pipe segment or where deterioration is contained to a small area. Repair technologies can be used to enhance structural stability of the host pipe, but the repair mechanism still relies on the host pipe for structural soundness (EPA, 2010). As shown in Figure 1 above, pipe repair technologies have been broken into three major technology categories: (1) pipe joint and leak seals, (2) pipe point repairs, and (3) pipe coatings. Table 3-2 below briefly describes each of the major pipe repair technology categories.

**Table 3-2. Description of Water Pipe Repair Technology Categories**

| **Pipe Repair Technologies** | |
|---|---|
| Pipe Joint and Leak Seals | Pipe joint and leak seal technologies can typically be installed by in-house operation and maintenance crews and are designed to repair leaking, cracked, or defective joints. Joints are commonly the weakest part of a pipeline, and these technologies are designed to seal leaking joints and prevent inflow and infiltration. There are three primary types of pipeline joint and leak seal technologies: (1) internal sleeves, (2) grouting, and (3) excavated repairs. |
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### 3.2.2. Water System Pipe Rehabilitation Technologies

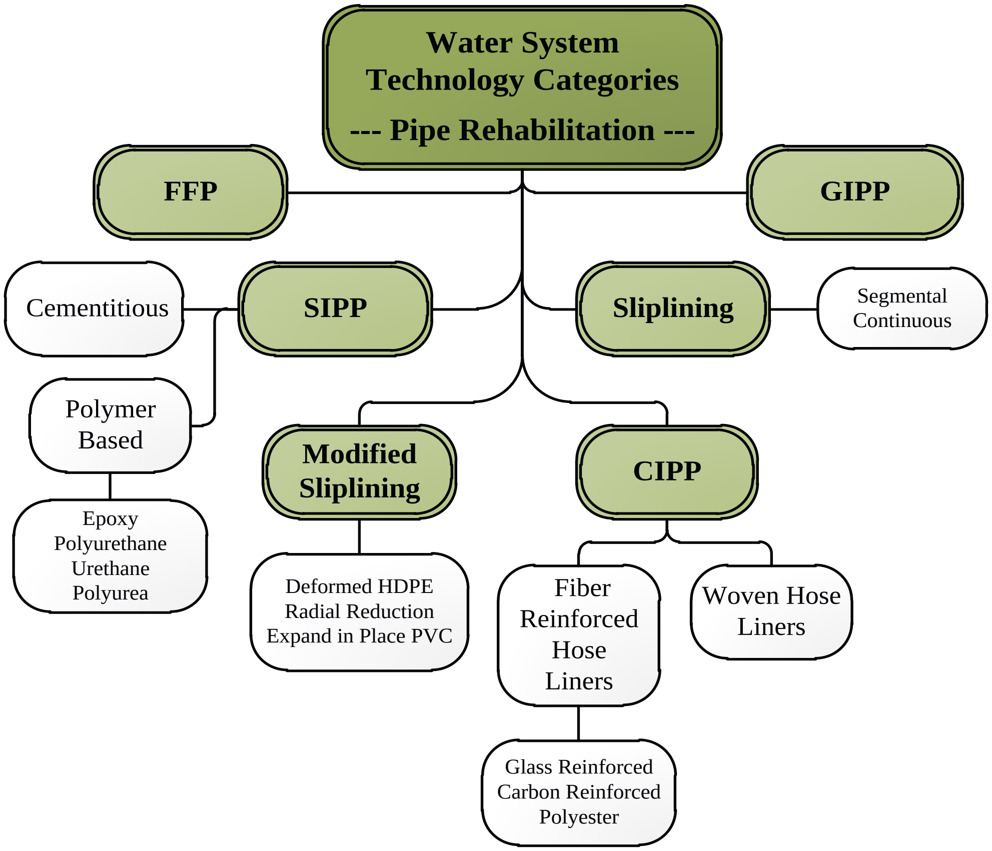


**Figure 3-2. Water Pipe Rehabilitation Technologies**

Drinking water pipeline rehabilitation technologies are used where the existing host pipe is structurally sound enough to at least partially support the use of the renewal technology. The drinking water pipeline rehabilitation technology categories are shown in Figure 3-2 above. These technologies are aimed at restoring the capacity of a defective pipeline, but slight increases in capacity are sometimes possible, primarily due to the reduction in surface friction that results from technology applications. Rehabilitation technologies also restore the structural integrity of the pipeline system, though still may rely on the host pipe for some support, and also extend the life expectancy of the pipeline, typically by at least 50 years. (EPA, 2010) The technologies are used where the defects are too numerous or severe for repair options to be feasible. As shown in Figures 2 above, rehabilitation technologies have been broken into six major technology categories: (1) Cured-in-Place Pipe (CIPP) Liners, (2) Fold and Form Pipe (FFP) Liners, (3) Grout-in-Place Pipe (GIPP) Liners, (4) Spray-in-Place Pipe (SIPP) Liners, (5) Sliplining, and (6) Modified Sliplining. These technologies are defined briefly in Table 3-3 below.

**Table 3-3. Description of Pipe Replacement Technology Categories**

| Pipe Rehabilitation Technologies | |
|---|---|
| Cured in Place Pipe (CIPP) Liners | Cured in Place Pipe (CIPP) Liners are one of, if not the most widely used form of pipeline rehabilitation for wastewater systems but are seldomly used in drinking water applications. The CIPP Liner tube is impregnated with a liquid thermosetting resin and then pulled or inverted into place within the pipeline and cured with hot water, steam, or UV lights to form a "pipe within a pipe". There are two primary types of CIPP liners used in water systems including (1) Reinforced Hose Liners and (2) Woven Hose Liners. |
| Fold and Form Pipe (FFP) Liners | Fold and Form Pipe (FFP) Liners used in waterlines are made from variations of polyethlyene (PE) material that has been folded into a shape such as "U" or "W" to reduce the cross-sectional area and facilitate insertion into small access pits which have to be excavated for liner insertion. Once in position, the folded pipe liner is expanded with pressurized water or air to fit tightly against the host pipe. The primary form of FFP Liner for waterlines utilizes a fiber reinforced PE liner tube for pipelines up to 12-inches in diameter. |
| Grout in Place Pipe (GIPP) Liners | Grout in Place Pipe (GIPP) Liners are internal liners that do not fit tightly against the host pipe and thus require grouting of the annular space. These liners are typically installed by hand in the form of a flexible panel liner for watermain rehabilitation. Once in place, the liner is held steady with internal reinforcements while the annular space between the host pipe and liner is filled with expanisve grout to create a host pipe-grout-liner system that can withstand internal pressure and external loadings. |
| Spray in Place Pipe (SIPP) Linings | Spray in Place Pipe (SIPP) Linings are cementitous or polymer-based linings that are sprayed onto the pipe wall to provide a semi- or potentially fully- structural rehabilitation solution. Cementitous SIPP Linings are typically braced with steel reinforcing mesh to provide added structural capabilities to the cementitious material. The structural capabilities of polymer linings are increased through the addition of reinforcing fibers and/or through application of the material as a "high-build" lining. |
| Sliplining | Sliplining is accomplished by either pushing or pulling a new, smaller diameter pipe through the deteriorated host pipe. There are two different methods for sliplining: (1) continuous sliplining and (2) segmental sliplining. Where adequate space is available, the new pipe can be pulled into place continuously, or where space is restricted, it can be pulled in one segment at a time. Continuous pull-in sliplining requires the use of pipes with fused, welded, or restrained joints, whereas segmental pushed-into place sliplining can use traditional joint types. Because sliplined pipes do not fit tightly against the host pipe, grouting of the annular space is required for structural stability. |
| Modified Sliplining | Modified sliplining technologies are used to insert a thermoformed pipe within the deteriorated host pipe, making use of various technologies to reduce the diameter of the new pipe to facilitate insertion. Once inside the host pipe, the new pipe is allowed to expand to its original cross section either naturally or through the use of pressurized air/water or a specialized re-rounding plug. Modified sliplining creates a tight-fitting "pipe within a pipe" that, unlike sliplining, does not require grouting of the annular space. There are three primary methods for modified sliplining including: (1) Deformed HDPE, (2) Expand-in-Place PVC, and (3) Radial Reduction. |

### 3.2.3. Water System Pipe Replacement Technologies

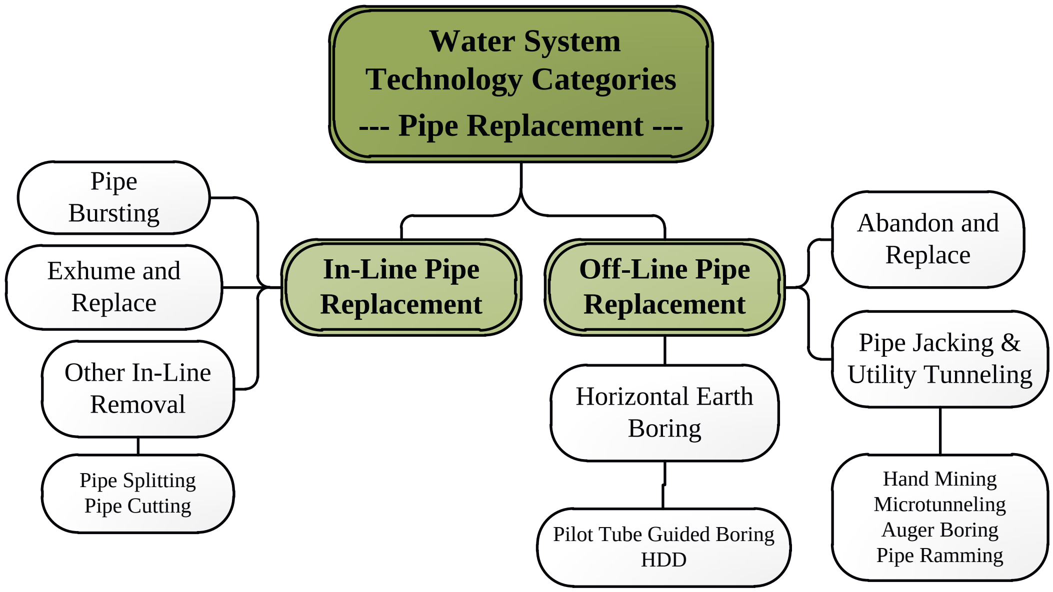


**Figure 3-3. Drinking Water Pipe Replacement Technologies**

Pipeline replacement technologies are used where the existing host pipe is no longer structurally sound enough to support repair or rehabilitation technologies or where the existing host pipe is severely deteriorated or collapsed. The drinking water pipeline replacement technology categories are shown in Figure 3-3 above. These technologies are designed to completely restore or increase capacity and structural integrity of a defective pipeline, and the old pipe is either abandoned in place or removed in some manner from its existing alignment (EPA, 2010). Replacement technologies re-start the life expectancy of the pipeline rather than just extending it with the new life expectancy is heavily dependent on the type of pipe chosen for installation. As shown in Figure 3 above, pipe replacement technologies have been broken into two major technology classes: (1) In-Line Replacement Methods and (2) Off-Line Replacement Methods. These are defined in Table 3-4 below.

**Table 3-4. Description of Pipe Replacement Technology Categories**

| **Pipe Replacement Technologies** | |
|---|---|
| In-Line Pipe Replacement | In-Line Pipe Replacement Technologies are used to remove the existing host pipe and replace it with a new pipe of equal or slightly larger diameter on the same alignment. Methods for in-line pipe replacement of waterlines include pipe bursting or splitting, exhume and replace, and other forms of in-line pipe removal. |
| Off-Line Pipe Replacement | Off-Line Pipe Replacement Technologies are used to install a pipeline through a new soil tunnel, typically parallel to the existing pipe alignment where possible. Methods for off-line pipe replacement include open trench, pipe jacking & utility tunneling, and horizontal earth boring. |

## 3.3. State of the Art Literature Review for Drinking Water Pipeline Renewal Technologies

### 3.3.1. Introduction and Scope of Review

Literature review is a critical first step in understanding the concepts involved in drinking water pipeline renewal engineering and in determining what knowledge already exists. It is important to understand what research has been completed or is underway so that the gaps in existing information can be identified and their significance evaluated. The literature review process began with the identification of sources from which to pull a comprehensive representation of literature types (major industry research reports, journal papers, conference proceedings, relevant theses, etc.). Table 3-5 below outlines the document source locations that were mined for all possible literature, including a description of common literature types found within that source.

**Table 3-5. Locations Mined for Literature Sources**

| Name of Resource | Location (where applicable) | Description of Available Literature |
|---|---|---|
| EPA - National Service Center for Environmental Publications (NSCEP) | http://www.epa.gov/nscep/index.html | This allows the user to search for all research reports or white papers published by the EPA. The searches performed were for broad searches such as "pipe renewal" as well as for specific technologies such as "cured in place pipe liner". |
| Compendex, Inspec, NTIS | | These bibliographic reference databases were searched for relevant sources, primarily for journal papers and conference proceedings, and where online sources were not available, a copy of the literature could usually be obtained through the Virginia Tech Library resources. |
| ASCE Civil Engineering Database (CEDB) | http://cedb.asce.org/ | This database was searched for all relevant ASCE journal papers and conference proceedings. |
| EBSCO Host | http://search.ebscohost.com/ | EBSCOHost was searched for all relevant academic journal articles, conference proceedings, magazine/newspaper articles, and books. Where direct links to articles were not available, a copy of the literature could usually be obtained through the Virginia Tech Library resources. |
| AWWA, NASTT, ISTT, and other prominent industry organization websites | | The websites allowed the location of research reports or white papers published by the the industry association so that a copy of the literature could be requested through the Virginia Tech Library resources. |

There were two basic types of literature that were reviewed: (1) major reports and (2) other literature. Major reports included research reports, workshop proceedings, etc. from key industry organizations and associations such as the EPA, Water Environment Research Foundation (WERF), American Water Works Association (AWWA), etc. Major industry documents/publications tended to focus on long-term research work that was completed or on capturing the main ideas from workshops that drive new research. These documents are important to understanding the gaps in knowledge that exist between literature and practice. Table 3-6 provides a list of the reports identified for use in developing the State of the Art Literature and Practice Reviews for drinking water pipeline renewal in North America.

**Table 3-6. Water Pipeline Renewal Technology Use Research Reports**

| | Title | Publisher | Year | System Type |
|---|---|---|---|---|
| 1 | Buried No Longer: Confronting America's Water Infrastructure Challenge | AWWA | 2012 | Both |
| 2 | Decision Support for Renewal of Wastewater Collection and Water Distribution Systems | EPA | 2011 | Both |
| 3 | Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | EPA | 2011 | Both |
| 4 | State of Technology Review Report for Rehabilitation of Wastewater Collection and Water Distribution Systems | EPA | 2009 | Both |
| 5 | Designing a Framework to Guide Renewal Engineering Decision-Making for Water and Wastewater Pipelines | Virginia Tech | 2010 | Both |
| 6 | Guidelines for Pipe Bursting | Army Corps of Eng. | 2001 | Both |
| 7 | AWWA M28 | AWWA | 2001 | DW |
| 8 | Performance Evaluation of Innovative Water Main Rehabilitation Cured-in-Place Pipe Lining Product in Cleveland, Ohio | EPA | 2012 | DW |
| 9 | Performance Evaluation of Innovative Water Main Rehabilitation Spray-on Lining Product in Somerville, New Jersey | EPA | 2012 | DW |
| 10 | Global Review of Spray-On Structural Lining Technologies | EPA | 2010 | DW |
| 11 | Control and Mitigation of Drinking Water Losses in Distribution Systems | EPA | 2009 | DW |
| 12 | Costs for Water Supply Distribution System Rehabilitation | EPA | 2002 | DW |
| 13 | The Clean Water and Drinking Water Infrastructure Gap Analysis | EPA | 2002 | DW |
| 14 | Multi-Agency Response to a Major Water Pipe Break: A Massachusetts Case Study and Evaluation | AMWA, WRF, WaterISAC | 2011 | DW |
| 15 | Evaulation of Trenchless Renewal Methods for Potable Water Distribution Pipes | UT Arlington | 2010 | DW |
| 16 | Testing & Design Life Modeling of Polyurea Liner for Potable Water Pipes | UT Arlington | 2010 | DW |
| 17 | AC Pipe in North America: Rehabilitation/Replacement Methods and Current Practices | NRC | 2009 | DW |
| 18 | Water Leak Detection and Repair Program | EPD | 2007 | DW |
| 19 | Review of Test Data and Field Trials for the MainSaver Process | TTC | 2007 | DW |
| 20 | Demonstration of Innovative Water Main Renewal Techniques | AWWA | 1999 | DW |

Essentially any type of literature reviewed that was not a major industry association/organization report or research report fell in the category of "other literature sources". The most common forms of other literature sources reviewed were journal papers and conference proceedings. The primary sources considered in this state of the art literature review for pipeline renewal technology use include those that were focused on providing actual technology use information or that covered examples of technology uses in case studies.

### 3.3.2. Intent and Scope of Review

This State of the Art Practice Review will seek to define the true state of the industry with regards to drinking water pipeline renewal technology use. The content is based on the experiences of utilities captured through a series of technology use case studies that were developed as well as through interviews with key utility personnel. The objective of the review is to determine the following:

(1) Which technologies are being implemented by utilities and how often;
(2) How the technologies are being used in utility systems;
(3) General benefits/limitations of the technologies; and
(4) Primary cost drivers for technology applications.

This Review will provide the above determinations for utilities in North America as a whole and defines each in terms of the major technology categories defined above in the "*Pipeline Renewal Engineering Technology Background Information Section*" of this paper. The broad technology categories and classifications have been carefully selected to encompass the more specific technologies and products available in an effort to provide information on as many different technologies as possible.

### 3.3.3. Drinking Water Pipe Repair Technologies

Pipe repair is common practice for every infrastructure owner, and several technologies are typically kept on-hand by utility maintenance and repair crews to handle pipe repairs. One of the major issues encountered in waterlines is corrosion, both internal and external, which can lead to defects such as circumferential cracking and joint leaks. If the leaks or cracks that develop in the pipe walls or at joints are not sealed, water will be forced out into the surrounding soil and eventually lead to bedding washout and subsequent failure. (Dr. Ray Sterling, State of Technology Review Report on Rehabilitation of Wastewater Collection and Water Distribution Systems, May 2009)

Where defects are localized, repair technologies can be installed to help the pipeline live out its design life at significantly reducing costs compared to replacement of the entire pipe segment. Corrosion and leakage are reported to cause 61% of failures in ferrous force mains and 30% of failures in non-ferrous force mains (Robert Morrison, March 2010), highlighting the importance of pipeline repair since these failures could be prevented with through pipe repairs if located early on. The major industry reports considered related to drinking water pipe repair technology usage are shown in Table 3-7 below which also note the individual technology types covered within each report. Examples of literature sources for each technology type are provided in the sections below which discuss the state of the technology for drinking water pipeline repairs.

**Table 3-7. Technologies Covered in Drinking Water Pipe Repair Technology Reports**

| Title | Water Pipeline Repair Technologies | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pipe Joint & Leak Seals | | | Pipe Point Repair | | Pipe Coatings | |
| | Internal Pipe Sleeves | Grouting | Excavate & Repair | Excavate & Repair | Internal Repair Methods | Cementitious | Polymer Based |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | X | | X | X | X | X | X |
| State of Technology Report for Force Main Rehabilitation | X | | X | X | X | | X |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | | | | | | X | X |
| Costs for Water Supply Distribution System Rehabilitation | | | | | | X | X |
| Rehabilitation of Water Mains - Manual of Water Supply Practices, M28 | X | | | | | X | X |
| Global Review of Spray-On Structural Lining Technologies | | | | | | X | X |

## Pipe Joint & Leak Seal Technologies

Joints are the weakest point of a pipeline, with their performance being dependent on several different factors such as the health of the pipeline itself, seal integrity, internal/external pressures and loadings, water chemistry, groundwater, and the characteristics of the surrounding soils (Claudio Dittel, 2008). Examples of pipe joint and leak seal technology usage from literature are shown in Figure 3-4 below. It is used in the installation of other repair methods such as an internal sleeve where it is covered by a material that with more ability to withstand pressure and that is NSF 61 approved if the waterline is carrying potable water.

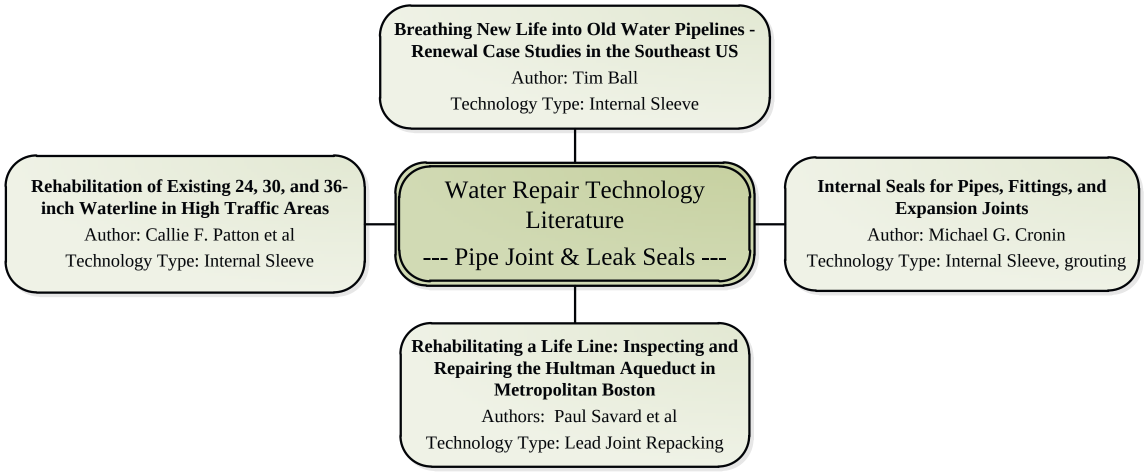


**Figure 3-4. Pipe Joint & Leak Seal Technology Application Literature Sources**

Based on literature, one of the most common methods for repair of joint defects that are not severely impacting the structural integrity of the pipeline are internal mechanical joint sleeves. The sleeves can be applied to pipelines with diameters greater than 16-inches and up to 216-inches, with larger sizes available on a case by case basis. Most examples of use in literature were for large diameter pipelines. Essentially, the technology consists of an elastomeric sleeve which is held in place by metal retaining bands, usually steel alloy. There are several issues to consider with regards to mechanical joint sleeves, the first of which is the requirement for man-entry. Also, since excavation is required more often than not because there are few existing access points on water main through which to gain entry into the pipeline. The sleeves have been used for leaking joints in potable pipelines as well as in other clean-water applications such as for the repair of a 120-inch carbon steel circulating water pipeline with expansion joints that carried raw water from a nearby river to a power plant (Croning, 2002).

Another application for the joint sleeves is the repair of bell and spigot joints which are very common in waterlines. The City of Houston used internal mechanical sleeves to repair cast iron water mains, while Cobb County Marietta Water Authority used them to repair PCCP water mains. Both pipe types had bell and spigot type joints. Additionally, the joint sleeves are used in situations where impacts to commercial and/or residential traffic as well as shut-down time are important considerations; internal sleeves can be installed quickly, reducing installation impacts for both issues. The City of Houston installations were on 24-, 30-, and 36-inch pipelines in areas where impacts to commercial and residential traffic were important factors (Callie F. Patton, 2006). Cobb County needed to minimize shut down time because the PCCP pipeline to be repaired was an 84-inch pipe at the treatment plant north of Atlanta with a circumferential that spanned the crown of the pipeline, extending down through both springlines (Ball, 2011).

A second internal option for repair of leaking bell and spigot joints is joint repacking. Traditional joints are packed with a water activated resin soaked fiber such as Oakum that is packed into the joint, activated so that it expands to completely seal the joint, made flush with the inside pipe surface, and covered with an appropriate mortar or grout which, if being used for a potable waterline, must be NSF 61 approved for such use (Prime Resins, 2010). Before making the repair, the mortar lining is removed from the pipe to expose the leaking gasket, and it was then repacked. The Massachusetts Water Resources Authority (MWRA) used this method in the repair of an 11.5-foot aqueduct after determining that it was more cost effective than other methods of repair such as point repairs using welded steel liner plates (Paul Sevard, 2011).

The oldest method for repairing joints requires local excavations at the site of the defect. If the joint condition is such that the structural integrity is compromised, the joint may be replaced completely. If the joint is sound enough for repair, the most common technology for excavated repairs is a full circumferential repair clamp installed to seal the leaking joint. There are specially designed repair clamps for waterlines that fit the traditional bell and spigot style joint. Prior to installation of the leak clamp, the joint of the pipe is often re-caulked to repair the seal as was typical practice in the City of Houston until the switch to internal methods was made (Callie F. Patton, 2006). Clamps are traditionally available in larger sizes for cast iron pipes than for PVC.

**Pipe Point Repair Technologies**

According to literature sources, it seems that most of the water pipeline point repairs are completed with either excavate and repair methods or with internal pipe wraps. Excavate and repair methods include replacement of short segments of the pipe, the installation of an external repair clamp, or the wrapping of the pipe exterior with a fiber-reinforced pipe wrap. Figure 3-5 provides examples of literature that discuss point repair technology applications.

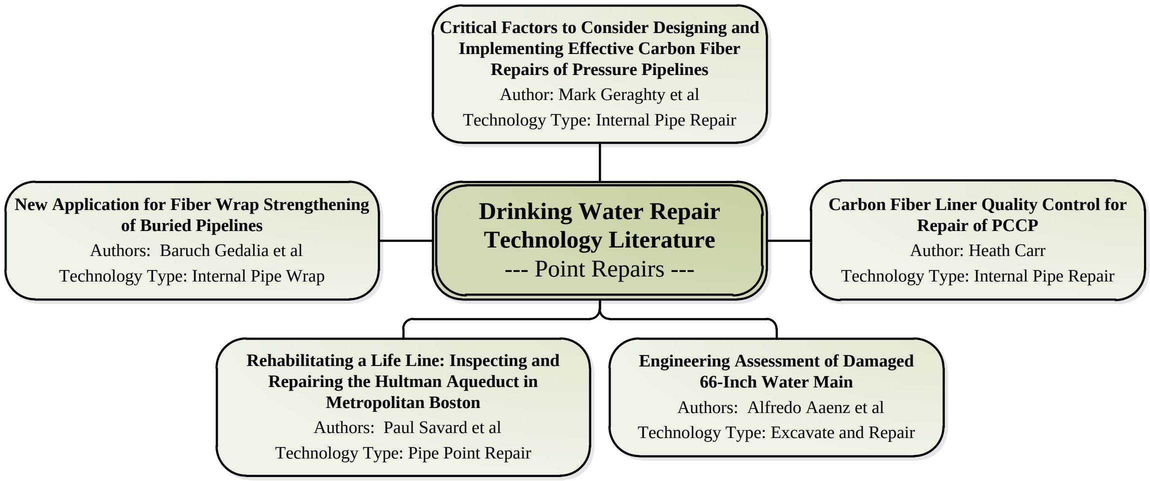


**Figure 3-5. Pipe Point Repair Technology Use Literature Sources**

Traditionally, excavate and repair techniques were most common for water main repair, and they are still standard protocol in the event of emergency failures where short segments of pipeline are often replaced. Where short segments of pipe need to be replaced, it is necessary to consider the potential need for special adapters or splicing mechanisms to join the new pipe segment to the original host pipe segments (Robert Morrison, March 2010). Full circumferential repair clamps can be used to seal leaks where the pipe wall is still structurally sound. Pipe repair clamps work by locking a flexible rubber gasket tightly against the location of the leak, thereby sealing it.

Another form of excavated point repair involves the application of a non-shrink cement grout that is allowed to harden on the exterior surface of the pipe so that it extends 1-foot past the defect in all directions. The grout is then covered with a Styrofoam material and the trench backfilled with approved cement-stabilized sand material. This method is discussed in a case study for the City of Houston for the repair of a 66-inch water main that required further rehabilitation but needed immediate attention (Alfredo Saenz, 2011).

A commonly implemented technology for point repair of waterlines is fiber-reinforced pipe wraps. These wraps can be applied to either the internal or exterior surface of the pipeline and are therefore both an internal and excavate and repair technology. Pipe wraps are particularly common for repair of PCCP water mains where the number of broken wires creates the need for structural repair. Howard County, MD used the fiber reinforced polymer (FRP) wrap to structurally repair a 66-inch PCCP transmission main where the construction of a railroad could not begin until the repairs were made (Mark Geraghty, 2010). Geraghty also provides an example for emergency repair in San Diego, CA for two large diameter pipelines, 84-inch and 96-inch, with high working pressures and strict limits on shut down time.

The Metropolitan Water District of Southern California (MWDSC) applied the FRP wrap to defects in a 201-inch feeder line that were 1,200 feet and 2,400 feet away from the closest access points. The feeder line carried water to surrounding districts, so shut down time needed to be minimized (Carr, 2007). Carr provides a great deal of information outlining the importance and steps involved in proper installation, highlighting the importance of quality control procedures and providing a number of reference documents for quality control of FRP wraps. Installation procedures are stressed in other literature sources as well, including the paper by Mark Geraghty that was discussed above.

The literature suggests that FRP wraps are particularly useful for PCCP pressure pipe applications with large diameter pipes that require structural reinforcement. When a 66-inch waterline beneath a major interstate ruptured in Denver, CO, FRP wrap was used to reinforce the newly installed pipe because the pipe alone did not have an adequate pressure rating. Layers of carbon fiber and glass fiber composites were used, with the glass fiber reinforced wrap required to prevent galvanic corrosion between the steel and carbon fiber material (Baruch Gedalia, 2010).

**Pipe Coating Technologies**

The primary coating for water mains in the United States is cement mortar lining which is the only coating technology with an available specification from AWWA (Dr. Ray Sterling, State of Technology Review Report on Rehabilitation of Wastewater Collection and Water Distribution Systems, May 2009). Besides cement mortar, epoxy is the only other coating material addressed by the AWWA Manual M28 for Rehabilitation of Water Mains. Examples of literature that provide examples of pipe coating applications are shown in Figure 3-6 below.

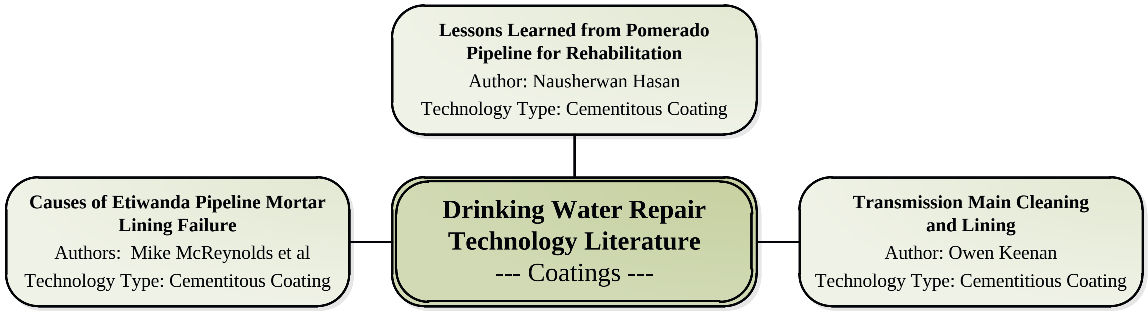


**Figure 3-6. Pipe Point Repair Technology Use Literature Sources**

Cement mortar coatings are used to maintain or slightly improve pipeline capacity by providing a smooth interior surface and preventing the development of tuberculation (Keenan, 2006). In his paper, Keenan provides examples of three different cases where cement mortar lining is applied to 30- and 36-inch cast iron water mains. The benefits were increased residual pressure, increased capacity, and smoother internal pipe surface, but the author also notes that excavations are required at all service connections and appurtenances, increasing shut down time but still significantly reducing costs compared to replacement. In much the same way, the City of San Diego (Hasan, 2008) used cement mortar to coat a new pipe after rehabilitation of a PCCP water main with steel liners and faced time constraints paired with restrictions to night work only due to the location of the pipeline.

Cement mortar coatings are prone to early failure if design and installation are not carried out correctly. The Metropolitan Water District (MWD) outside of Los Angeles experienced premature failure of a 144-inch, 5.3 mile long welded steel feeder pipe that was lined with a ¾-inch thick layer of cement mortar in the early 1990's. Lining failure in that case was extreme, and long sections of the pipeline had delaminated mortar or was missing the mortar altogether. Constant pressure fluctuations and the size of the pipe were thought to be causes of the failure, and in hindsight, a flexible lining would have been more appropriate for a pipeline with such variations in stress levels. (Mike McReynolds, 2010) The author provides pictorial examples of the lining failures and as well as an example from LADWP and Saudi Arabia where linings failed prematurely due to temperature fluctuations and corrosion caused by high Chlorine-ion content in the salt water it carried, respectively. These examples were discovered by MWD during their research into other utility experiences with similar cement mortar failures.

The use of spray on polymer-based coatings is a common practice in other countries such as the United Kingdom but is just beginning to catch on in the United States. This could be a potential reason for the lack of available literature on polymer-based coating applications. Epoxy coatings are somewhat common for bridging small cracks and gaps as well as for corrosion control, but they are not ideal for high-build applications due to their long curing time.

### 3.3.4. Water Pipe Rehabilitation Technology Usage

The technologies available for waterline renewal continue to advance, and this paired with other benefits such as decreased social and environmental disruption and reduced project costs have led to steadily increasing sources for literature on rehabilitation technology uses. Table 3-8 below provides a list of the major research reports that provide information on rehabilitation technology usage, noting the technologies addressed within.

## Table 3-8. Technologies Covered in Drinking Water Pipe Rehabilitation Technology Reports

| Title | Drinking Water Pipeline Rehabilitation Technologies | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CIPP Liners | | | FFP Liners | | GIPP Liners | | | SIPP Liners | | Sliplining | | Modified Sliplining | | |
| | Felt Hose Liners | Woven Hose Liners | Fiber-Reinforced Hose Liners | Thermoformed PVC Liners | Deform/Reform PE Liners | Spiral Wound Liners | Tube Liners | Panel Liners | Cementitious | Polymer Based | Continuous | Segmental | Deformed HDPE | Radial Reduction | Expand in Place PVC |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| State of Technology Report for Force Main Rehabilitation | X | X | X | X | X | X | | | X | X | X | X | X | | X |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | | | | | | | | X | X | X | | | | | |
| Costs for Water Supply Distribution System Rehabilitation | X | X | X | X | X | | | | | | X | X | X | X | |
| Demonstration of Innovative Water Main Renewal Techniques | | X | X | | | | | | | | | | | X | |
| Rehabilitation of Water Mains - Manual of Water Supply Practices, M28 | X | X | X | X | X | | | | X | X | X | X | X | X | X |
| Global Review of Spray-On Structural Lining Technologies | | | | | | | | | X | X | | | | | |
| Evaluation of Trenchless Renewal Methods for Potable Water Distribution Pipes | X | X | X | X | X | | | | X | X | X | X | X | X | |
| TTC Evaluation Report: Review of Test Data and Field Trials for the MainSaver Process | | | | | | | X | | | | | | | | |

## Cured in Place Pipe (CIPP) Liner Technology Usage

CIPP Liners are not as common for drinking water applications as for wastewater applications. A traditional CIPP liner utilizes a felt tube impregnated with polyester or styrene resin but is not used for waterline rehabilitation because it does not have an adequate pressure rating, and styrene resins are not approved for use in potable water applications. The two common types of CIPP Liner for water pipe applications are woven hose liners and fiber-reinforced hose liners. It was surprisingly difficult to find publications documenting the use of these technologies within utilities in North America which is an indication of the innovative nature of the technologies. Examples for water pipe CIPP installations are shown in Figure 3-7 below.

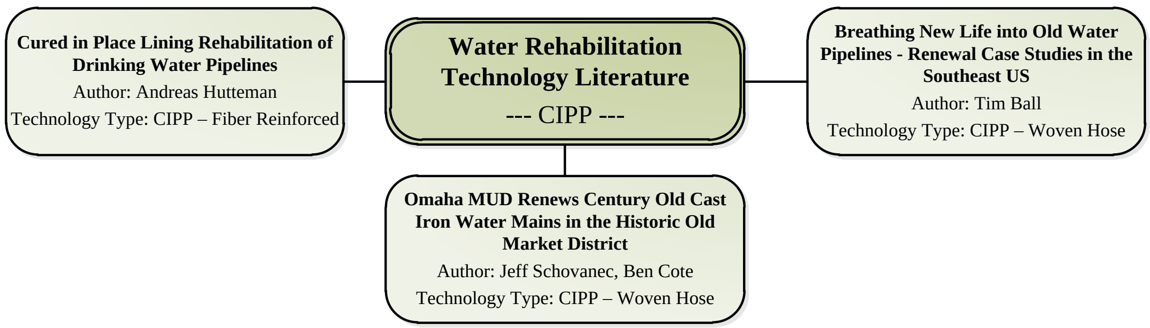


**Figure 3-7. Pipe Rehabilitation Technology Use Literature Sources**

CIPP liners for waterlines are limited to use in pipes up to 60-inches in diameter, and whereas it is a completely trenchless technology for sewer applications, it requires at least two excavations to provide access to a waterline (Behnam Hashemi, 2011). The technologies must also obtain the NSF 61 certification for materials such as the resin that would potentially come in contact with the water. All of these factors make CIPP Liners less common for waterline than for sewerline applications.

Charleston Water System (CWS) utilized a woven hose liner to structurally rehabilitate an 8-inch cast iron and ductile iron water main, with a portion of the cast iron pipe having been previously lined with cement mortar. The location of the project was in a somewhat remote location where the installation would have little to no impact on the public, and there were no active service connections on the portion of the main to be lined. (Ball, 2011) These two factors make the location great for a pilot project, but realistically, these are two very important factors to consider when choosing a technology.

A more accurate reflection of technology application was documented by the City of Omaha who utilized a woven hose CIPP Liner to rehabilitate portions of a 10-inch and a 12-inch pipeline, both of which were located in an old historic part of the City. The project dealt with a number of individual lining segments, multiple excavations, active and inactive service connections, appurtenance replacement, and setup of a temporary bypass system. (Jeff Schovanec, 2011) This paper presents considerations for installation costs as well as comparisons to traditional open trench replacement.

Fiber-reinforced CIPP Lining technology was used in the Czech Republic to rehabilitate various lengths of pipeline in rough terrain and with bends ranging from 11° to 30° (Huttermann, February 2008). All examples of use for use of this type of liner were from other Countries, suggesting that it has not yet caught on in the United States.

## Fold and Form Pipe (FFP) Liner Technology Usage

It was difficult to locate literature that documented the use of FFP Liners in the United States, though there are examples of use in foreign countries such as the United Kingdom. One example of a FFP Liner installation in the U.S. provided in the document listed in Figure 3-8 below.

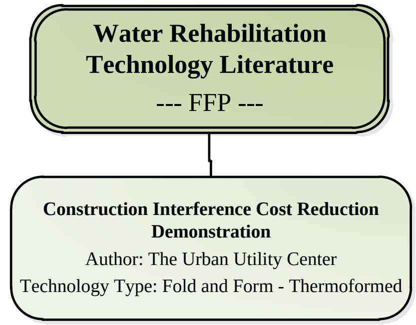


**Figure 3-8. Pipe Rehabilitation Technology Use – FFP Liner Literature Sources**

In the United Kingdom, the use of fold and form thermoformed liners is common for water main and other pressurized pipe system rehabilitation, but not in the U.S. The St. Louis County Water Company (SLCWC) used a FFP Liner to rehabilitate three 6-inch distribution mains beneath high-traffic railroad tracks (Urban Utility Center, 2005). This was, however, only a pilot of the technology for the water company, highlighting the infant state of this rehabilitation method in the U.S.

## Grout-in-Place Pipe (GIPP) Liner Technology Usage

Most GIPP Liner technologies available, like other rehabilitation technologies, are more frequently used in wastewater system applications, but there were multiple examples of steel GIPP liners, especially for large diameter PCCP transmission mains. The literatures sources shown in Figure 3-9 provide good examples of the liner installations and design/construction considerations.

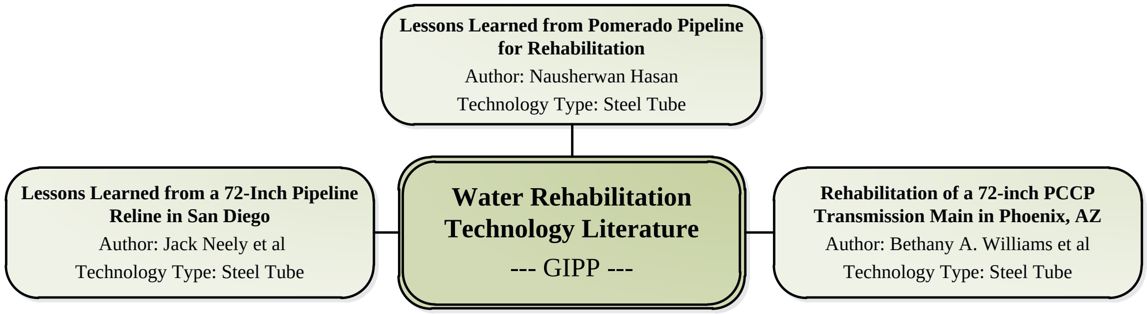


**Figure 3-9. Pipe Rehabilitation Technology Use – GIPP Liner Literature Sources**

The City of Phoenix used a "solid can" type steel liner to rehabilitate a 72-inch diameter PCCP transmission main which involved the insertion of a steel liner that was banded to prevent the liner plates from expanding until they were in within the host pipe (Bethany Williams, 2006). Grout was injected around the steel liner once it was expanded to fill the annular space and anchor the liner to the host pipe. A thin coating of mortar was then applied to protect the steel material from corrosion. The San Diego County Water Authority used the same method to rehabilitate two segments of a pipeline, one 69-inches and the other 84-inches in diameter; the resulting loss in internal diameter totaled 3-inches for each segment. (Hasan, 2008). The utility also used it to rehabilitate a 72-inch PCCP transmission main, though the focus of this paper was on the design issues of project related to the site location environmental sensitivities and close proximity to residential neighborhoods rather than the construction phase of the project (Jack Neely, 2009).

### Sprayed-in-Place Pipe (SIPP) Liner Technology Usage

Though cementitious and polymer based materials have been used for years as non-structural coating technologies, SIPP Liners are a relatively new technology that uses the same materials to achieve semi- or fully-structural rehabilitation solutions. The technology is still innovative, but two examples of use are provided in the literature sources in Figure 3-10.

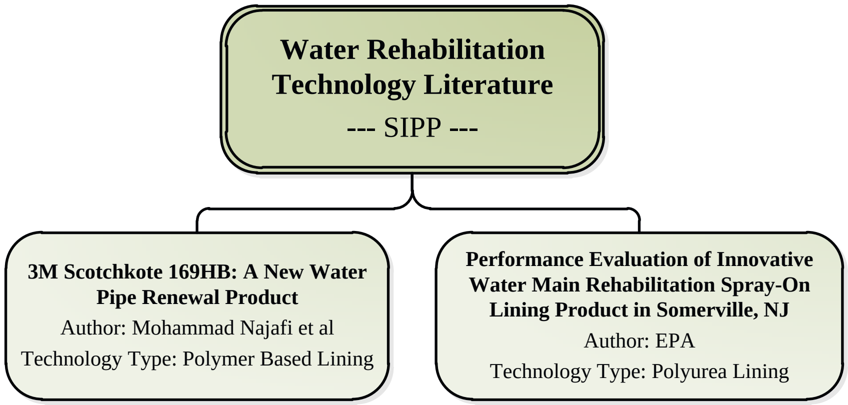


**Figure 3-10. Pipe Rehabilitation Technology Use – SIPP Liner Literature Sources**

There are several literature sources available that provide lab testing results for SIPP Liners such as Pipeline Rehabilitation with Fiber-Reinforced Mortar Lining by G.K. Luk for cementitious linings and Testing and Evaluation of a New Potable Water Pipe Renewal Product by Trupti Kulkarni et al. and the Water Research Foundation report titled Global Review of Spray-On Structural Lining Technologies for polymer based linings. The EPA performed a pilot project in Somerville, NJ to test the installation of a high-build polymer based lining as a semi-structural solution since the host pipe still needs to have some degree of structural soundness. This application failed, however, leading to the conclusion that high-build lining materials still require some research before they will be ready for a full integration into the market.

### Modified Sliplining Technology Usage

Modified sliplining can be used in water pipe rehabilitation, with examples of use demonstrated by the literature shown in Figure 3-11. As with so many other rehabilitation technologies for waterlines, other countries such as Australia and the UK much more experience with this technology.

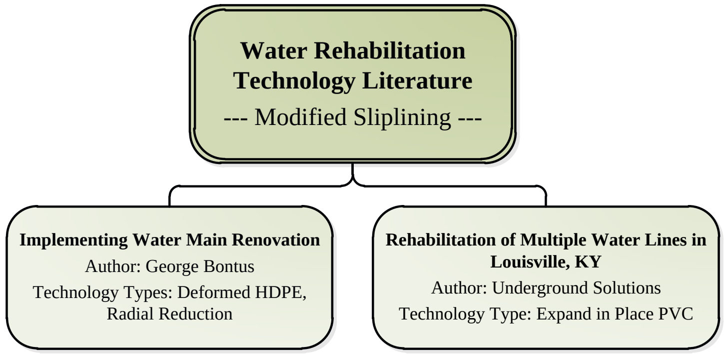


**Figure 3-11. Pipe Rehabilitation Technology Use – Modified Sliplining Literature Sources**

Louisville Water used an expand-in-place PVC technology to rehabilitate approximately 2,000 LF of water mains with diameters ranging from 6- to 12-inches at several locations throughout their system (Underground Solutions, 2012). The City of Amarillo, TX used a radial reduction technology to provide a class IV, fully structural rehabilitation solution (Matt Wassam, 2011). Perhaps the best example of radial reduction found in literature was by the City of Calgary who used modified sliplining to rehabilitate a 12-inch water main that ran through residential areas and where open cut would have had too great an impact on matured spruce trees (Bontus, 2008).

### Sliplining Technology Usage

Sliplining is a well-known method for rehabilitation, but it is not ideal in many cases because of the associated loss in diameter. Most of the major technology reports address sliplining in a general sense, though nearly all of the examples in literature were for large diameter rehabilitation. Figure 3-12 lists three case studies found in literature that document the use of sliplining.

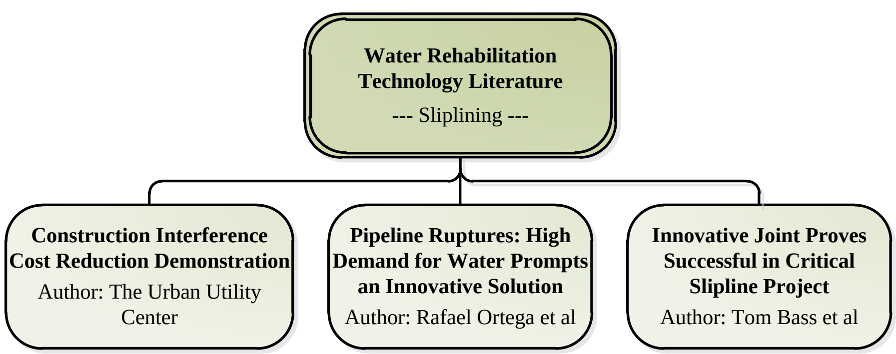


**Figure 3-12. Pipe Rehabilitation Technology Use – Modified Sliplining Literature Sources**

Halifax Water in Nova Scotia used sliplining to rehabilitate a 48-inch PCCP transmission main with a spirally welded steel pipe that utilized a unique O-ring rubber-gasket joint (Tom Bass, 2011), and in Ottawa, a 914-mm cast iron water main was sliplined with an 840-mm HDPE pipe (Urban Utility Center, 2005). This paper focused on the benefits of sliplining in an urban area where the utility could not afford to lose capacity.

### 3.3.5. Water Pipe Replacement Technology Usage

Pipe replacement is the most common form of renewal, with dig and replace methods being the preferred alternative for water utilities across the United States. Innovative replacement technologies have allowed the installation of waterlines in otherwise challenging locations such as beneath wetlands or surface structures. Table 3-9 below provides a list of the major research reports that provide information on replacement technology usage.

**Table 3-9. Technologies Covered in Drinking Water Pipe Replacement Technology Reports**

| Title | Water Pipeline Replacement | | | | | | |
|---|---|---|---|---|---|---|---|
| | In-Line Pipe Replacement | | | | Off-Line Pipe Replacement | | |
| | Pipe Bursting | Pipe Reaming | Exhume & Replace | Other In-Line Pipe Removal | Pipe Jacking & Utility Tunneling | Horizontal Earth Boring | Abandon & Replace |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | X | X | X | X | X | X | |
| State of Technology Report for Force Main Rehabilitation | X | X | X | | X | X | X |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | X | | | | | | |
| Costs for Water Supply Distribution System Rehabilitation | X | | | | X | X | X |
| Demonstration of Innovative Water Main Renewal Techniques | X | | | | | | |

## In-Line Pipe Replacement Technology Usage

In-line pipe replacement is an effective means of replacement when the density of underground infrastructure makes using the existing soil tunnel most desirable, but there are other factors to consider as well such as the number of service connections and temporary bypass requirements. Figure 3-13 below lists three papers that provide examples of use for multiple in-line replacement technologies.

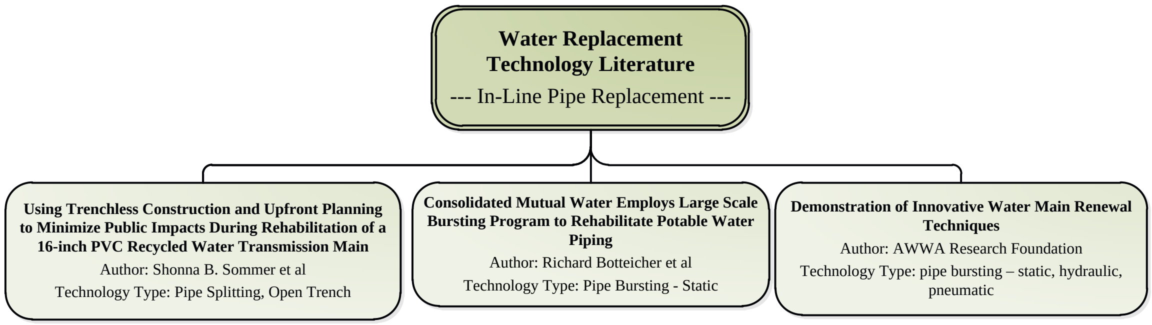


**Figure 3-13. Pipe Replacement Technology Use – In-Line Replacement Examples**

There are two heavily cited forms of waterline replacement, open trench and pipe bursting. Open trench methods are so common-place now that the methodology is not often included in case study papers. Instead, trenchless technologies such as pipe bursting are used and then compared to the costs or impacts of open trench. (Behnam Hashemi, 2011) (Richard (Bo) Botteicher, 2011)

In other cases, open trench is used to supplement trenchless methods. The Calleguas Municipal Water District in California used pipe splitting to replace a 16-inch PVC recycled water transmission main that had failed seven times in the same area within 12 years (Shonna B. Sommer, 2009). One of the limitations of trenchless methods is that open-cutting is still required at every connection, valve, etc. In this case, pipe splitting was the primary technology used in the project, but open trench was used on segments of the pipeline where the number of connections or type of connection (tee connection in a busy intersection for example) made pipe splitting uneconomical.

Because of the popularity that pipe bursting in particular has gained, utilities are in some cases beginning to start their own "in-house" replacement crews that are certified for pipe bursting installation procedures such as joint fusion for thermoplastic pipes. Consolidated Mutual Water Company outside of Denver did just this, getting their technicians certified for fusion of fusible PVC joints and proper installation techniques so that all pipe bursting could be done through an in-house program (Richard (Bo) Botteicher, 2011) . This reduced costs by eliminating the bid process for all bursting projects as well as costs associated with third parties such as contractors or consultants.

Two, more specific pipe bursting projects were completed by the cities of Chicago and Houston. In Chicago, static pipe bursting was used to replace a 6-inch cast iron water main with an 8-inch ductile iron, bell-less joint pipe. Houston used hydraulic pipe bursting to replace a 6-inch cast iron pipe with a 6-

inch HDPE pipe. The City also used an 8-inch HDPE sleeve to protect the 6-inch HDPE pipe because of the fear that settled pieces of cast iron left over from the burst would damage the new HDPE material in the future. Houston also completed a pneumatic pipe bursting project to replace a 6-inch asbestos cement pipe with a 6-inch HDPE pipe. (Arun K. Deb, 1999)

**Off-Line Pipe Replacement Technology Usage**

Off-line pipe replacement technologies include those used for open trench projects, pipe jacking & utility tunneling, and horizontal earth boring. All of these are common practices for pipe installation, and there is a significant quantity of information available for these technologies. Figure 3-14 lists examples of literature that provide details for off-line replacement technology usage.

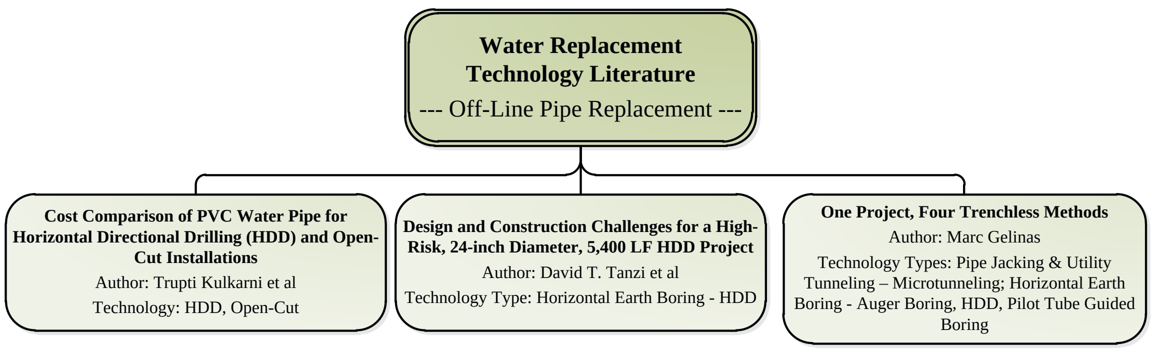


**Figure 3-14. Pipe Replacement Technology Use – Off-Line Replacement Examples**

Many replacement projects are completed in conjunction with other forms of renewal. In the Alameda County Water District service area in California, a pipe replacement project had a number of difficult crossings. The District used Microtunneling beneath the interstate; Auger Bore and Jack Tunneling beneath the aqueduct; Horizontal Directional Drilling (HDD) beneath the major arterial roadway; and Pilot Tube Guided Boring beneath a second major arterial roadway. (Marc Gelinas, 2010) This case study is useful in explaining why technologies were chosen as well as how they were used.

The City of Athens, Texas used HDD to replace a cast iron pipe with a new 6-inch restrained joint PVC pipe on a parallel alignment, while the City of Eastland, TX used HDD to replace an undersized 2-inch cast iron waterline with a 6-inch PVC pipe. Clay County, FL did essentially the same thing, replacing a 2-inch cast iron pipe with a 4-inch PVC pipe. (Trupti Kulkarni, 2011) This paper also discusses the cost per linear foot of open-trench versus HDD which is an important determinant in technology selection. All of these case studies document the transition from more traditional cast iron pipe to the more recent favorite, plastic. Middlesex Water Company also made the switch, using HDD to replace a 24-inch cast iron pipe with a 24-inch Fusible PVC (David J. Tanzi, 2011)

## 3.4. State of the Art Practice Review for Drinking Water Pipeline System Renewal Technologies

### 3.4.1. Introduction

There is often an apparent disconnect between the state of the industry as portrayed by academia through research reports and conference/journal publications and the true state of the industry in the eyes of the actual infrastructure owners. Industry conferences and journals are excellent methods for academics and technology providers to showcase innovative technologies and advanced technology applications, and while these outlets are useful for raising awareness of solutions available to solve pipeline system problems, they capture only snapshots of the complete picture.

In the past, academics, industry professionals, and infrastructure owners alike have been able to easily collect information from existing literature sources on the vast array of products available in the market today, but the literature is not necessarily an accurate representation of the technologies most commonly used in practice. Technology providers are also more than willing to supply information on their technologies, but this information only provides a picture of what is available to infrastructure owners. In reality, most of the water and wastewater utilities in the United States only utilize a handful of the technologies available to them.

### 3.4.2. Intent and Scope of Review

This State of the Art Practice Review will seek to define the true state of the industry with regards to drinking water pipeline renewal technology use. The content is based on the experiences of utilities captured through a series of technology use case studies that were developed as well as through interviews with key utility personnel. The objective of the review is to determine the following:

1. Which technologies are being implemented by utilities and how often;
2. How the technologies are being used by utilities in their systems;
3. General benefits and limitations of the technologies; and
4. Primary cost drivers for technology applications.

This Review will provide the above determinations for utilities in the United States as a whole and defines each in terms of the drinking water pipeline renewal technologies listed above in the "Background Information Section" of this thesis. There are an incalculable number of technologies available for drinking water pipeline renewal and even more products that make use of different combinations of technologies, making it impossible to address every technology available in the industry today. The broad technology classifications and types have been carefully selected to encompass the more specific technologies and products available in an effort to provide useful information on as many different technologies as possible.

### 3.4.3. Approach

Drinking water utility participation was essential to a thorough investigation of the true state of the industry. Utilities all across the nation and even were contacted to participate in the initiative to document overall utility experiences with drinking water pipeline renewal technologies, and 17 full and 5 abbreviated case studies were developed to capture as complete a picture as possible. At the end of the development period for full case studies which require a great deal of data and time to develop, abbreviated case studies were developed that captured only the basic information of technology use including, but not limited to, information such as technology type, product name, project location and conditions, project length, pipe types and materials involved, and benefits/limitations for use.

The objective of case study development was to provide a clear view of the state of the drinking water industry related to pipeline renewal technology use, so it was desirable to cover an even distribution of technology types as well as an even geographic distribution of utilities. Table 3-10 shows the distribution of renewal types covered by the case studies. Figure 3-15 below shows the name and geographic location of utilities for which case studies were developed, with blue dots denoting locations for which full case studies were developed and red pins denoting locations where abbreviated case studies were developed. Upon review of the case study by the utility involved and an expert on the topic, case studies will be published in the new Water Infrastructure Database, WATER*i*D (www.waterid.org). Case studies for technology uses across the nation were able to be captured, with the exception of EPA Region 7 which includes Kansas, Missouri, Iowa and Nebraska. While initial meetings were held with people in that region, either timing was not appropriate for them to participate or there were critical issues with the transfer of private data.

**Table 3-10. Water Technology Case Study List and Distribution**

| Full Case Studies | | Abbrev. Case Studies | |
|---|---|---|---|
| Repair | 3 | Repair | 1 |
| Rehabilitation | 5 | Rehabilitation | 4 |
| Replacement | 9 | Replacement | 0 |
| **Total** | **17** | **Total** | **5** |


**Figure 3-15. Geographic Distribution of Case Studies**

### 3.4.4. Water System Pipe Repair Technology Use in Practice

Three full case studies and one abbreviated case study were developed for pipe repair technologies. However, most of the project included the use of multiple technology types and will appear below more than once as the case studies are discussed below by technology type.

#### Pipe Joint and Leak Seal Technologies

There was one case study that dealt with pipe joint and leak seal technologies as shown in Figure 3-16 below, but it is worth noting that the joint sealing method was not the primary focus of the case study.

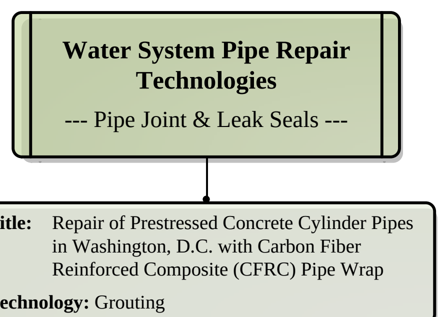


**Figure 3-16. Water System Repair Technology Case Studies – Pipe Joint and Leak Seals**

In order to prepare the interior of the pipeline for the application of the internal pipe wrap, there were several defects that had to be addressed. If the surface was not properly repaired, the pipe wrap would be unable to properly adhere to the pipe wall. Internal joint parging, patching of the outer coating, or patching of the internal lining were performed with a high-strength, polymer modified cementitious mortar.

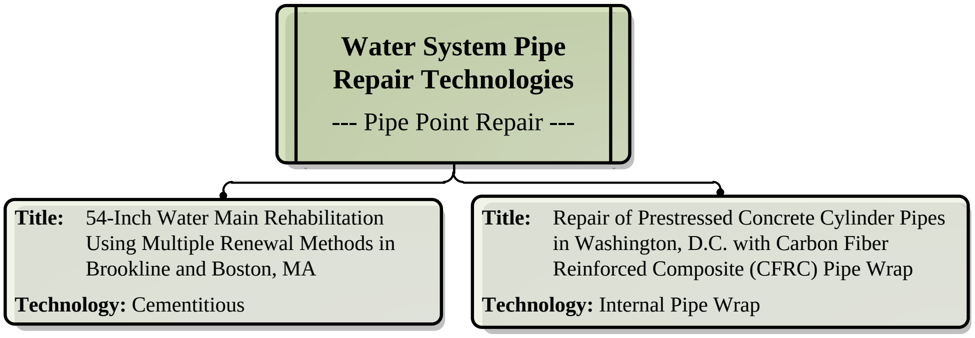


**Figure 3-17. Water System Repair Technology Case Studies – Pipe Point Repairs**

### Pipe Point Repair Technologies

One case study dealing with pipe point repair technologies was developed, as shown in Figure 3-17 above.

The Washington Suburban Sanitary Commission (WSSC) used an internal pipe wrap that was adhered to the internal pipe surface and did not, therefore, require grouting. Two different types of pipe wrap were used: a glass-fiber reinforced polymer (GFRP) wrap and a carbon-fiber reinforced polymer (CFRP) wrap. One layer of the GFRP wrap was applied in a longitudinal direction, followed by 2-6 layers of hoop CFRP wrap depending on the amount of structural support the defect required for repair.

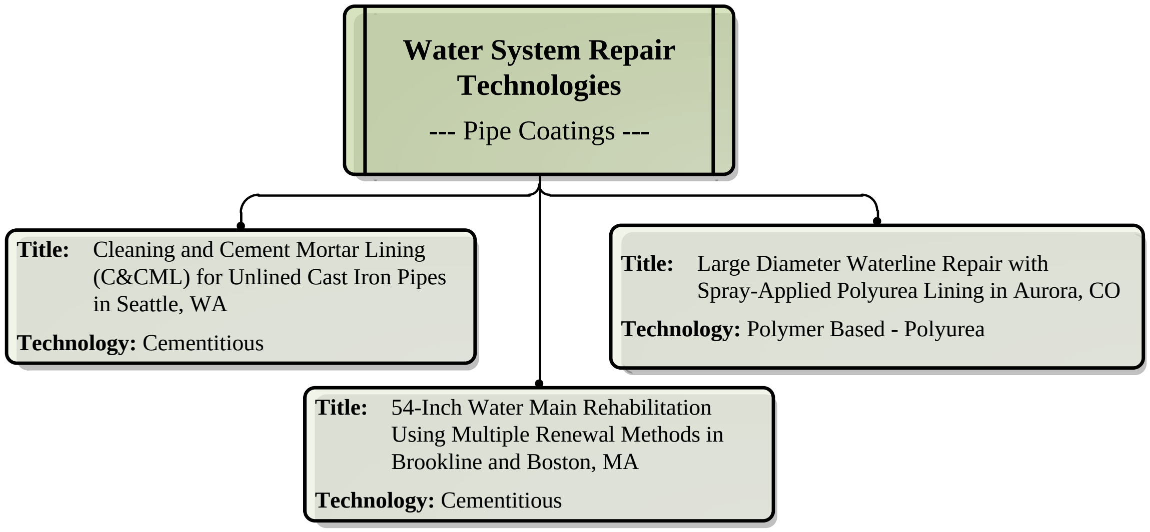


**Figure 3-18. Water System Repair Technology Case Studies – Pipe Coatings**

### Pipe Coating Technologies

There were three case studies developed that dealt with non-structural pipe coating technologies, and these are shown in Figure 3-18 above.

As a general rule, there were many more utilities that used cementitious linings because of the transmission main cleaning and cement mortar lining (C&CML) programs that were in place. Seattle Public Utilities began this program in June of 2003 with a neighborhood in northwestern Seattle which included the lining of approximately 19,000 linear feet of 8, 10, and 24-inch diameter unlined cast iron water mains. MWRA also used C&CML as part of the rehabilitation of the 54-inch Water Main in Brookline and Boston, MA. Both utilities used it as a class I, non-structural coating to prevent corrosion, inhibit the growth of tubercles on the interior pipe walls, and improve water quality. For Seattle, it was a significant undertaking because approximately 37% (~ 700 miles) of their system, as of 2007, was unlined cast iron pipe.

The other type of pipe coating is polymer based which was used in Aurora, CO to prevent further degradation due to corrosion in a 66-inch welded steel pipeline suspended along the spillway channel of a dam. It was previously lines with a tar coal epoxy interior coating, but it had deteriorated over time and now had areas of blistering, disbondment, and minor pitting as well as complete failure. A number of different repair technologies were evaluated for use before a polyuria coating was chosen, and the primary cited benefit of polyuria above all other lining options was its short cure time.

### 3.4.5. Water System Pipe Rehabilitation Technology Use in Practice

Five full case studies and four abbreviated case studies were developed for pipe rehabilitation technologies. Each of the rehabilitation technology categories is discussed separately below with details about the technologies covered in utility case studies.

**Cured-in-Place Pipe (CIPP) Liner Technologies**

There were two case studies developed for CIPP Liners as shown in Figure 3-19 below, both of which dealt with woven hose liners. CIPP lining of water mains is not a common practice but is becoming more common as technologies improve and become more cost effective for utilities to use.

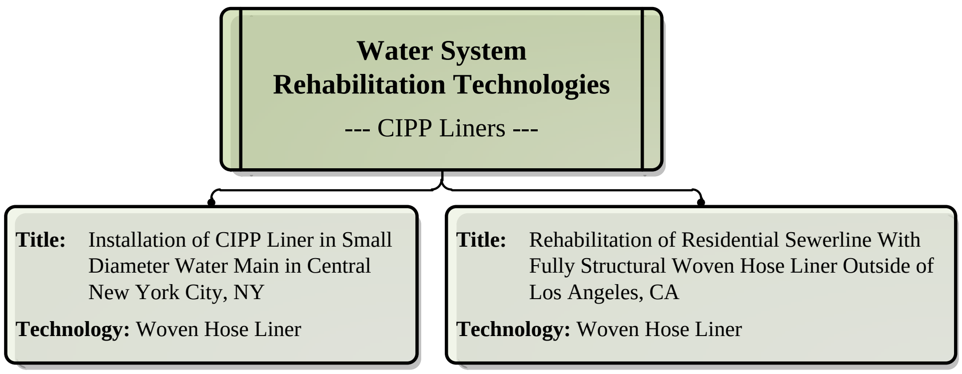


**Figure 3-19. Water System Rehabilitation Technology Case Studies – CIPP Liners**

The Los Angeles Department of Water and Power (LADWP) used a woven hose CIPP Liner to rehabilitate 8-inch steel and 8-inch cast iron water mains in residential areas in early 2000. The utility needed an NSF 61 liner approved for use in potable water mains and also needed a Class IV fully structural solution. The installation was successful, but it is not a commonly used method for water main rehabilitation in their system.

The New York Department of Design and Construction (DDC) also installed a woven hose liner, but this was in 2010, a decade after the LADWP installation. DDC chose to use the proprietary product because a current water main replacement segment in Manhattan had a short segment of pipeline that was ideal for a pilot test of the new product. The 12-inch cast iron water main would only require 230 LF of lining, but most importantly, the segment was straight and had only one active service connection. The project only took 1 week to complete.

## Fold and Form Pipe (FPP) Liner Technologies

There were no full case studies developed for FFP Liners, but one abbreviated case study was found as shown in Figure 3-20 below.

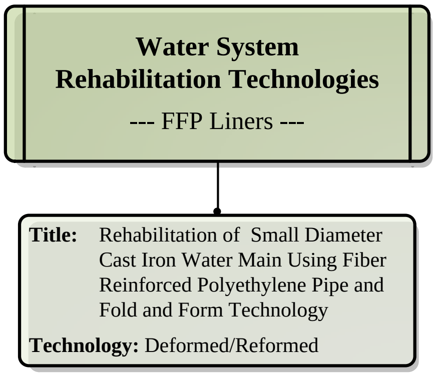


**Figure 3-20. Water System Rehabilitation Technology Case Studies – FFP Liners**

The Town of Highland, IN had a problematic 8-inch cast iron water main that had an extensive history of circumferential breaks along one portion of the pipeline buried under 10-inch thick concrete pavement with heavy traffic. When the main finally failed, the water pressure damaged the wall of a residential basement, and the Town began investigating alternatives for renewal. The main issues were associated with gaining access to the pipeline and with adjacent utilities/obstructions. A number of exhume or abandon in place alternatives were evaluated, as well as a three trenchless technologies (pipe bursting, a CIPP Liner and a FFP Liner). The FFP Liner was chosen based on its installation cost, its burst strength, its ability to maintain flexibility after installation and reduce the likelihood of shear failure, and its ability to provide a fully structural solution independent of the host pipe. The installation of this technology was significant because of the challenging site conditions, but it was also significant because there were only two other agencies in the United States that had installed the technology. Over 250,000 LF of the product have been installed in Britain, once again highlighting a lag between technology availability and implementation in the United States versus other countries such as Britain or the UK.

## Grout-in-Place Pipe (GIPP) Liner Technologies

There were no full case studies developed for GIPP Liners, but one abbreviated case study was created as shown in Figure 3-21 below. This is not a technology commonly used to rehabilitate water pipelines.

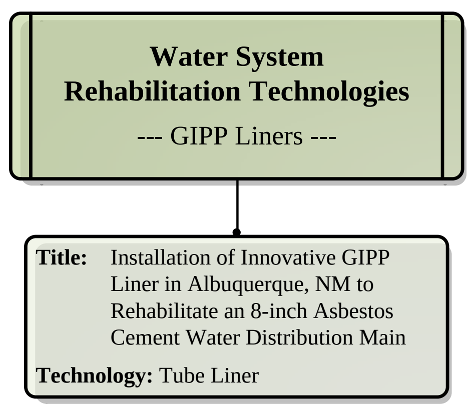


**Figure 3-21. Water System Rehabilitation Technology Case Studies – GIPP Liners**

The City of Albuquerque, NM chose an innovative GIPP Liner to rehabilitate an 8-inch asbestos cement water distribution main and was the first to try the product commercially in North America. There were a couple of significant challenges during installation, the first of which was maintaining tension during pull-in. A vacuum is pulled to deflate the liner before the liner is installed, but in the first two installation segments, the tension was not maintained. When the tension was released, the liner tended to fold, increasing resistance to the swabbing pig which is sent through the pipeline after insertion to re-round the liner and allow grout to be injected into the annular space between the liner and host pipe. At one point, the pig got stuck, and the pressure had to be increased significantly to keep pushing it down the line. This resulted in the liner ends splitting, but because the splits were so close to the pipe end, the pig was pushed past the split to pressurize the pipeline and keep the liner tight against the host pipe until the grout cured. Grout dispersal was determined to be the biggest problem with the installation, but this was solved if the liner did not lose tension during deflation.

### Sprayed-in-Place (SIPP) Liner Technologies

There was not a full case study developed for SIPP Liner technologies, but an abbreviated case study was created as listed below in Figure 3-22.

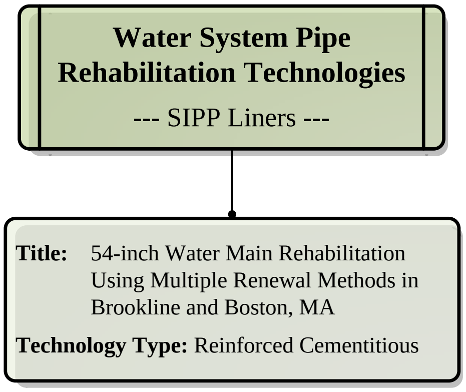


**Figure 3-22. Water System Rehabilitation Technology Case Studies – SIPP Lining**

The Massachusetts Water Resources Authority (MWRA) used reinforced concrete lining as a Semi-Structural rehabilitation method for rehabilitation of a segment of 54-inch water main as part of a much larger rehabilitation project. A layer of cement lining was first applied over the rivets, and a web of metal reinforcements was then welded into place as shown in Figure 3-23. Another layer of cement lining was then installed over the reinforcing layer to create a self-supporting liner. Man entry was required for welding and lining applications, so confined space entry permits, safety plans, rescue teams, etc had to be in place before the rehabilitation could begin.

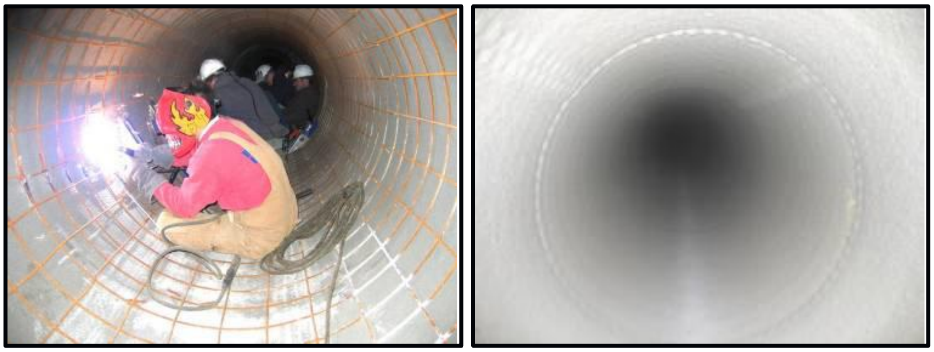

**Figure 3-23. SIPP Lining Welding of Reinforcements (left) and Finished Pipeline (right) (Authority, 2009)**

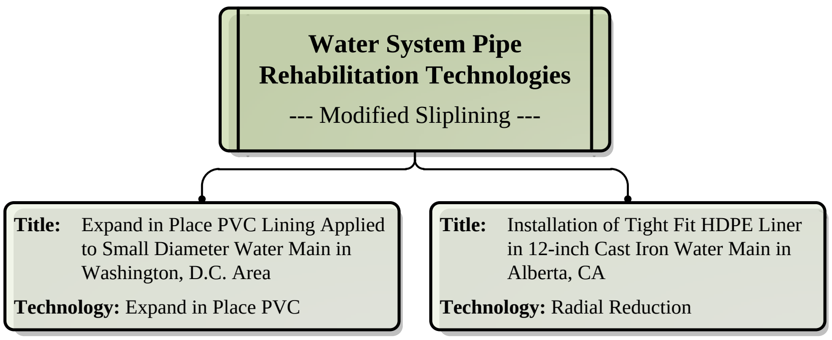


**Figure 3-24. Water System Rehabilitation Technology Case Studies – Modified Sliplining**

## Modified Sliplining Technologies

Two full case studies were developed for modified sliplining technologies as shown in Figure 3-24 above.

WSSC used expand in place PVC pipe to rehabilitate a 12-inch cast iron water main from 1918 in one of the oldest neighborhoods in the city. Whereas several utilities now are making the switch from metal to plastic, WSSC had only 10 miles of PVC pipe and no HDPE pipe in their system at the time this case study was written in 2011. This installation of PVC pipe was a pilot project to explore the possibilities of more cost effective water main rehabilitation than dig and replace. Interestingly enough, however, the installation of the technology ultimately failed to be successfully installed within the system. There were mis-communications between WSSC and the contractor almost immediately with regards to the detail for the water house connections, resulting in a delayed project start date. There were three attempts at installation, only two of which attempted expansion. The first expansion failed due to a failed joint fusion, while the second expansion failed when pressurization created a hole in the liner wall. After the second failure, the decision was made not to attempt expansion of the third installation and pulled the technology out so that open trench excavation could be used instead. One of the primary considerations that pushed WSSC to forego another shot at expansion was the approaching winter weather and the challenges associated with maintaining the temporary bypass supply for all customers; temporary bypass is undesirable in winter where there is a high likelihood of the pipeline freezing, and it is also undesirable during the holiday seasons due to increased flow demands. It is worth noting that this installation took place in 2003, and the product has made significant advances since that point; this was a pilot installation for an innovative version of the product.

In Alberta, Canada, a 12-inch cast iron water main was rehabilitated with a 12-inch HDPE pipe using radial reduction technology to insert the new liner pipe into the host pipe. The liner pipe was about 10-inches in diameter when it was first pulled into place, and after stabilization from natural reversion, it had a diameter of about 11-inches. The ends of the liner were then plugged so that a stepped water pressure induced inversion process could force the liner back out to fit as tightly as possible against the host pipe. The installation process was fairly smooth, with one delay resulting from a failed hydraulic power pack during the reduction of the first liner segment. There was also a need to slightly modify the retraction process when diameters after final reversion were smaller than expected, and a switch from variable diameter steel insert wedges with traditional adapters to solid wall stainless steel inserts and electro-fusion restraints was made to resolve issues with leaking at the liner termination during pressure testing. Before construction even began, one of the challenges faced by the City was finding a solution that would not impact the matured spruce trees planted almost directly above the pipe alignment along an arterial street.

**Sliplining Technologies**

One technology case study for sliplining was created, and two were created as 'abbreviated case studies.' Figure 3-25 lists all three of the case studies available.

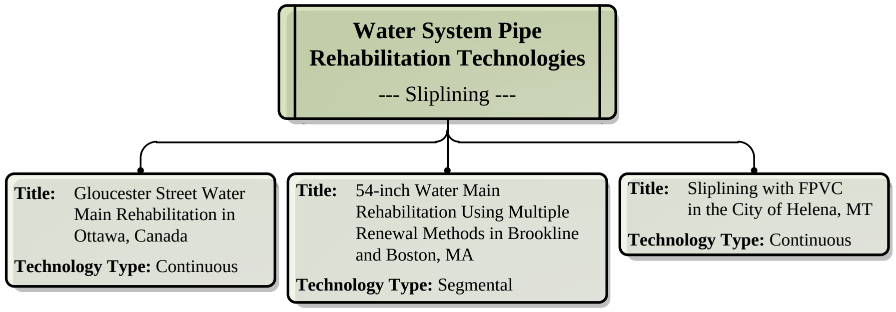


**Figure 3-25. Water System Rehabilitation Technology Case Studies – Sliplining**

The Massachusetts Water Resources Authority (MWRA) used segmental sliplining to rehabilitate one segment of a 54-inch water main as part of a much larger rehabilitation project. The new pipe had a smaller diameter than the host pipe and was installed in segments that were hand-welded together from within the pipeline. Man entry was required for welding of the liner pipe ends, and once inside the host pipe, the new liner pipe was held in position with spacers, securing it for grouting of the annular space. The grout provided additional strength for the new liner pipe and also had a corrosion inhibitor that acted as part of an integrated corrosion protection system. This particular segment needed structural renewal due to its location beneath Route 9. Figure 3-26 below shows a picture of the liner pipe insertion and man-entry for welding and grouting.

**Figure 3-26. Segmental Sliplining Operations (Authority, 2009)**

In Ottawa, Canada a cast iron water main had already failed twice and needed to be structurally renewed, as approximately 37% of its wall thickness had deteriorated over time due to corrosion. The location of the water main was the primary challenge because it crossed under every major north-south arterial road into center-city. Sliplining with an 840 mm HDPE pipe with fused joints was chosen as the preferred method for rehabilitation. One challenge was that two bends in the pipeline could not be negotiated by the HDPE pipe, so the pipe was replaced via open trench at these bends. Special fused ends allowed the connection of the HDPE pipe to the concrete pipe that would be used around bends. One note provided was that even with the density of underground infrastructure, the project was completed without the need for no utility relocations were required. This highlighted the importance and cost savings associated with an accurate base map.

In Helena, MT, the City used a continuous pull method to slipline just over 5,000 LF of 20-inch steel water main with 16-inch fusible PVC pipe. The project was initiated due to leaks in the pipeline, and one of the major challenges was space because the project was located near the airport right along a roadway with little to no open space. Excavations and pits were carefully planned based on the location of valves and an angled portion of pipe that had to be excavated anyway. The pipe was installed via only two pulls due, in part, to strategic pit locations.

### 3.4.6. Water Pipe Replacement Technology Usage

Nine full case studies and no abbreviated case studies were developed for pipe replacement technologies. Each of the technology categories is discussed separately below with details about the technologies covered in within the case study.

**In-Line Pipe Replacement Technologies**

Four full case studies were developed for in-line water pipe replacement technologies as shown in Figure 3-27 below.

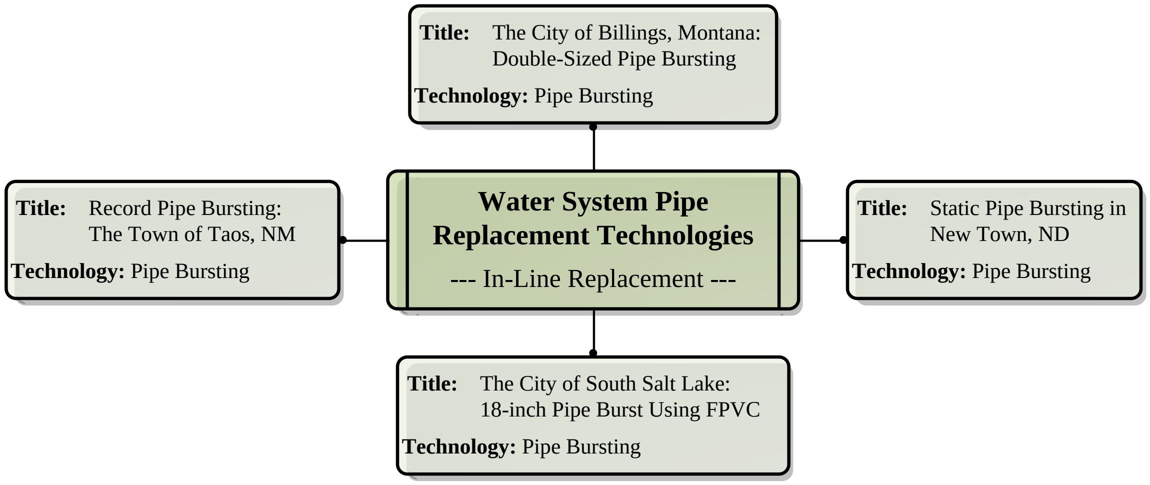


**Figure 3-27. Water System Replacement Technology Case Studies – In-Line Pipe Replacement**

All four of the case studies developed for in-line replacement technologies used pipe bursting. The Town of Taos, NM used static pipe bursting to replace about 16,500 LF of 8-inch fiberglass-wrapped PVC pipe with 10-inch HDPE pipe. The project ran through residential areas as well as beneath major thoroughfares. The two major concerns were surface disruption and out-of-service time for customers. Budgeting for the project did not have room for landscaping, sidewalk, curb/gutter, or asphalt replacement, so trenchless technologies were investigated.

The City of Billings, MT implemented a long-term, successful in-house pipe bursting program to handle as many of their own system replacements as possible. The City purchased their own equipment, and several of their staff members have been certified by the pipe supplier (Underground Solutions) for PVC pipe joint fusion. The City has replaced about 3,000 LF of pipeline to date and plans to replace nearly 27,000 LF before the project is complete.

The cast iron water mains in New Town, ND were only just over 50 years old, but they were already in need of renewal due to the high mineral content of the soil weakening the pipe from the outside and the high pH source water causing issues with built up mineral precipitation within. There were increasing leaks and breaks, so the Town decided to renew nearly 13,000 LF of pipe. Before choosing pipe bursting as the ultimate solution, a 1,100 LF section of 6-inch cast iron main was burst as a trial run. Pit placement was critical in reduce the number of excavations, and therefore reducing project costs, and flexible connecting rods made it possible to burst around large radius bends.

The City of South Salt Lake City, UT installed an 18-inch fusible PVC water line via static pipe bursting in 2009. The project was initiated after a redesign of the major interstate led designers to find that the existing waterlines beneath the roadway could not handle the new pressures. Open trench was not a viable option primarily because of the difficulty in shutting an entire interstate down for waterline replacement.

### Off-Line Pipe Replacement Technologies

Four full case studies were developed for off-line water pipe replacement technologies as shown in Figure 3-28 below.

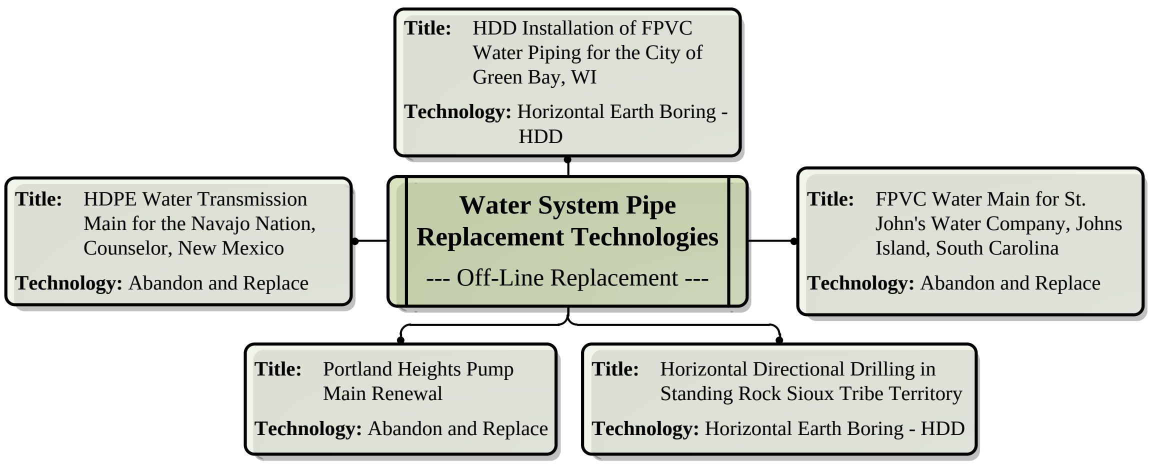


**Figure 3-28. Water System Replacement Technology Case Studies – Off-Line Pipe Replacement**

The City of Green Bay, WI replaced an existing water main with an 8-inch fusible PVC water main via HDD technology. Bentonite and No-Sag Gel were used to maintain smooth drilling operation and help the pilot hole retain its shape, and as drilling moved forward, the drill head location was tracked by on-site crew with an above ground technology to detect sonde in drill head.

The City of Jenks, OK used HDD to install 10-inch DR 11 HDPE pipe 10-feet below the Polecat Creek bed. During significant rain events, heavy runoff and sandy soils combined to create unfavorable conditions at the location where the water main crossed the creek in the City, causing 4 failures within 18 years. The City decided a permanent solution was needed and decided to move the pipeline completely out of the stream channel. The existing pipeline ran along the bank of one of the widest sections of the Polecat Creek where bank failures during runoff events caused the pipe to fracture.

The Standing Rock Sioux Tribe needed to transport water 80 miles from a different town, Nageezi, to their own location in Counselor, NM so that running water could be provided to the remaining portions of their territory without it. The installation included 13 miles of 24-inch DR 7.3 and DR 9 pipe, primarily with open trench methods, but a small amount of HDD was also used where the terrain, the crossing of the Grand River for example, prevented the use of traditional open trench methods. The Grand River crossing proved even more difficult because heavy rains added additional, unexpected depth to the River.

There was a significant difficulty in this project with the variations in rock hardness. A specific tool had to be brought in to deal with the softer rock areas because softer rock kept sticking to the initial back-reaming tool. However, the softer rock tool had a hard time with harder sections of rock, leading to a 3 week delay in completion of the bore hole for pull-in. Stringing the pipe together for one pull also proved challenging because of the variations in elevation and the bending roadways by which the pipe had to be laid. In some cases, culverts had to be installed to allow the lay-down pipe to pass beneath roadways while still providing residents access to their homes. The entire pull took 14 hours.

A new transmission main was put into place on John’s Island because of increased demand, primarily due to tourism. Conventional open trench methods were not acceptable because of environmental concerns associated with nearby wetlands, and the high public profile that the project would have. FPVC was found to be the most cost effective in conjunction with HDD installation technology. While HDPE was originally specified, but a 10% cost savings was realized once FPVC was compared to the HDPE option. A total of 109 pipe joints were fused for the project starting from December 2007. The Project had to maneuver multiple river and wetland crossings, as well as a run under a row of protected trees. There were also difficulties with an active airfield and archaeological concerns, and as a result, over 50 private easements were required before construction could begin.

Open trench installation was chosen as the best solution by the Portland Water Bureau (PWB) to replace one of their pump mains primarily because PWB had no experience with HDPE lining but had extensive, successful experiences with open trench installation. The high confidence in installation quality and significantly larger number of certified contractors for open trench paired with the more than 150 year design life that could be achieved made it a more viable option in the eyes of the Bureau. CIPP Liners were also considered, but it had only a 50 year life expectancy and increased maintenance expectations due to its shorter service life.

## 3.5. Water System Pipeline Renewal Technology Usage – Synthesis of Current Practices from State of the Art Literature and State of the Art Practice Reviews

### 3.5.1. Purpose and Scope of Synthesis

In the above sections, the state of the industry was defined in terms of the technology practices commonly cited in literature and the technology practices based on case studies written to capture actual utility experience rather than vendor-driven claims. The experiences described in the previous sections are synthesized below to provide an overall view of the State of the Industry for Water Pipe Renewal Technology availability and use. It is important to understand that these snapshots only capture the current time period, and thus the state of the literature and practice reviews will need to be updated to stay current with existing trends.

### 3.5.2. Pipe Materials

Traditionally, the materials used in water systems include AC, CI, DI, PCCP, Steel, PE, and PVC, and though there are other pipe types, the types listed above account for just over 97% of distribution pipelines (Dr. Ray Sterling, State of Technology Review Report on Rehabilitation of Wastewater Collection and Water Distribution Systems, May 2009). In general, the trend for pipe materials seems to be shifting from traditional metal pipes to plastic pipes such as PVC and HDPE. This shift is predominantly in small diameter distribution pipelines since there are size limitations for thermoplastic materials. Large diameter transmission mains continue use predominantly PCCP, steel, or lined iron.

### 3.5.3. Trends by Renewal Type

A general trend in technology usage was seen through literature and in practice.

These observations are discussed below by type of renewal.

**Repair Technologies**

For sealing joints, mechanical sleeves seemed to be the most common technology cited in literature. The mechanical sleeves have the ability to withstand high internal pressures which would explain their frequent use in other applications such as repair of power plant circulating lines (Croning, 2002). One of the major benefits cited was the ability of the sleeves to structurally reinforce bell and spigot joints which are common in waterlines and are often the source for leaks. Literature is available as well that speaks more on the application for sleeves such as *Rehabilitation Scenarios for Sustainable Water mains* by Khaled Shahata et al.

For small holes and cracks, the use of internal carbon and glass reinforced-fiber reinforced pipe wrap was very common, and there are many sources available to provide details on the concepts and applicable situations for use (Baruch Gedalia, 2010) as well as the quality control recommendations and proper installation procedures (Carr, 2007). While external repair clamps are an old and proven technology that have likely been used by most utilities at some point, the most significant factors for the time and cost of repairs to waterlines is excavating the leak and dewatering the pipeline (EPA, November 2009). This could be a possible reason for the shift in focus to repair technologies such as internal wraps that do not require excavation. One of the benefits cited by WSSC in their use of internal CFRP wrap is the quick installation and effectiveness of the technology. It has been used extensively by the utility to make repairs to the large diameter PCCP transmission mains in their system.

Capturing repair technology use within utilities was difficult because repairs are typically made by in-house operation and maintenance crews, and detailed procedures for actual repair technology installations are not well documented. Repair clamps, for example, are often used as quick and easy repair options, but specific applications are not common in literature. The technology is, however, listed in all major industry reports that provide descriptions of water system pipe repair technologies such as the EPA State of the Technology Report and the EPA Report for Control and Mitigation of Drinking Water Losses in Distribution Systems.

Another common repair technology is pipe coatings. The use of cementitious coatings was commonly cited in literature and heavily used in practice as well. Cement Mortar Lining is a particularly common practice in water utilities today, with several utilities such as Seattle Public Utilities, Louisville Water, and Los Angeles Department of Water and Power all using it as a regular pipeline renewal practice. Polymer-based linings were not as commonly cited in literature as far as examples of use, but there is a plethora of information available explaining the technical background and applicability of the technology such as *Evaluation of Trenchless Renewal Methods for Potable Water Distribution Pipes* by Abhay Jain or *Global Review of Spray-On Structural Lining Technologies* by Dan Ellison which discusses the applicability of epoxies and polymer based materials as both coatings and semi-structural linings. Aurora Water used the coating to make repairs of their suspended water main, and cited one of the main benefits of the polyuria lining to be its ability to cure quickly so that the pipeline can be reinstated quickly.

**Rehabilitation Technologies**

One of the main challenges in rehabilitation of waterlines is the need for at least two excavations for installation and then additional excavations at service connections, valves, and other appurtenances (Behnam Hashemi, 2011). Where there are multiple connections or excavation points required, it is more cost effective at some point for the utility to just excavate the entire pipeline for full replacement rather than rehabilitation.

CIPP liners are a promising technology for water system application but examples of use are very limited in literature and very difficult to find in practice. No utilities that were interviewed used CIPP Liners regularly. The need for the liner and all materials to be NSF 61 approved for use in potable water and have the ability to withstand internal working pressures make them less commonly used in water applications than sewer. The commonly used resins for sewer applications such as styrene are difficult to get approved for use in potable water, and materials such as needled felt do not have the capability to withstand pressure without some type of reinforcement. Most of the examples of use from literature in the United States including the installations in the Charleston Water System (Ball, 2011) and the City of Omaha (Jeff Schovanec, 2011) were pilot projects. The case study developed for New York City was also a pilot project, suggesting that there is considerable interest in this technology within the United States. UV Curing of the woven hose and reinforced hose liners is also an advancement that is not commonly used in the United States at present but that has the potential to reduce curing times considerably.

The other commonly cited rehabilitation technology is SIPP Linings, but there were few examples of their use in practice, most likely because until now cement mortar and polymer based materials have been thought of as non-structural solutions. There are a number of advantages associated with spray-on polymer linings, most notably the reduces curing time and therefore the total time the water main has to remain out of service (Dan Ellison, 2010). There is extensive literature available evaluating their applicability and their effectiveness for semi-structural applications such as *Pipeline Rehabilitation with Fiber-Reinforced Mortar Lining* by G.K. Luk; *Global Review of Spray-On Structural Lining Technologies* by Dan Ellison et al; and *Testing & Design Life Modeling of Polyurea Liners for Potable Water Pipes* by Mustafa Kanchwala. The EPA also did a pilot evaluating the performance of a semi-structural SIPP Lining, but the ultimate determination was that the technology was still in need of improvement (John Matthews, February 2012). In practice, the utilities that had used SIPP Linings had used cementitious material that was reinforced with steel mesh. The one case study provided for SIPP Lining in Boston used steel reinforcing that was welded together to form a "cage" within the pipeline to provide structural support for the cementitious lining that was applied.

There is a lot of literature available documenting the exploration of new ways to rehabilitate water lines. However, there are very few alternatives available that are actually used extensively by utilities in practice. Other countries such as the UK use technologies such as CIPP and SIPP Liners extensively in their systems as well as modified sliplining technologies. The examples from utilities that use modified sliplining for water main rehabilitation had issues with expansion and joint integrity, and when searching for literature documenting the use of these products in the United States, there were only examples of pilot projects. While there is certainly promise in the innovative solutions coming available.

**Replacement Technologies**

In-Line Pipe Replacement for water system pipelines is fairly limited to pipe bursting. This was exemplified by the fact that all literature sources and case studies for in-line pipe replacement were different forms of pipe bursting. The primary limitation cited for pipe bursting, and in many cases the reason it was eliminated as a solution in renewal projects, are the ground vibrations which can be harmful to surrounding utilities or above ground obstructions. Explanations, background, limitations, and cost information for pipe bursting are available through many sources such as *Water Pipeline Renewal Evaluation Using AWWA Class IV CIPP, Pipe Bursting, and Open Cut* by Behnam et al which compares the benefits, limitations, and costs of each of these methods for use in water. One of the benefits of pipe bursting is that it allows the installation of a new pipeline in the same location as the old pipeline, preserving valuable underground infrastructure. It also allows for a small degree of upsizing which is great for situations where an increase in capacity is the driver for rehabilitation. In situations such as The City of Billings, MT, in-house pipe bursting programs have been developed to reduce costs associated with replacement.

In some cases, trenchless technology is not an applicable or cost effective method for installation such as where there would be numerous services to reconnect, and exhume and replace methods have to be used. These methods also may be required where an upsizing beyond the limitations of pipe bursting are needed. Detailed information on pipe bursting including installation procedures, design considerations, and costs can be found in the TTC Technical Report #2001.02, *Guidelines for Pipe Bursting*.

In regard to off-line pipe replacement, the most common methods are abandon and replace and HDD. Open trench construction is often chosen because of difficult soil conditions such as rock where trenchless installations have limited capability. Abandon and replace techniques are often used where the existing pipe alignment has access issues or obstructions that make a parallel alignment more attractive, or where there are too many issues with taking the pipeline out of service for replacement. In this case, the new pipeline is typically installed on the parallel alignment and the old pipe left in place to act as an overflow. In the case study for Replacement of a Pump Main in Portland, OR, a parallel pipe was installed and the old main used as an alternate pipe should the new main need to be shut down for maintenance or repair.

HDD has found success in the water pipe replacement industry primarily due to its usefulness in installing pipelines beneath obstructions and through environmentally sensitive areas. Most every example in literature and in the case studies used HDD because there was some type of water body, roadway, or other obstruction. Jenks, OK used it to install a pipe beneath a creek bed, the Sioux Tribe used it beneath a river, and John’s Island used it to cross several rivers and wetlands. The most notable limiting condition for HDD installations is the soil characteristics, though factors such as weather and depth of the alignment also play an important role. Technical information on HDD

### 3.5.4. Drivers for Renewal

The Government Accounting Standards Board (GASB) Statement Number 34 was released in June 1999 and required all utilities to report the value of all assets on a balance sheet. The value could be calculated using a standard calculation for infrastructure depreciation expenses based on historical acquisition costs or through implementation of an effective asset management system which required proof that the utility was maintaining assets at least well enough to meet minimum standards or spending enough on maintenance to prevent deterioration. Even so, in 2002 the Government Accounting Office released a report estimating that 33% of water utilities were not maintaining their assets at an appropriate level and that 29% were not able to maintain their current target service levels of service with their existing sources of income. Regulations and mandatory accounting for assets has become one of the drivers for water pipe renewal, and many utilities set a minimum percent of their pipelines that need to be renewed each year to stay on track.

Other drivers for renewal of waterlines are customer complaints. Some utilities have set up GIS systems that track the location of customer complaints such as those related to water quality, water discoloration, or pressure issues. When frequent complaints begin to appear in one location within the system, the utility can plan for inspection and possible renewal of those areas of the system in their budget. Water utilities strive to provide a certain level of service to their customers, so customer complaints are often a good way to identify problem areas.

External corrosion is a major issue driving water pipe renewal. Many pipes have been installed with cathodic protection systems either external to the pipeline or integrated into the pipe system in grouts as was demonstrated in the case study for sliplining of the 54-inch Water Main in Boston. Internal corrosion is an issue as well and can take a couple of different forms. Internal corrosion can degrade the pipe walls causing the thickness of the pipe wall to decrease over time until eventually failure occurs; it can cause the 'growth' of tubercles which lead to water quality, capacity, and pressure issues; and it can cause graphitization which is the most difficult to detect because it weakens the pipe without changing its appearance. Corrosion was cited in many literature sources as the primary reason for initiation of renewal. External corrosion, for example, was one of the issues in the 66-inch Water Main assessment which injected a "sleeve" of grout around the pipe exterior to seal the resulting leak off from the surrounding soil medium (Alfredo Saenz, 2011).

### 3.6. Conclusion

While the technologies available for renewal of water system pipelines have come a long way, there are still advancements needed before the technologies available for water system pipe renewal will offer anywhere close to the spread of options offered for wastewater system pipe renewal. The State of the Art Literature and State of the Art Practice Reviews above were based on examples of technology applications from literature and on examples of technology use identified through contact with utilities, respectfully. In general, the primary difference in what was found in literature versus practice was the literature sources focused on providing examples of innovative technology uses, pilot projects, for example, while in actuality utilities were only using a handful of technologies actually available to them. Most utilities were open about their tendencies to stick to practices with which they are comfortable and confident in. Until new technologies have been proven, the risk, especially in large diameter water mains, associated with failure is too high to warrant their application.

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# CHAPTER 4.

## State of the Art Literature and Practice Review for Wastewater System Pipelines

Kristi K. Steiner[1] and Sunil K. Sinha[2]

**Abstract:** Over the last few years, several advancements have been made in wastewater pipe renewal technologies that have allowed utilities to utilize innovative renewal techniques that decrease project costs, the impact of the project on the surrounding citizens and environment, and allow for expedited pipeline renewals compared to traditional open trench methods. The challenge now is in getting utilities to implement new innovative technologies within their system. This paper provides background information for the technologies available for the renewal of wastewater system pipelines and then provides State of the Art Literature and State of the Art Practice Reviews based on technology use trends in literature and technology use trends practiced by utilities. The information from both reviews is then synthesized to provide a clear view of the state of the wastewater pipeline renewal technology industry, including the trends by pipe material, drivers for renewal, and technology type.

**Keywords:** wastewater pipe renewal, repair, rehabilitation, replacement, pipeline renewal technology, state of the art literature review, state of the art practice review, utility technology use

### 4.1 Introduction

There are over 16,000 sewer systems in the United States, each with needs that are unique to their size, geographic location, and system characteristics. Over 740,000 miles of gravity sewer mains serve approximately 190 million people (EPA, 2010), while an additional 60,000 miles, representing approximately 7.5% of the sewer systems, are force mains (Ray Sterling L. W., May 2009). Some of the pipes within the sewer system are over 100 years old and have far exceeded their original design life expectancy. Increasing issues with the deteriorating pipelines are caused by cracks, internal corrosion, build-up of fats, oils, and grease, root intrusions, joint leaks, and several other problems that lead to overflows and/or eventual failure (Ray Sterling L. W., May 2009). Each year there are over 40,000 sanitary sewer overflows (SSOs) which can have devastating impacts on the surrounding environment as well as on public health (Ray Sterling J. S., July 2010). Renewal of the deteriorating pipelines has been

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gaining popularity over time, and competitive markets have made technologies and products more affordable to infrastructure owners. This paper discusses the technologies available through State of the Art Literature and State of the Art Practice Reviews, with the Literature Review focus being on examples of technology uses found in literature, and the Practice Review focus being on examples of technology uses captured through the development of utility case studies and interviews.

### 4.2 Pipeline Renewal Engineering Technology Background Information

The United States Environmental Protection Agency (EPA) defines Pipeline Renewal to be "the application of infrastructure repair, rehabilitation, and replacement technologies to return functionality to a drinking-water distribution system or wastewater collection system." (Ray Sterling J. S., July 2010) The line between whether to repair, rehabilitate, or replace a pipeline is often a fine one, and each utility currently has its own protocol for making this decision. Flow charts and decision support models that can be tailored to the individual utility and its system needs are often used to help guide pipeline renewal decisions. These models range in complexity, with models available that are specifically designed for water systems, specifically designed for wastewater systems, or are designed for general use. More information on decision support models is available in the EPA report *Decision Support for Renewal of Wastewater Collection and Water Distribution Systems* (July 2011). The EPA provides a few generalized guidelines and host pipe requirements describing appropriate situations for the application of each type of pipeline renewal, and these are summarized in Table 4-1 below.

**Table 4-1. Renewal Engineering Components and Descriptions of Use (Ray Sterling J. S., July 2010)**

| Pipeline Renewal Component | Description of Applicable Uses |
|---|---|
| Repair | 1. Host pipe is structurally sound<br>2. Existing pipeline provides acceptable flow capacity<br>3. Host pipe can serve as support structure for applied technology |
| Rehabilitation | 1. Extends operational life of the pipeline, generally by at least 50 years<br>2. Completely or almost completely restores hydraulic and structural functionality of host pipe |
| Replacement | 1. Host pipe is severely deteriorated or collapsed and unable to provide the level of service in its current condition<br>2. Host pipe cannot support installation of repair or rehabilitation systems<br>3. Existing pipeline requires additional flow capacity |

To further complicate the decisions required for pipeline renewal, there are a number of different technologies available for each component of pipeline renewal and several products available to represent each technology. In the EPA *State of Technology Report for Rehabilitation of Wastewater Collection Systems* released in July 2010, over 100 different technologies were identified. To facilitate the evaluation of drinking water pipeline renewal technologies, the repair, rehabilitation, and replacement technologies have been classified into broad technology categories as shown in Figures 1 through 3. Each of these categories was defined in a way that captured as many of the more specific technologies available to the industry today as possible.

### 4.2.1 Wastewater System Pipe Repair Technologies

Pipeline repair technologies are used to restore normal pipeline operating conditions or repair small, localized leaks along the pipeline. The technologies are typically used where the defect is not severe enough to require renewal of the entire pipe segment or where deterioration is contained to a small area. Repair technologies can be used to enhance structural stability of the host pipe, but the repair mechanism still relies on the host pipe for structural soundness (Ray Sterling J. S., July 2010). As shown in Figure 4-1 below, pipe repair technologies have been broken into three major technology categories: (1) pipe joint and leak seals, (2) pipe point repairs, and (3) pipe coatings. Table 4-2 below briefly describes each of the major pipe repair technology categories.

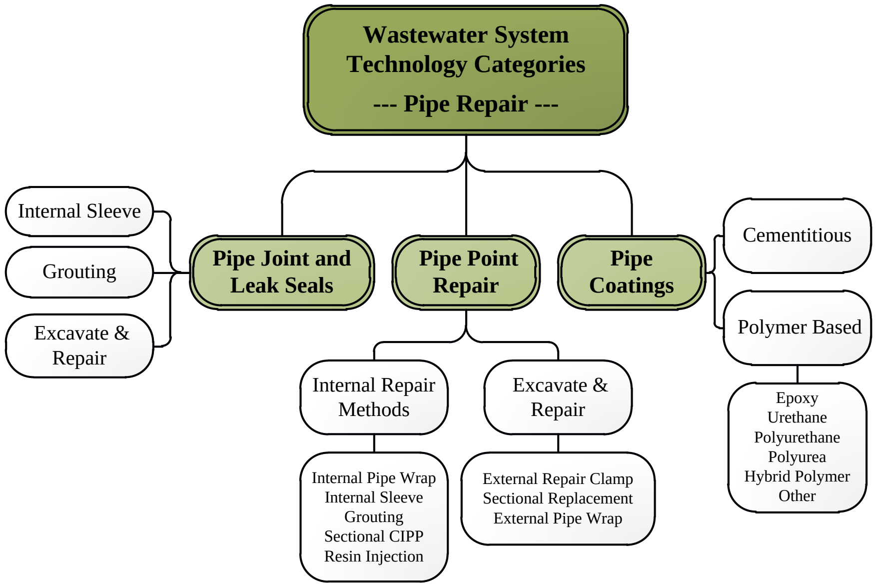


**Figure 4-1. Wastewater System Technology Categories**

**Table 4-2.** Description of Pipe Repair Technology Categories

| **Pipe Repair Technologies** | |
|---|---|
| Pipe Joint or Leak Seals | Pipe joint and leak seal technologies can typically be installed by in-house operation and maintenance crews and are designed to repair leaking, cracked, or defective joints. Joints are commonly the weakest part of a pipeline, and these technologies are designed to seal leaking joints and prevent inflow and infiltration. There are three primary types of pipeline joint and leak seal technologies: (1) internal sleeves, (2) grouting, and (3) excavated repairs. |
| Pipe Point Repairs | Pipe point repair technologies are those technologies used to fix short sections of pipeline with a range of structural solutions and are designed to repair sections of pipeline with semi- or fully- structural repair options. There are two primary forms of point repair technologies: (1) Internal Point Repair Technologies and (2) Excavate and Repair Technologies. technologies Examplse of internal point repair technologies include internal pipe wraps, internal sleeves, grouting, sectional CIPP liners, and resin injection. Examples of Excavate and Repair Technologies include exteral repair clamps, sectional replacement methods, and external pipe wraps. |
| Pipe Coatings | Pipe coatings are applied by hand or robotically to span small defects in the pipe wall or provide protection from degradation mechanisms such as corrosion. These linings are not considered stand-alone repair technologies and provide very little to no added structural integrity to the pipeline. There are two types of coating available: (1) cementitious and (2) polymer-based. |

### 4.2.2 Wastewater System Pipe Rehabilitation Technologies

Pipe rehabilitation technologies are used where the existing host pipe is structurally sound enough to at least support the installation of the renewal technology. These technologies are aimed at restoring the capacity of a defective pipeline, but slight increases in capacity are sometimes possible, primarily due to the reduction in surface friction that results from technology applications. Rehabilitation technologies also restore the structural integrity of the pipeline system, though still may rely on the host pipe for some support, and also extend the life expectancy of the pipeline, typically by at least 50 years. (Ray Sterling J. S., July 2010) The technologies are used where the defects are too numerous or severe for repair options to be feasible. As shown in Figures 4-2 below, rehabilitation technologies have been broken into six major technology categories: (1) Cured-in-Place Pipe (CIPP) Liners, (2) Fold and Form Pipe (FFP) Liners, (3) Grout-in-Place Pipe (GIPP) Liners, (4) Spray-in-Place Pipe (SIPP) Liners, (5) Sliplining, and (6) Modified Sliplining. These technologies are defined in Table 4-3 below.

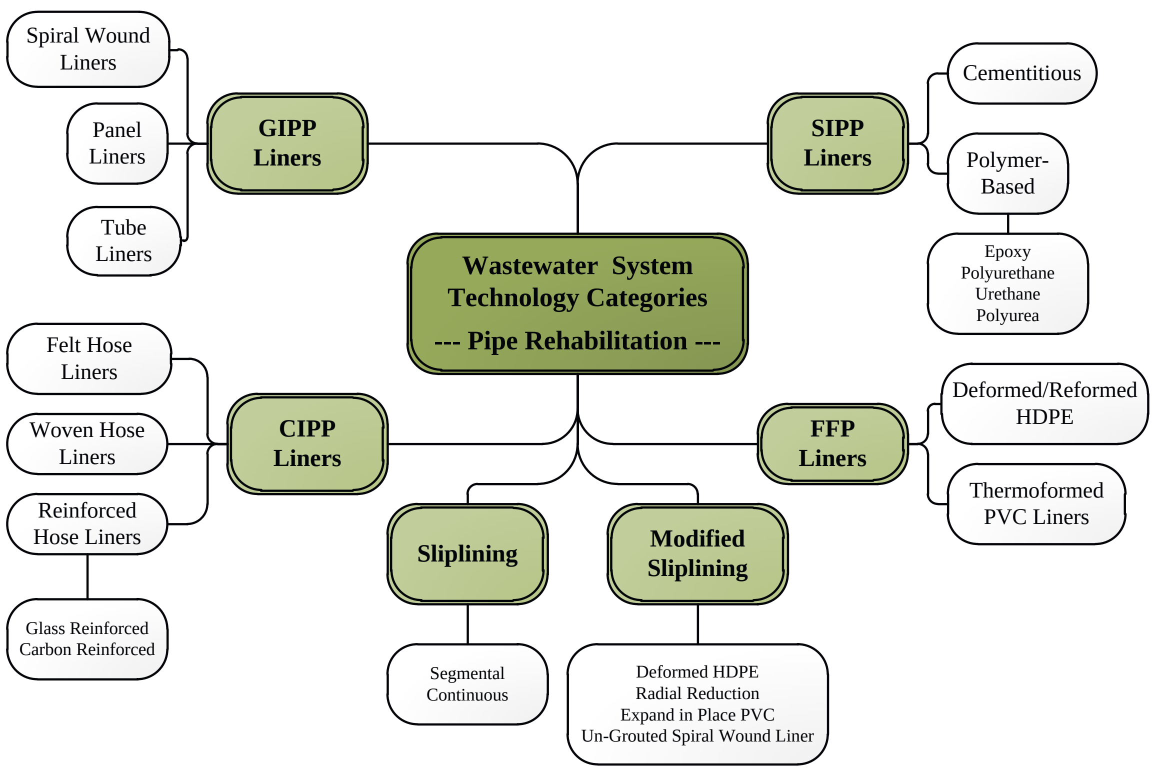


**Figure 4-2.** Wastewater Pipe Rehabilitation Technologies

## Table 4-3. Description of Pipe Replacement Technology Categories

| **Pipe Rehabilitation Technologies** | |
|---|---|
| Cured in Place Pipe (CIPP) Liners | Cured in Place Pipe (CIPP) Liners are one of, if not the most widely used form of pipeline rehabilitation. The CIPP Liner tube is impregnated with a liquid thermosetting resin and then pulled or inverted into place within the pipeline and cured with hot water, steam, or UV lights to form a "pipe within a pipe". The three primary types of CIPP liners include: (1) Felt Hose Liners, (2) Reinforced Hose Liners, and (3) Woven Hose Liners. |
| Fold and Form Pipe (FFP) Liners | Fold and Form Pipe (FFP) Liners are PVC or HDPE liners that have been folded into a shape such as "U" or "W" to reduce the cross-sectional area and facilitate insertion into an existing access point should one already exist. Waterlines require small access pits to be excavated for liner insertions. Once in position, the folded pipe liner is expanded with pressurized water or air to expand it to fit tightly against the host pipe. there are two primary types of liners: (1) Thermoformed PVC Liners and (2) Deformed/Reformed HDPE Liners. |
| Grout in Place Pipe (GIPP) Liners | Grout in Place Pipe (GIPP) Liners are internal liners that do not fit tightly against the host pipe. These liners can be installed (1) by hand in the form of panel liners, (2) by hand or machine in the form of spiral wound liners, or (3) pulled/pushed into place as pre-welded tube liners. Once in place, the liner is typically held in place with internal reinforcements while the annular space between the host pipe and liner is filled with expanisve grout to create a host pipe-grout-liner system that can withstand external loadings. |
| Spray in Place Pipe (SIPP) Linings | Spray in Place Pipe (SIPP) Linings are cementitous or polymer-based linings that are sprayed onto the pipe wall to provide a semi- or potentially fully- structural rehabilitation solution. Cementitous SIPP Linings are typically braced with steel reinforcing mesh to provide added structural capabilities to the cementitious material. The structural capabilities of polymer linings are increased through the addition of reinforcing fibers and/or through application of the material as a "high-build" lining. |
| Sliplining | Sliplining is accomplished by either pushing or pulling a new, smaller diameter pipe through the deteriorated host pipe. There are two different methods for sliplining: (1) segmental sliplining and (2) continuous sliplining. Where adequate space is available, the new pipe can be pulled into place continuously, or where space is restricted, it can be pulled in one segment at a time. Continuous pull-in sliplining requires the use pipes with fused, welded, or restrained joints, whereas segmental pushed-into place sliplining can use traditional joint types. Because sliplined pipes do not fit tightly against the host pipe, grouting of the annular space is required for structural stability. |
| Modified Sliplining | Modified sliplining technologies are used to insert a thermoformed pipe within the deteriorated host pipe, making use of various technologies to reduce the diameter of the new pipe to facilitate insertion. The cross-section may also be altered and restrained with temporary bands until it has been successfully inserted into the host pipe. Once inside the host pipe, the new pipe is allowed to expand to its original cross section either naturally or through the use of pressurized air or water. Modified sliplining creates a tight-fitting "pipe within a pipe" that, unlike sliplining, does not require grouting of the annular space. There are four primary methods for modified sliplining including: (1) Deformed HDPE, (2) Expand-in-Place PVC, (3) Radial Reduction, and (4) Un-Grouted Spiral Wound Liner |

### 4.2.3 Wastewater System Pipe Replacement Technologies

Pipe replacement technologies are used where the existing host pipe is no longer structurally sound enough to support repair or rehabilitation technologies or where the existing host pipe is severely deteriorated or collapsed. These technologies are designed to completely restore or increase capacity and structural integrity of a defective pipeline, and the old pipe is either abandoned in place or removed in some manner from its existing alignment (Ray Sterling J. S., July 2010). Replacement technologies re-start the life expectancy of the pipeline rather than just extending it, so the new life expectancy is heavily dependent on the type of pipe chosen for installation. As shown in Figure 3, pipe replacement technologies have been broken into two major technology classes: (1) On-Line Replacement Methods and (2) Off-Line Replacement Methods. These are defined in Table 4-4 below.

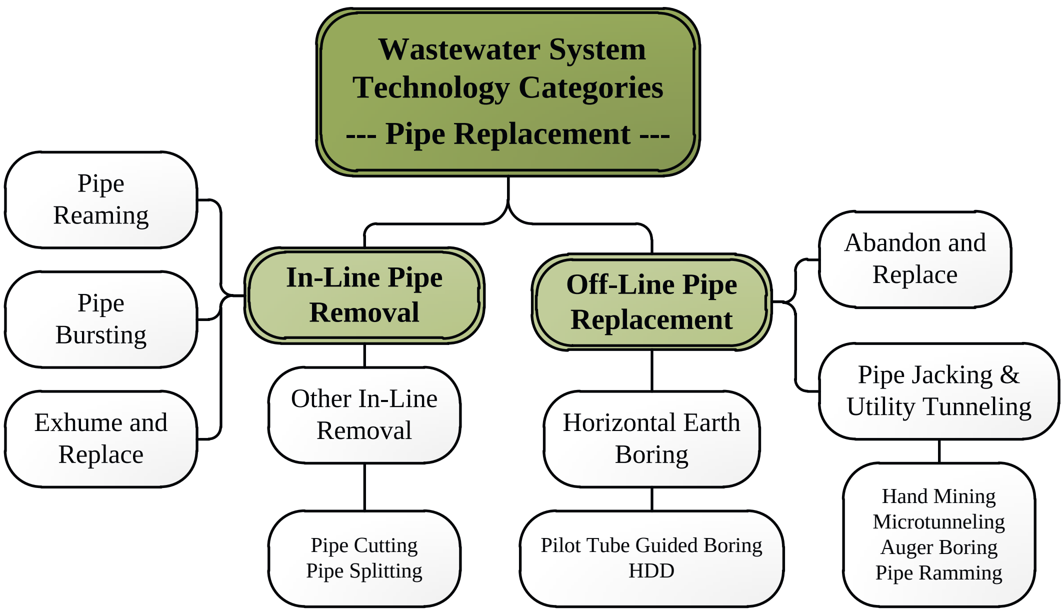


**Figure 4-3. Wastewater Pipe Replacement Technologies**

**Table 4-4. Description of Pipe Replacement Technology Categories**

| **Pipe Replacement Technologies** | |
|---|---|
| In-Line Pipe Replacement | In-Line Pipe Replacement Technologies include those technologies used to remove the existing host pipe and replace it with a new pipe of equal or slightly larger diameter along the same alignment. Methods for in-line pipe replacement include pipe bursting, pipe splitting, pipe reaming, exhume and replace, and other forms of in-place pipe removal. |
| Off-Line Pipe Replacement | Off-Line Pipe Replacement Technologies include those technologies used to install a pipeline through a new soil tunnel, typically parallel to the existing pipe alignment if possible. Methods for off-line pipe replacement include open trench abandon and replace, pipe jacking & utility tunneling, and horizontal earth boring. |

## 4.3 State of the Art Literature Review for Wastewater System Pipeline Renewal Technologies

### 4.3.1 Introduction

Literature review is a critical first step in understanding the concepts involved in wastewater pipeline renewal engineering and in determining what knowledge already exists. It is important to understand what research has been completed or is underway so that the gaps in existing information can be identified and their significance evaluated. The literature review process began with the identification of sources from which to pull a comprehensive representation of literature types (major industry research reports, journal papers, conference proceedings, relevant theses, etc.). Table 4-5 below outlines the document source locations that were mined for all possible literature, including a description of common literature types found within that source.

**Table 4-5. Locations Mined for Literature Sources**

| Name of Resource | Location (where applicable) | Description of Available Literature |
|---|---|---|
| EPA - National Service Center for Environmental Publications (NSCEP) | http://www.epa.gov/nscep/index.html | This allows the user to search for all research reports or white papers published by the EPA. The searches performed were for broad searches such as "pipe renewal" as well as for specific technologies such as "cured in place pipe liner". |
| Compendex, Inspec, NTIS | | These bibliographic reference databases were searched for relevant sources, primarily for journal papers and conference proceedings, and where online sources were not available, a copy of the literature could usually be obtained through the Virginia Tech Library resources. |
| ASCE Civil Engineering Database (CEDB) | http://cedb.asce.org/ | This database was searched for all relevant ASCE journal papers and conference proceedings. |
| EBSCO Host | http://search.ebscohost.com/ | EBSCOHost was searched for all relevant academic journal articles, conference proceedings, magazine/newspaper articles, and books. Where direct links to articles were not available, a copy of the literature could usually be obtained through the Virginia Tech Library resources. |
| AWWA, NASTT, ISTT, and other prominent industry organization websites | | The websites allowed the location of research reports or white papers published by the the industry association so that a copy of the literature could be requested through the Virginia Tech Library resources. |

There were two basic types of literature that were reviewed: major reports/research reports and other literature. Major reports included research reports, workshop proceedings, etc. from key industry organizations and associations such as the EPA, Water Environment Research Foundation (WERF), American Water Works Association (AWWA), etc. Major industry documents/publications tend to focus on long-term research work that has been completed or on capturing the main ideas from workshops that drive new research. These documents are important to understanding what research has been completed or is underway and where the gaps in knowledge exist. Table 4-6 provides a list of the reports identified to be most relevant to the use of wastewater pipeline renewal technologies in the United States.

**Table 4-6. Wastewater Pipeline Renewal Technology Use Research Reports**

| Title | Publisher | Year |
|---|---|---|
| A Retrospective Evaluation of Cured-in-Place-Pipe (CIPP) Used in Municipal Gravity Sewers | US Environmental Protection Agency (EPA) | 2012 |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | US Environmental Protection Agency (EPA) | 2011 |
| Decision Support for Renewal of Wastewater Collection and Water Distribution Systems | US Environmental Protection Agency (EPA) | 2011 |
| State of Technology Report for Rehabilitation of Wastewater Collection Systems | US Environmental Protection Agency (EPA) | 2010 |
| State of Technology Report for Force Main Rehabilitation | US Environmental Protection Agency (EPA) | 2010 |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | US Environmental Protection Agency (EPA) | 2009 |
| Emerging Technologies for Conveyance Systems: New Installations and Rehabilitation Methods | US Environmental Protection Agency (EPA) | 2008 |
| Exfiltration in Sewer Systems | US Environmental Protection Agency (EPA) | 2000 |
| Construction Cost of Underground Infrastructure Renewal: A Comparison of Traditional Open-Cut and Pipe Bursting Technology | University of Texas at Arlington | 2008 |
| Guidelines for Pipe Bursting | US Army Corps of Engineers | 2001 |
| New Pipes for Old: A Study of Recent Advances in Sewer Pipe Materials and Technology | Water Environment Research Federation (WERF) | 2000 |

Essentially, any type of literature reviewed that was not a major industry association/organization/research report fell in the category of "other literature sources". The most common forms of other literature sources reviewed were journal papers and conference proceedings. The primary sources considered in this state of the art literature review for pipeline renewal technology use include those that were focused on providing actual technology use information or that covered how the technology was used and for what purpose.

### 4.3.2 Wastewater Pipe Repair Technologies

Pipe repair is common practice for every infrastructure owner, and several technologies are typically kept on-hand by utility maintenance and repair crews to handle pipe repairs. One of the major issues encountered in waterlines is corrosion, both internal and external, which can lead to defects such as circumferential cracking and joint leaks. If the leaks or cracks that develop in the pipe walls or at joints are not sealed, water will be forced out into the surrounding soil medium and eventually lead to bedding washout and subsequent failure. (Ray Sterling L. W., May 2009)

Where defects are localized, repair technologies can be installed to extend the life of the existing pipe, significantly reducing costs compared to replacement of the entire pipe segment. Corrosion and leakage are reported to cause 61% of failures in ferrous force mains and 30% of failures in non-ferrous force mains (Robert Morrison, March 2010), highlighting the importance of pipeline repair since these failures could be prevented with through pipe repairs if found early on. The major industry reports considered related to drinking water pipe repair technology usage are shown in Table 4-7 below which also notes the individual technology types that are covered within each report. Examples of literature sources for each technology type are provided in the sections below which discuss the state of the technology for wastewater pipeline repairs.

**Table 4-7. Technologies Covered in Wastewater Pipe Repair Technology Reports**

| Title | Wastewater Pipeline Repair Technologies | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pipe Joint & Leak Seals | | | Pipe Point Repair | | Pipe Coatings | |
| | Internal Pipe Sleeves | Grouting | Sectional CIPP | Excavate & Repair | Internal Repair Methods | Cementitious | Polymer Based |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | X | X | | | X | X | X |
| State of Technology Report for Force Main Rehabilitation | X | | X | X | X | | X |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | | | X | | X | X | X |
| Emerging Technologies for Conveyance Systems: New Installations and Rehabilitation Methods | X | X | X | | X | X | X |
| New Pipes for Old: A Study of Recent Advances in Sewer Pipe Materials and Technology | X | X | | | X | X | X |
| Exfiltration in Sewer Systems | | X | | X | X | | |

## Pipe Joint & Leak Seal Technologies

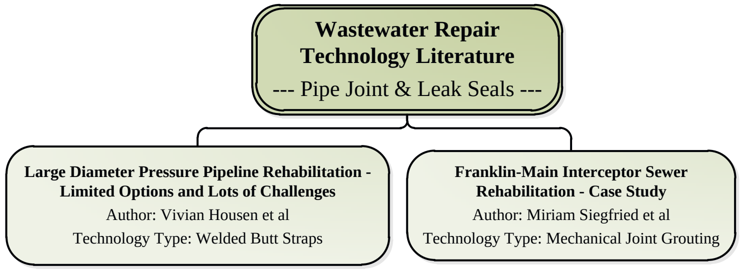


**Figure 4-4.** Wastewater Repair Technologies – Examples of Use for Pipe Joint & Leak Seals from Literature

Figure 4-4 above shows examples of joint and leak seal technology use from literature sources. One of the most commonly used technologies available for sealing leaking joints is chemical grouting (Robert S. Amick, December 2000). This method uses an inflatable packer to isolate the joint from flow and pushes chemical grout through cracks into the soil surrounding the pipe. It creates a waterproofing collar external to the pipe that seals the leaking joint. Before choosing chemical grout as a solution, it is important to make sure that leak is not allowing water to enter the pipe at a rate that will cause resin washout before the grout is allowed to cure. Problems with resin washout will be evident once grout pumps are turned on since the dye colored grout will re-enter the sewer a few seconds after injection. (Miriam Siegfried, March 2004)

Mechanical joint sleeves and welded joint repairs are two additional technologies available for the repair of joints, and they are also applicable for pressure applications. The Livermore-Amador Valley Water Management Agency considered both for repairs to the joints of a 24- to 36-inch force main that was severely corroded before cement mortar lining was applied, ultimately choosing welded butt straps due to concerns with operation and maintenance with the mechanical joint sleeve. (Vivian Housen, March 2004) For weld joint repairs, the existing corrosion has to be completely removed so that a new butt strap can be welded in place.

## Pipe Point Repair Technologies

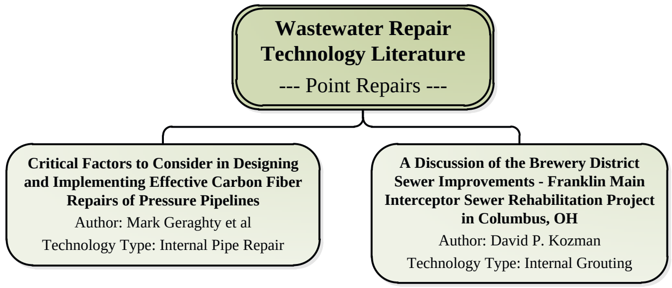


**Figure 4-5.** Wastewater Repair Technologies – Pipe Point Repair in Literature

Figure 4-5 above shows examples of point repair technology use from literature sources. Pipe point repair technologies are used where there are small pinholes, cracks, or leaks in the pipe wall need to be repaired. They are also frequently used to repair defects in preparation for the installation of other renewal technologies. Common methods of point repair include robotic repair, grouting, internal sleeves, and CIPP short liners (Robert S. Amick, December 2000).

In Columbus, Ohio, a two-part epoxy mix was used to repair a CIPP Lining that had just been installed. The liner had two discolored areas with pinholes in the polyurethane coating through which water could enter the pipe. These pinholes were patched with the epoxy mix, as was the portion of the pipe wall that was removed for sampling purposes. (Kozman, August 2002) CIPP Liners can be used to perform sectional repairs for sections of the pipe that are between 3- and 30- feet in length where the diameter of the pipeline is between 6- and 48-inches. These can be installed by a liner/bladder assembly, a packer wrapping method, or pull-in and inflate. The main benefit of these point repair technologies is their ability to be installed trenchlessly and accost effectively. It is important to realize that the resin extremely important, as it is the primary contributor to the structural capabilities of the liner. (Shaun M. Flanery, July 2008)

Another technology that has become popular for the repair of pressurized pipelines is fiber reinforced wraps. In Waukegan, IL, a wrap was used to repair several segments of a 54-inch effluent force main, some that were quite deep, ran through residential neighborhoods, and were in close proximity to other utilities. This installation stressed the importance of having a clean, dry surface on which to apply the wrap that is structurally sound and roughened with abrasive blasting. (Mark Geraghty, 2010) Any defects impacting the structural integrity of the pipeline have to be repaired before the wrap can be applied.

**Pipe Coating Technologies**

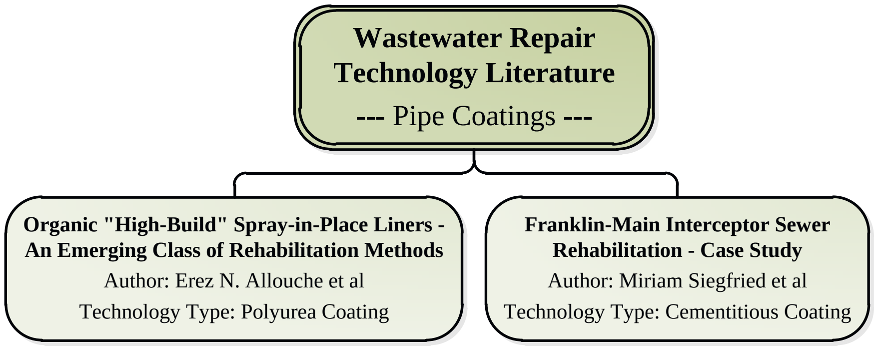


**Figure 4-6. Wastewater Repair Technologies – Pipe Coatings in Literature**

Figure 4-4 above shows examples of pipe coating technology use from literature sources. Pipe coatings are primarily used to protect the internal surface of the pipe from the effects of corrosion, though they can also be used to span small gaps and holes in the pipe. Polymer-based linings have the ability to span small holes and stop leaks more effectively than cement mortar (Dan Ellison, 2010). The coatings can also be used to make repairs before further renewal is completed. In Norristown, PA a coating was used before the application of an SIPP Liner. The coating was applied to the invert of the pipeline to repair the severe damage that corrosion had caused. (Erez N. Allouche, June 2009) Other than the application of CML as a corrosion inhibitor which is common practice in many utilities, coatings tended to be used in conjunction with other renewal methods.

### 4.3.3 Wastewater Pipe Rehabilitation Technology Usage

The technologies available for waterline renewal continue to advance, and this paired with other benefits such as decreased social and environmental disruption and reduced project costs have led to steadily increasing sources for literature on rehabilitation technology uses. Table 4-8 below provides a list of the major research reports that provide information on rehabilitation technology usage.

**Table 4-8.** Technologies Covered in Wastewater Pipe Rehabilitation Technology Reports

| Title | Wastewater Pipeline Rehabilitation Technologies | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CIPP Liners | | | FFP Liners | | GIPP Liners | | | SIPP Liners | | Sliplining | | Modified Sliplining | | | |
| | Felt Hose Liners | Woven Hose Liners | Reinforced Hose Liners | Thermoformed PVC Liners | Deform/Reform PE Liners | Spiral Wound Liners | Tube Liners | Panel Liners | Cementitious | Polymer Based | Continuous | Segmental | Deformed HDPE | Diametrical Reduction | Expand in Place PVC | Un-Grouted Spiral Wound Liners |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | X | X | X | X | X | X | | X | X | X | X | X | X | X | | |
| State of Technology Report for Force Main Rehabilitation | X | | X | X | X | X | | | X | X | X | X | | X | X | |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | X | X | X | X | | X | | X | X | X | | | | | | |
| Emerging Technologies for Conveyance Systems: New Installations and Rehabilitation Methods | | | X | X | X | X | | X | X | X | | | | | | |
| New Pipes for Old: A Study of Recent Advances in Sewer Pipe Materials and Technology | X | X | X | X | X | X | X | X | X | | X | X | | X | | |
| Exfiltration in Sewer Systems | X | X | X | X | X | X | | | | | X | X | X | X | X | X |
| A Retrospective Evaluation of Cured-in-Place-Pipe (CIPP) Used in Municipal Gravity Sewers | X | X | X | | | | | | | | | | | | | |

## Cured in Place Pipe (CIPP) Liner Technologies

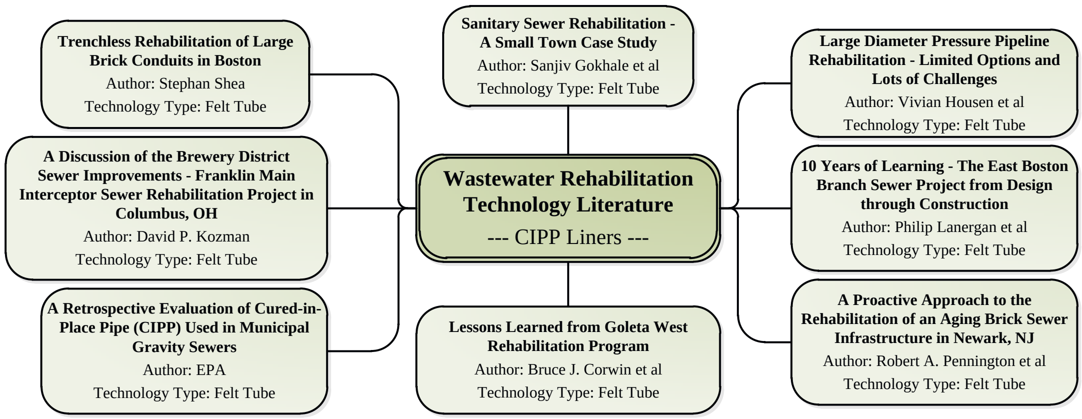


**Figure 4-7.** Wastewater Rehabilitation Technologies – CIPP Liners in Literature

Figure 4-7 above shows examples of CIPP Liner technology use from literature sources. There is a great deal of information available for CIPP liner methods, materials, installation procedures etc. including all three of the EPA State of Technology Reports relating to sewer rehabilitation (Ray Sterling J. S., July 2010) (Ray Sterling L. W., May 2009) (Robert Morrison, March 2010). In January 2012 the EPA also published a summary report that details two CIPP Liner installations, one in Denver, CO and one in Columbus, OH (Erez Allouche, September 2011). It compares all of the project sites, recommends future testing protocol, and provides extensive background information on CIPP liners.

In Newark, NJ a long term pipe assessment and rehabilitation program was put in place in the 1990s, and the utility was able to document several interesting lessons learned over the years. (Robert A. Pennington, 2008) First, recommendations for successful projects include proactive communication with impacted customers, isolating work areas to extent possible, minimizing road closures, and utilizing temporary bypass pumping. Most all of the sewers have been egg-shaped brick sewers, and all have been greater than 20-inches in diameter. Pennington also recommends lateral logging and accounting for each active and inactive connection, stabilizing void areas in the brick before lining, and required documentation for work completed pre- and post-lining.

The Massachusetts Water Resources Authority (MWRA) uses CIPP Liners extensively in their system to meet federal regulations associated with the Boston Harbor cleanup to control the CSOs in their system. As part of this initiative, the East Boston Branch Sewer (EBBS) Relief project rehabilitate 1 mile of 36" x 42" egg shaped sewers. (Phillip Lanergan, 2011) One of the major lessons learned in that installation was to make sure to be very clear and proactive in calling out the pipelines for CIPP to protect critical sewers in bid documents. A different municipality in Boston, the Boston Water and Sewer Commission, used CIPP to rehabilitate a 57" x 66" inverted egg shaped brick sewer. (Shea, 2007) Many technologies were considered, but ultimately CIPP was chosen for its long history of successful rehabilitation since it has been used in the system since 1982 for both circular and odd shaped pipelines. The challenge was that they had never lined a pipe this large. The installation was completed successfully with a couple of challenges. Loud machinery was required for the installation, and it was operated both day and night. Adjacent residents complained about the night noise, but since the utility was only in that location for a short time, the issue was not difficult to resolve. The major issue was with odor complaints from a restaurant with faulty plumbing. Odors from the curing process had entered the basement of the building through the plumbing, and though the contractor was able to resolve the problem, future design phase procedures would take this into account.

The Goleta West Sanitary District in California had used multiple phases of rehabilitation so that prior to beginning the next phase, the success of the previous phase could be evaluated. In all but the last phases, CIPP was one of several options provided to bidders, and in the last phase it was the only choice because it was a more important sewer that needed to be rehabilitated with only one material. In all other phases, CIPP was used for 6-inch pipelines only. Most of the issues from the initial phases had to do with root intrusion at service connections and between the liner and host pipe. CCTV inspections of the previous phases showed that at laterals, 70% of the root intrusion was in the spiral wound liners which were used for pipes greater than or equal to 8-inches in diameter. Only 30% of the root intrusion occurred in CIPP liners, and thus the last phase only allowed CIPP liners in the bidding process. (Bruce J. Corwin, 2010)

Columbus, OH was able to use CIPP in a historic, congested, heavily traveled downtown area that had been installed in the 1800s (Kozman, August 2002). Kozman et al. provides great details on the setup of bypass pumping systems, cleaning and preparation of the pipeline required for CIPP installation, and details for exact installation process including time of day, curing time, curing temperature, cooling times, etc. The pipeline had two 30° bends and had to make a transition between a 60-inch and 66-inch pipe. Physical inspections following curing found two areas where the lining was discolored and pinholes had developed in the polyurethane coating through which water was entering. The cause of the discoloration was residue from water and contaminants that entered through the pinholes, but the cause of the pinholes could not be determined. One of discolored sections was pryed off of the wall for testing, and the utility found that adherence was not an issue since bricks came off with the lining. Pennington et al. also provides several explanatory pictures.

When a large diameter pipeline in the San Francisco Bay area needed rehabilitation in a segment with a transition between gravity and force main, CIPP was one of the main considerations for the gravity portion of the sewer. While pressure liners were available, their use was not well documented enough for the utility to validate its use. Ultimately, CIPP could not be used because when overlapping CIPP liners, the overlap can only be on the upstream side of flow direction, where this would have a CIPP liner with overlap on both the up- and down-stream flow directions. An overlap on the downstream side could allow water to flow under liner and corrode underlying material. The utility also noted that the overlapping liners can only handle pressures up to 10 psi. No viable transition could be made to the CML material that was to be applied on pressure portion of pipeline. (Vivian Housen, March 2004)

**Fold and Form Pipe (FFP) Liner Technologies**


**Figure 4-8.** Wastewater Rehabilitation Technologies –FFP Liners in Literature

Figure 4-8 above shows examples of FFP Liner technology use from literature sources. FFP Liners are an effective way to eliminate exfiltration from sewer systems. Because joints and seams are the weakest part of pipes and liners, the “U” shaped FFP liners, once installed, provide an advantage for the utility in that they are a seamless, jointless pipe. (Robert S. Amick, December 2000)

The Hampden Township used FFP liners as part of an I/I reduction program which is a common program in utilities. The pipelines within the system that were 8-inches in diameter were rehabilitated with FFP liners; this included approximately 2,100 LF of lining. Lining the sewers rather than performing open trench replacement cut the cost of renewal in half. There was one change order and one attempted change order in the project. The change order was made to remove concrete that had hardened in the bottom of the pipe, but the utility had no knowledge of how the concrete had gotten there. The attempted change order was a request from the contractor who claimed excessive grout was required at pipe joints, but the utility was able to dispute the change order because of requirements they had included in the specifications for the project. These two change orders highlight the importance of pipeline inspection in initial project phases as well as detailed, well thought out specifications.

**Grout-in-Place Pipe (GIPP) Liner Technologies**

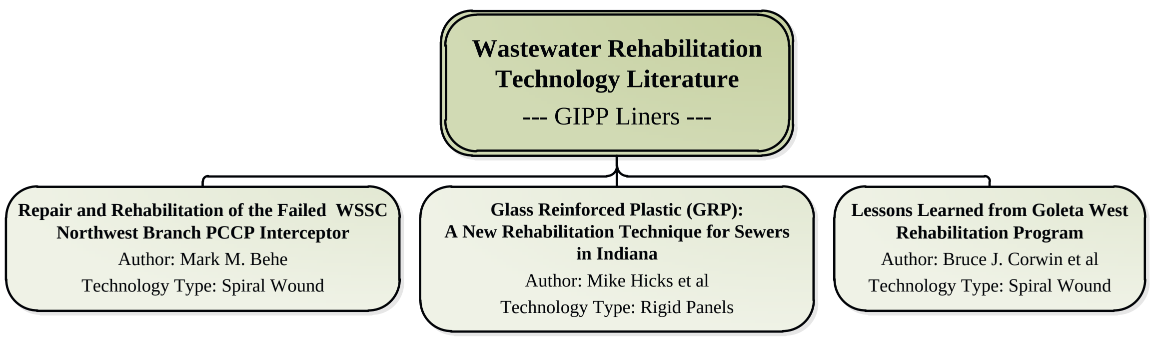


**Figure 4-9.** Wastewater Rehabilitation Technologies –GIPP Liners in Literature

Figure 4-9 above shows examples of GIPP Liner technology use from literature sources. GIPP liners were developed to increase the cost effectiveness of large-diameter sewer and tunnel rehabilitation and have been used by utilities such as the City of Fort Wayne and the City of Chicago (Parsons Corporation, July 2006).

The City of Fort Wayne, Indiana was able to use the technology to rehabilitate a 72-inch brick sewer beneath a very busy multi-lane road near the downtown area. The urban location as well as the 90° bend with an diagonal crack and a section of missing brick made installation very difficult. The crack was thought to have occurred due to the creation of soil voids by groundwater infiltration which led to loss of external support and uneven loadings that cause deflections, cracking , and deformation. GIPP was chosen using glass reinforced plastic (GRP) panels because it was the only option that could structurally renew the pipe, maintain or increase flow capacity, and be installed trenchlessly within the established budgets. (M. Hicks, 2004)

Hicks provides more information on the design and installation requirements for the technology as well as extensive details for its use in this project. GRP Panels are available for pipelines up to 144-inches in diameter (Jason Consultants International, Inc., 2000).

In the Goleta West Rehabilitation Program, spiral wound liners were used in initial phases for all pipes greater than or equal to 8-inches in diameter. The primary limitation of the technology was that there were several issues with root intrusion at lateral connections as well as between the liner and host pipe. For this reason, CIPP was used for rehabilitation for all pipelines in the final phase of the project rather than spiral wound. (Bruce J. Corwin, 2010) WSSC was able to use spiral wound to make emergency repairs to their sewer system after the failure of a 66-inch PCCP sewer interceptor caused a massive sink hole to form. (Mark M. Behe, 2009) Spiral wound lining does not always require the installation of a temporary bypass system since it can be installed with some flow in the pipeline, but this project required bypass because of the failed pipe and because flows in the interceptor were too great for installation without it.

**Sprayed-in-Place Pipe (SIPP) Liner Technologies**

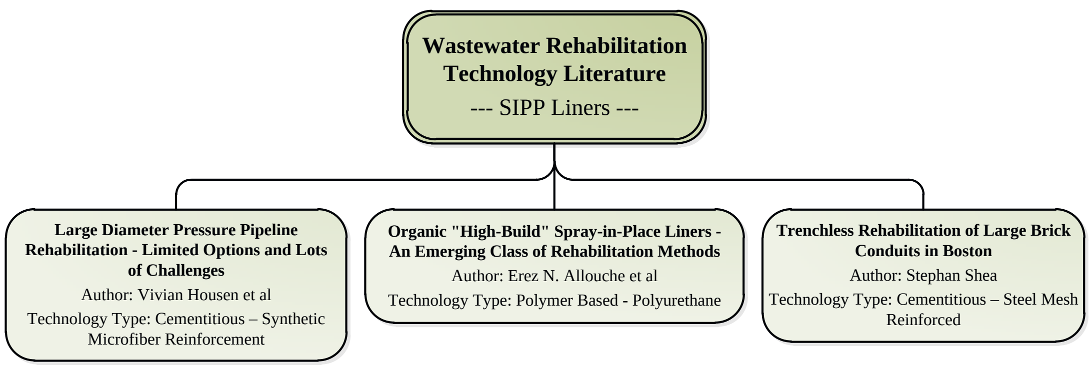


**Figure 4-10.** Wastewater Rehabilitation Technologies – SIPP Liners in Literature

Figure 4-10 above shows examples of SIPP Liner technology use from literature sources. While the use of cementitious SIPP Linings have been used in the United States for many years, the application of high-build polymer or epoxy mixture is still new to the industry and has not quite caught on. One of the major benefits of the polymer/epoxy concrete linings is that they are self-cleaning and thus require little to no associated O&M costs. The upfront costs for the product, however, are 10-20% higher than linings that are just cement. (Parsons Corporation, July 2006) Cement mortar is limited in the degree of structural rehabilitation it can accomplish on its own due to its lack of tensile strength, though it does have some ability to “heal” small cracks that form over time. (Dan Ellison, 2010) Fiber reinforcements such as steel or polypropylene fibers have been mixed with the cement mortar in an effort to improve structural capabilities, but there has not been any significant testing to verify how well the fiber reinforcements work. One issue encountered with centrifugally cast concrete that was macro-synthetic fibre reinforced was getting the right consistency for the lining to prevent its buildup on the spray nozzle (D.R. Morgan, 2010)

Cement mortar linings are common, and where full structural repair is needed, shotcrete and gunite are common solutions. These two technologies differ primarily in the way they are activated. With shotcrete, water is added the nozzle whereas with Gunite, air is added to the nozzle. (Parsons Corporation, July 2006) Shotcrete was used in Boston to rehabilitate a difficult approximately 1,500 LF of 132” x 90” egg shaped brick sewer, and the 8-inch concrete liner was structurally reinforced with hand-welded steel reinforcements. This took approximately 65 working days to complete, and as QA/QC measures, independent testing of the concrete was performed by testing core samples. (Shea, 2007) A more traditional cement mortar lining was used by LAVWMA to rehabilitate their export pipeline which ranged in diameter from 24- to 36-inches and included a transition from gravity to force main. Originally CIPP was going to be used for the gravity portion of the project, but there was no good way to transition from CIPP liner material to CMP, so CMP was used to rehabilitate the entire pipeline. (Vivian Housen, March 2004)

In Norristown, PA, a 60-inch diameter storm sewer had severe structural issues due to corrosion and abrasive materials, but replacement was not an option due to its location beneath a highway. A 6.5 mm thick polyurethane liner was applied to rehabilitate the pipe, but before the liner could be sprayed into place, the deteriorated invert of the pipe had to be repaired. A wide strip of concrete was poured along the entire 600 feet of pipe invert to structurally repair it. With SIPP liners, it is also important to thoroughly clean the pipe surface. If not, the lining will not be able to fully adhere to the pipe wall, and failure will likely occur. It took 2 days for the 6.5 mm thick polyurethane liner to be installed. (Erez N. Allouche, June 2009)

## Sliplining


**Figure 4-11.** Wastewater Rehabilitation Technologies – Sliplining in Literature

Figure 4-11 above shows examples of sliplining technology use from literature sources. There are two different types of sliplining, continuous and segmental. Continuous is typical for small diameter pipelines whereas large diameter pipes are more commonly inserted with segmental techniques. (Robert S. Amick, December 2000) Common materials for continuous insertion include those that can be butt-fused together such as PVC, HDPE, or polypropylene. Segmental installations typically use materials such a s PE, HDPE, PVC, Ductile Iron, steel and GRP.

The advantages of sliplining are that large radius bends can be negotiated, continuous sliplining results in a pipeline with very few or no joints, and the host pipe is not needed for structural support. The two major limitations are the reduction in flow capacity and requirements for grouting of the annular space. With segmental sliplining, there may be numerous joints which is sometimes considered a drawback, and with continuous insertions, the increased space requirements for lay-down can be restricting. (Chapter 3 - Culvert Pipe Liner Guide, July 2005)

In the Franklin Main Sewer Interceptor, two of the segments constructed in 1892 were to be rehabilitated with sliplining. The pipes consisted of 3,400 LF of 30-inch 3-course brick sewer and ran under streets, apartment buildings, a paved hockey rink, an open baseball field, and through heavily wooded park land. The depths of the sewer ranged from 3-feet to 31-feet below the surface which would have represented significant challenges for open cut replacement options. Sliplining with a 24-inch pipe was determined to be most appropriate. (Miriam Siegfried, March 2004)

Newport, Rhode Island used sliplining to rehabilitate a 36-inch PCCP that conveyed 80% of the city's wastewater for processing and ran directly beneath the historic and tourist-y part of the City. The host pipe had extensive internal and external deterioration, and one nearby portion of the pipeline had already failed. All things considered, a 30-inch fusible PVC pipe was used to solve the structural issues. Once in place, the annular space was grouted, the pipe pressure tested, and reconnected to the rest of the force main. The most critical part of the sliplining project was maintaining the tight schedule (Botteicher, 2011)

**Modified Sliplining**

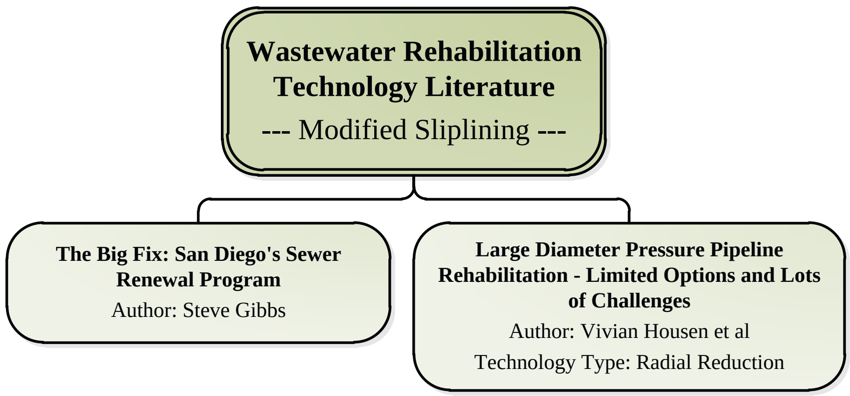


**Figure 4-12.** Wastewater Rehabilitation Technologies – Modified Sliplining in Literature

Figure 4-12 above shows examples of modified sliplining technology use from literature sources. Modifies sliplining was listed as options in several sources, but other technologies always seemed to have the advantage. In the Goleta West rehabilitation of the half gravity sewer-half force main rehabilitation project, a thin-wall non-structural HDPE was considered for use in the gravity section because of its abrasion and impact resistance, ability to accommodate pressure, and its ability to span gaps/holes up to 6-inches in diameter for 24- to 36-inch pipelines. The disadvantages were the insertion pit requirements, lay down area requirements, and limitations to deflection angles which was problematic due to the number of horizontal and vertical bends exceeding 11.25°. (Vivian Housen, March 2004)

There is a very limited amount of literature available on un-grouted spiral wound liners, but San Diego used an un-grouted spiral wound liner to rehabilitate 59,000 LF of sewer pipe throughout the system, most of which were 8-inches in diameter. The City found an advantage in this technology since in most cases it could be installed in live flows, eliminating the need for expensive bypass pumping. (Gibbs, 2007)

### 4.3.4 Wastewater Pipe Replacement Technologies

Pipe replacement is the most traditional form of renewal, with dig and replace methods being the preferred alternative for utilities across the United States. Innovative replacement technologies have allowed the installation of wastewater pipelines in otherwise challenging locations such as beneath wetlands or surface structures. Table 4-9 below provides a list of the major research reports that provide information on replacement technology usage.

**Table 4-9.** Technologies Covered in Wastewater Pipe Replacement Technology Reports

| Title | Wastewater Pipeline Replacement Technologies | | | | | | |
|---|---|---|---|---|---|---|---|
| | In-Line Pipe Replacement | | | | Off-Line Pipe Replacement | | |
| | Pipe Bursting | Pipe Reaming | Exhume & Replace | Other In-Line Pipe Removal | Pipe Jacking & Utility Tunneling | Horizontal Earth Boring | Abandon & Replace |
| Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report | X | X | X | | X | X | |
| State of Technology Report for Force Main Rehabilitation | X | | X | | X | X | X |
| Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains | X | | | | | | |
| Emerging Technologies for Conveyance Systems: New Installations and Rehabilitation Methods | X | | X | X | X | X | X |
| New Pipes for Old: A Study of Recent Advances in Sewer Pipe Materials and Technology | X | | | X | | | |
| Exfiltration in Sewer Systems | X | | | | | | |
| Guidelines for Pipe Bursting | X | X | | X | | | |
| Construction Cost of Underground Infrastructure Renewal: A Comparison of Traditional Open-Cut and Pipe Bursting Technology | X | | X | | | | X |

## In-Line Pipe Replacement Technologies

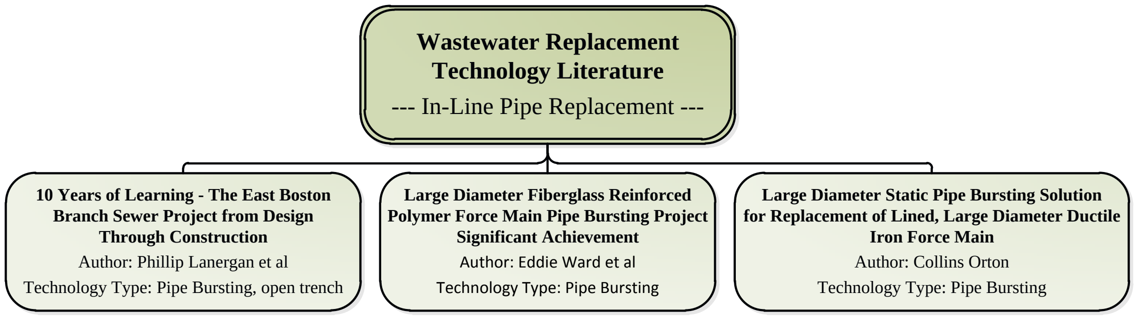


**Figure 4-13.** Wastewater Replacement Technologies – In-Line Pipe Replacement in Literature

Figure 4-13 above shows examples of in-line pipe replacement technology use from literature sources. Pipe bursting is by far the most common type of in-line pipe replacement today, besides possibly dig and replace, an d over 90% of the pipe bursting completed is pneumatic. (Robert S. Amick, December 2000) Bursting works best for brittle pipe materials such as clay, cast iron, concrete, asbestos and some plastics, and where ductile iron is concerned, the operation is called pipe splitting rather than pipe bursting because the pipe is literally just split open rather than burst. Pipe bursting can be used for pipes up to 36-inches, sometimes larger. There are limitations to the project conditions for which it is applicable, and pipe bursting should not be used in expansive soils, where obstructions form a completely collapsed pipe, if point repairs exist with ductile material, and on concrete enveloped pipes. Upsizing is common, though there are limtations to how much the pipe can be upsized which is heavily dependent on the diameter of the pipe as well as on other project conditions such a s the ones listed above. The ability to install a pipe within the same soil tunnel and upsize the pipeline are two of the commonly cited benefits of the technology. An important lesson noted was the need to leave the liner alone for a few hours before reconnections and backfilling are performed. This is to allow the pipe to adjust to its new location and temperature so the ends are cut off at the proper location.

In the City of Tallahassee, Florida, a 36-inch fiberglass reinforced polymer mortar (FRPM) force main failed in three locations after a tropical storm, and though at first hesitant, the project was completed using pneumatic pipe bursting. To ease their minds, a pilot project was completed for the first 280 LF of the project, and when this went smoothly, the remaining length of force main was replaced by the same method. Some significant lessons learned came from this project including cutting blade requirements, equipment settings and requirements, methods for tracking the bursting head. An interesting solution to issues the City had with the time it took to fuse pipe joints versus mechanical joint adapters to the PE pipe was to have two fusing machines. The disassembly and lowering of the fusion machine into the receiving pit for fusing of joint adapters was the time intensive part, so the City had two fusion machines on site, one on the ground level for regular fusion and one that was kept disassembled for fusion of joint adapters. (Eddie Ward, March 2011)

In Boston, approximately 1 mile of 12-inch and 15-inch diameter VCP was upsized to 16-inch and 20-inch diameter HDPE pipe with mostly pipe bursting, but a small amount of cut and cover was required as well. One of the important components of pipe bursting projects is well-written specifications, especially with regards to defining potential obstructions and how to handle them. Open cut was used because of possible seawalls and abandoned foundations that were listed on record documents. Another section of pipe for which pipe bursting was planned to upsize a pipe from 18-inches to 36-inches was performed by in-line Microtunneling instead. The last minute decision was based on limitations in the degree of upsizing that could be performed with pipe bursting technology, and this upsize exceeded the limits. One notable issue encountered with pneumatic bursting was the noise; during the first and only day where pneumatic pipe bursting was used, the contractor received several noise complaints from residents. The project was in a densely populated part of East Boston, and future designs would need to account for the excessive noise. As it turned out, the contractor had to switch to static pipe bursting anyway due to unforeseen subsurface conditions. (Phillip Lanergan, 2011)

In Wilmington, NC, the bursting of a 20-inch ductile iron force main that had been lined three times but still could not maintain pressure. The City first attempted to cut out the liners, but this was too difficult and time and labor intensive. Instead, the City was able to use static bursting to replace the force main with a 22-inch HDPE pipe. The host pipe was about 7-feet deep and located in an area with a high water table, so the site was continuously dewatered throughout the project operations. In all, the bursting took only 4.5 hours in two pulls performed 2 days apart. The second pull ran directly under a pressurized water main, so it took a bit longer, with workers taking care not to damage the water main. The driver for this project was the threat of a sewer moratorium by the State if the force main was not replaced or repaired.

## Off-Line Pipe Replacement Technologies

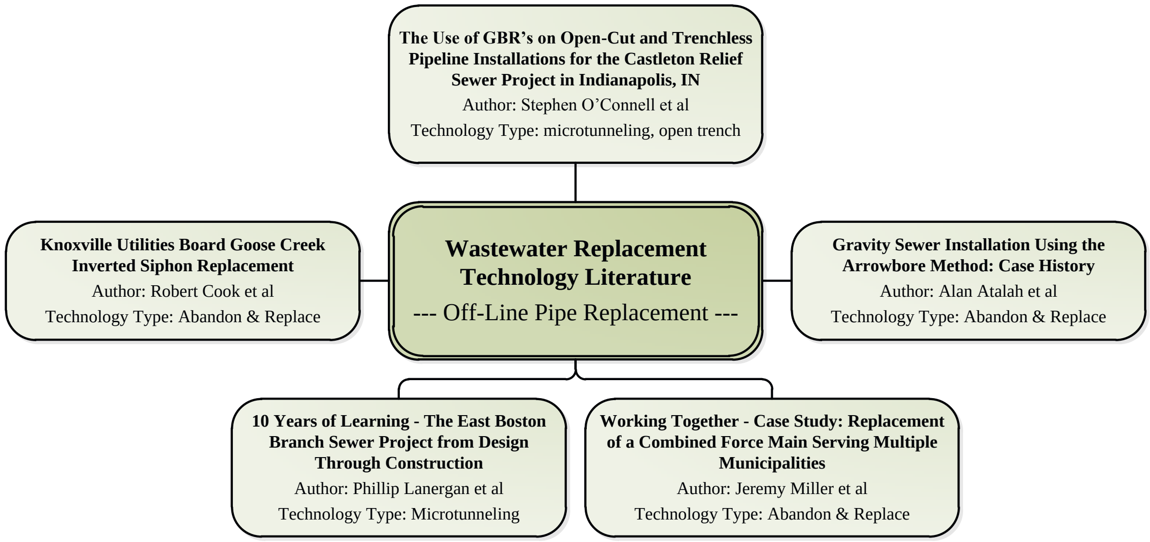


**Figure 4-14.** Wastewater Replacement Technologies – Off-Line Pipe Replacement in Literature

Figure 4-14 above shows examples of off-line pipe replacement technology use from literature sources. The difference between pipe jacking and utility tunneling is that pipe jacking uses pre-manufactured pipe segments that are jacked into place from a drive shaft so that the pipe is installed directly behind the tunnel excavations. Utility Tunneling involves the excavation of the tunnel with internal supports, and once tunnel excavations are complete, the sections of pipe are transported into place within the tunnel. (Hashemi, December 2008) The two most commonly seen forms of pipe jacking & utility tunneling are microtunneling and auger boring.

In Indiana, a 13,800-foot long relief sewer needed replacement, so 3,000 LF of 42-inch RCP was replaced via Microtunneling, while the remaining 11,000 LF of 36- to 42-inch pipe was replaced with open trench construction. The 42-inch RCP to be replaced with Microtunneling was 10- to 30-feet below the ground surface and 5- to 25-feet below the water table. The primary challenges were identified to be due to critical structures along the alignment such as a multi-barreled culvert, drainage ditch, and Keystone Avenue Bridge. The pipe to be replaced via open trench was at depths ranging from 8- to 30-feet below the ground surface, with groundwater levels ranging from 2- to 10-feet below the ground surface. Neither of the projects had been completed at the time the paper was written, but the author focuses instead on the importance of geotechnical baseline reports and how they can be used to predict project conditions and improve the contract documents. (Stephen O'Connell, March 2011) A different form of Microtunneling called pilot tube microtunneling has been steadily increasing in popularity and is essentially a hybrid of directional drilling, Microtunneling machine boring, and auger boring. (Boschert, 2007)

In Berea, Ohio, HDD was used to install 400 LF of 12-inch PVC pipe approximately 40-feet below the ground surface. The only significant issues came when the, at about 350 feet, the drilling head was not staying on alignment, presumably because it encountered sandstone rock. When the drill head was retracted, all of the cutting teeth had been worn down by the rock, and a new specialized rock drill head was used to complete to bore hole. A 20-inch back reamer was used to create a soil tunnel large enough to pull in the 12-inch PVC pipe. The primary lessons learned were that the HDD methods worked well in clay soils, but special considerations are required for potentially rocky soils. The project highlighted the importance of pre-project soil explorations, as well as the need to include dispute settlement clauses and contingency funds in future project documents. (A. Atalah, 2006)

Open trench construction remains the most commonly used method for replacement and can be performed as either abandon and replace or excavate and replace. In general, open cut requires excavation, installation of trench wall support, bedding and laying of pipe, embedment, backfill and compaction, and surface restoration. (Hashemi, December 2008) In the North Cornwall Township in Pennsylvania, a 2,000-foot segment of 14-inch ductile iron force main with a long break history needed to be replaced. One of the main challenges was coordination between the four municipalities that shared a stake in this pipeline. Two options were presented including replacement on a similar alignment and installation of a parallel force main to create two separate systems. While trying to come to a common consensus, the force main suffered its 5th break over a span of 4 years, and the Pennsylvania DEP issued a Notice to Violation for unauthorized discharge of wastewater into a nearby creek with threats of fines up to $400,000 should another break result in unauthorized discharge. As a result, all four municipalities agreed on the least expensive option to keep the force main combined.

In Knoxville, TN, open cut methods were used to replace the largest inverted siphon in the system which was a 12-inch and 24-inch duel pipe system. The project was driven by an EPA consent decree, and upon inspection, the utility found a blockage in the 12-inch siphon. As a result, the project schedule was fast-tracked, and the siphons were replaced with 878 LF of 18-inch and 24-inch diameter ductile iron pipe. The double barrel system was installed on a parallel alignment to the existing system.

Issues encountered included a 5-month construction delay due to permitting reviews as well as the discovery of a prehistoric site at the inlet structure with fragments from 370 to 100 BC.

## 4.4 State of the Art Practice Review for Drinking Water Pipeline System Renewal Technologies

### 4.4.1 Introduction

There is often an apparent disconnect between the state of the industry as portrayed by academia through research reports and conference/journal publications and the true state of the industry in the eyes of the actual infrastructure owners. Industry conferences and journals are excellent methods for academics and technology providers to showcase innovative technologies and advanced technology applications, and while these outlets are useful for raising awareness of solutions available to solve pipeline system problems, they capture only snapshots of the complete picture of technology use in the industry.

In the past, academics, industry professionals, and infrastructure owners alike have been able to easily collect information from existing literature sources on the vast array of products available in the market today, but the literature is not necessarily an accurate representation of the technologies most commonly used in practice. Technology providers are also more than willing to supply information on their technologies, but this information only provides a picture of what is available to infrastructure owners. In reality, most of the water and wastewater utilities in the United States only utilize a handful of the technologies available to them.

### 4.4.2 Intent and Scope of Review

This State of the Art Practice Review will seek to define the true state of the industry with regards to wastewater pipeline renewal technology use. The content is based on the experiences of utilities captured through a series of technology use case studies that were developed as well as through interviews with key utility personnel. The objective of the review is to determine the following:

1. Which technologies are being implemented by utilities and how often;
2. How the technologies are being used by utilities in their systems;
3. General benefits and limitations of the technologies; and
4. Primary cost drivers for technology applications.

This Review will provide the above determinations for utilities in the United States as a whole and defines each in terms of the drinking water pipeline renewal technologies listed above in the “Background Information Section” of this thesis. There are an incalculable number of technologies available for wastewater pipeline renewal and even more products that make use of different combinations of technologies, making it impossible to address every technology available in the industry today. The broad technology classifications and types have been carefully selected to encompass the more specific technologies and products available in an effort to provide useful information on as many different technologies as possible.

### 4.4.3 Approach

Wastewater utility participation was essential to a thorough investigation of the true state of the industry. Utilities all across the nation and even were contacted to participate in the initiative to document overall utility experiences with drinking water pipeline renewal technologies, and 29 full and 3 abbreviated case studies were developed to capture as complete a picture as possible. At the end of the development period for full case studies which require a great deal of data and time to develop, abbreviated case studies were developed that captured only the basic information of technology use including, but not limited to, information such as technology type, product name, project location and conditions, project length, pipe types and materials involved, and benefits/limitations for use.

The objective of case study development was to provide a clear view of the state of the drinking water industry related to pipeline renewal technology use, so it was desirable to cover an even distribution of technology types as well as an even geographic distribution of utilities. Table 4-10 shows the distribution of technologies covered by the case studies. Table 4-11 below shows the geographic location of utilities for which case studies were developed. Upon review of the case study by the utility involved and an expert on the topic, case studies will be published in the new Water Infrastructure Database, WATER*i*D. Case studies for technology uses across the nation were able to be captured, with the exception of EPA Regions 1, 2, and 7. While initial meetings were held with people in that region, either timing was not appropriate for them to participate or there were critical issues with the transfer of private data.

**Table 4-10.** Wastewater Technology Case Study Distribution

| WW Full Case Studies | | WW Abbrev. Case Studies | |
|---|---|---|---|
| Repair | 4 | Repair | 0 |
| Rehabilitation | 10 | Rehabilitation | 1 |
| Replacement | 15 | Replacement | 1 |
| **Total** | **29** | **Total** | **2** |

**Table 4-11.** Geographic Distribution of Case Studies

| | EPA Region - WW | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **Repair** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 |
| **Rehabilitation** | 0 | 0 | 3 | 1 | 4 | 0 | 0 | 2 | 1 | 0 |
| **Replacement** | 0 | 0 | 3 | 4 | 2 | 3 | 0 | 1 | 1 | 2 |
| **Total** | 0 | 0 | 6 | 5 | 6 | 3 | 0 | 3 | 2 | 2 |

### 4.4.4 Wastewater System Pipe Repair Technologies

Three full case studies and one abbreviated case study were developed for pipe repair technologies. However, most of the project included the use of multiple technology types and will appear below more than once as the case studies are discussed below by technology type. If a technology does not appear below, no case studies were developed that represented it.

**Pipe Point Repair Technologies**

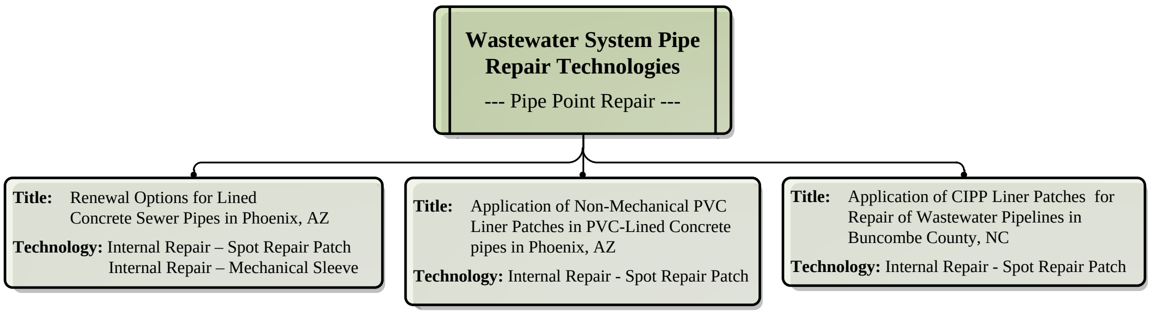


**Figure 4-15. Wastewater System Pipe Repair Technologies – Point Repair Technologies**

There were a total of 3 case studies developed for point repair technologies as shown in Figure 4-15 above.

Buncombe County, NC has used CIPP Short Liners extensively in their system to renew almost every type of pipe material in their system, with the exception of Orangeburg pipe which is removed upon discovery. CIPP short liners are used to repair a single defect or very few defects that are close together and that do not threaten the structural integrity of the pipeline. This technology is more cost effective than relining the entire segment when the defects are localized. The benefit of this technology is that it allows for repairs under streets or other above ground obstructions where excavate and repair technology applications would be far too costly. The short liners also require little to no design or right-of-way acquisition for installment, and they are purchased in pre-packaged kits and can therefore be purchased ahead of time to be kept on hand. Weather was an important factor for Buncombe County to consider because of their location in the mountains of North Carolina. Cold weather can make installations more challenging because it slows down the curing process. The CIPP patch preparation and insertion into the manhole are shown in Figure 4-16.

**Figure 4-16.** Resin Application (left), Wrapping of Liner on Inflatable Device (center), and Insertion of Liner into Manhole (right) (images courtesy of the Metropolitan Sewerage District of Buncombe County, NC)

The City of Phoenix used non-mechanical PVC liner patches to repair defects or failed joint strips on the PVC-Liner installed to the interior of concrete sewer pipes to protect them from corrosion. Joint strip failure was the most common problem cited by the City in use of the PVC-Liner. If the defect was small enough (nail head hole, nick, small cut, etc.) a joint weld strip could be hot-air welded into place to seal the defect. For larger cuts, blisters, or pockets where the weld strips had "let go" of the PVC Liner, the existing liner had to be cut out, the area cleaned, and a new patch of PVC material welded into place. An interesting note made by the City regarding the installation dates of the failed weld strips. Initially, the manufacturer sent their trained staff to make the welds. Once they stopped, certified contractors began performing the welds and the rate of weld strip failure increased. Where numerous defects exist, it is worth considering a more cost effective technology such as a CIPP Short Liner like the ones used in the Buncombe County system since removing defects and welding patches becomes tedious where several are required close together. The limitations of this technology include its heavy reliance on the quality and training of the installer and the need in some cases for the use of a temporary bypass system. Figure 4-17 shows an example of a repair with just a weld strip and with a larger piece of new PVC material

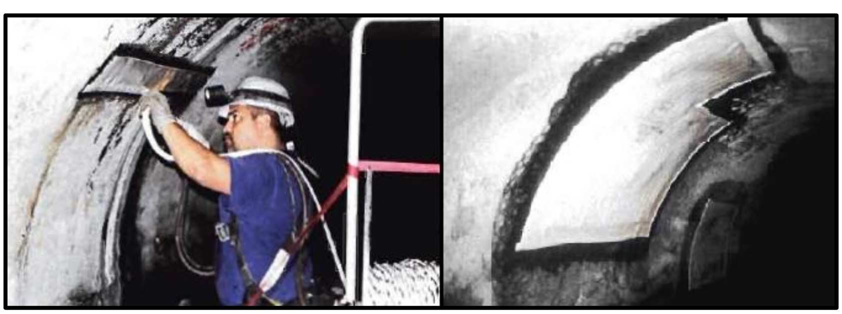

**Figure 4-17.** Small Patch Repair (left) and Larger Liner Patch Repair (right) (Project Engineering Consultants, LTD. , August 31, 2005)

As an extension of the PVC-Lined concrete pipe point repair case study, a second case study was developed to capture the other technologies used or at least considered as repair options. A second type of point repair technology that is useful for small pipe-wall defects is an internal mechanical sleeve. The sleeve must be centered over the defect so that it covers is sealed to least 6-inches of sound pipe wall on any side of the defect. The sleeve is held in place with jacks while grout is injected into the annular space between the sleeve and host pipe. The grout provides extra strength for the collapsible sleeve and locks it into position so that even when the hinges rust away, the sleeve will be firmly locked in place. The limitations of this technology are that it can only be installed within pipelines greater than 30-inches in diameter and may require bypass pumping for installation depending on project conditions.

**Pipe Coating Technologies**

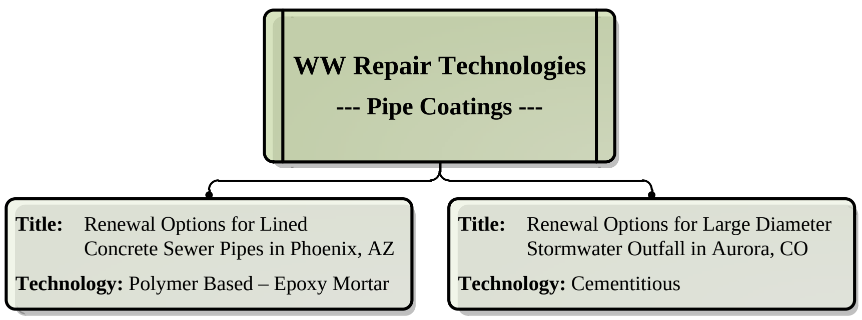


**Figure 4-18.** Wastewater System Pipe Repair Technologies – Point Coating Technologies

There were a total of 2 case studies developed for point coating technologies, one for cementitious and one for epoxy, as shown in Figure 4-18 above.

A second repair option that has been successfully used by the City of Phoenix for repair of their PVC-Lined concrete sewer pipes is coating of PVC Lining with a three-component epoxy mortar lining that consisted of a base, a hardener, and aggregate to create a protective coating that could withstand both harsh chemical reactions and abrasion. It is very important to properly prepare the surface of the pipeline before applying coatings, and in fact, this is one of the commonly cited limitations by utilities who use any type of coating. If the surface of the pipe is not adequately cleaned, the coating will not adhere to the pipe wall and delamination is inevitable. Also before application of the coating, deep defects had to be repaired to create a smooth, even surface for application. Another drawback is the time required for full curing of the coating which can be up to 28 days.

Aurora Water also used coatings as one of the methods for repair of their 96- and 120-inch diameter outfall pipe. A thick layer of cementitious grout material was applied along the invert of the pipeline, extending up the pipe wall far enough to prevent water from touching the metal pipe material. As is evident in Figure 4-19, the interface of the grout-pipe wall interface had begun to corrode. This was due to high flow levels that would sometimes rise above the grout coating and cause water to pool on the edges of the partial coating. A 4-inch thick layer of grout was applied to extend the current coating 3-up the pipe wall towards the crown on each side. This would stop deterioration and corrosion from spreading.

**Figure 4-19.** 4-inch Thick Cementitious Coating Applied to Pipe Invert (ICON Engineering, Inc., February 2008)

### 4.4.5 Wastewater System Pipe Rehabilitation Technologies

### Cured in Place Pipe (CIPP) Liner Technologies

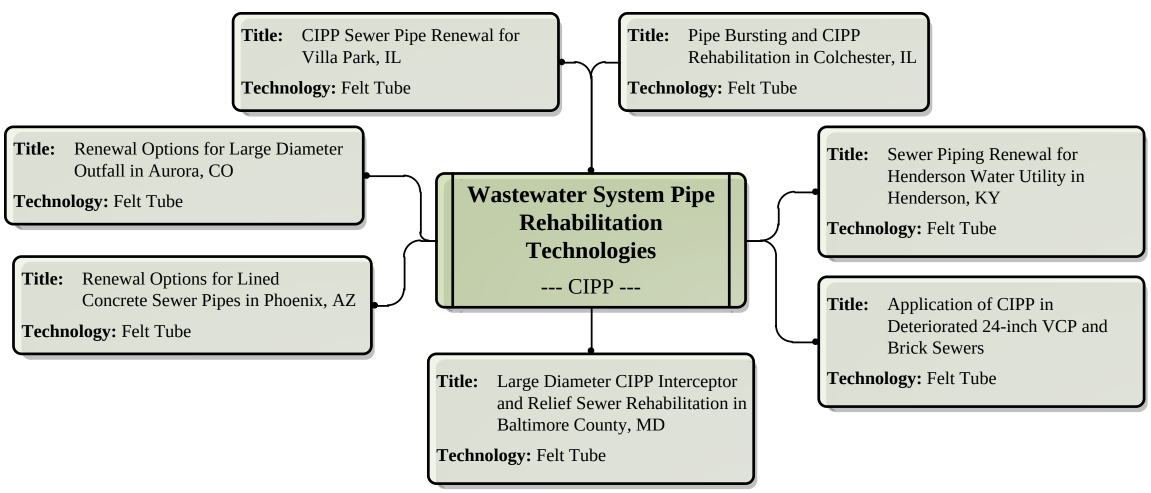


**Figure 4-20.** Wastewater System Pipe Rehabilitation Technologies – CIPP Liner Technologies

Figure 4-20 above shows examples of CIPP Liner technology use in practice. In two of the case studies, CIPP Liners were discussed as options for renewal. The City of Phoenix considered it for the rehabilitation of their PVC-Lined concrete pipes, in part because it would eliminate the need to repeatedly repair the failing joint weld strips. A standard, felt tube CIPP liner would be used, and one of the main limitations would be the requirements for a temporary bypass system to be installed. Aurora Water also considered it for their large diameter outfall rehabilitation project, but it would only be available for use in the 96-inch portion of the renewal project due to the technology limitations for pipe diameter set by the manufacturer. Even the 96-inch CIPP Liner was limited to pull-in lengths of 200-feet, and curing would take a full 24-hours.

In Villa Park, IL, CIPP Lining was used in conjunction with directional drilling to rehabilitate several segments of sewer main ranging in diameter from 8- to 18-inches. Over 50,000 LF of sewer main was lined in all. The driver for installation of the CIPP Lines was excessive I/I in the system. The project was challenging due to its location in an urban/suburban area where impacts to several surface obstructions, traffic, and business operations had to be strongly considered. Because it was hard for the City to estimate levels of I/I before system rehabilitation, the effectiveness of I/I removal was marked by the 15% and 30% reductions in total inflow for a 1-year and 30-year storm event respectively.

Like Villa Park, Henderson Water Utility used CIPP Liners as the primary rehabilitation method, using it to address issues throughout the system with water tightness and structural integrity. It was used to rehabilitate over 18,700 LF of combined sewers ranging in diameter from 8- to 48-inches, and once rehabilitated, the combined sewers were turned into sewers to carry stormwater only. New pipes were installed to handle wastewater flows. The initiative to separate combined sewers into stormwater sewers and gravity mains is a common initiative throughout the nation since it greatly reduces the flows the system has to handle after rain events, thereby reducing the risk of overflows. Like many other utilities, the City of Henderson initiated their sewer rehabilitation as part of a control plan agreed upon with the EPA. The major challenge faced was the installation of the liners through the historic downtown where surface, traffic, and business disruptions had to be kept to a minimum. The City used steam curing which reduces the cure time to between 8 and 10 hours. A limitation the City experienced was that some of the pipe was not structurally sound enough to support pull-in of the new liner, so exhume and replace methods were required. Figure 4-21 below shows the bypass system and CIPP installation.

**Figure 4-21.** Temporary Bypass (left) and CIPP Installation in the City of Henderson (center and right) (images courtesy of the City of Henderson)

The City of Columbus, OH used CIPP Liners to rehabilitate two segments of a 24-inch VCP sewer interceptor that was originally installed in 1913. There were a number of challenges to overcome including several bends with joint deflections ranging from 5° to more than 17° as well as installation beneath dense residential developments, recreational park areas, and along the bank of the Olentangy River. A traditional felt tube liner was used which provided a structural solution at costs that were estimated to be 30-40% less than that of using open trench methods.

There were a number of important lessons that came out of the Columbus, OH CIPP Liner installation. Originally, the City tried using grout packer systems to because of the issues expected with CIPP Liner installation in areas where there were a significant number of joint leaks. This failed, however, because river water was leaking into the system at velocities greater than what had been anticipated, causing wash-out of the grout before it had time to cure. To fix the problem, a pre-liner was installed prior to CIPP lining that would protect the liner from resin wash-out and allow it to properly cure. A thicker CIPP liner was also utilized so that even if outer layers of the liner could not cure, a minimum thickness of the inner layers would still be able to cure to provide adequate structural support. The last adjustment made to the system was the use of an advanced resin containing Alumina Trihydrate enhanced polyester which had the capability to absorb heat from the circulating hot water much more quickly than typical resins, dispersing it through the walls more quickly and evenly to facilitate curing of the liner.

The City of Columbus, as part of the same project, also used CIPP Liners to rehabilitate a collapsed 30-inch 3-ring brick sewer in need of immediate attention. Man-entry was required to apply a flashcoat of shotcrete reinforced with welded wire fabric to stabilize the crown of the pipe and replace missing layers of soil, brick, and mortar as well as to make certain that the pipeline was safe for workers applying the shotcrete.

With the shotcrete in place, the CIPP Liner was pulled into the host pipe for inflation and curing. A pull-in process was used to install the liner, but as the liner was pulled in, it dislodged loose bricks which then fell into the pipe invert and were subsequently lined over. The lined-over bricks were discovered during the post-installation CCTV inspection, and the contractor had to cut out the areas, remove the brick, and install CIPP Liner Patches to create a smooth liner. The City banned pull-in-place methods for brick sewers as a result of this project. While the CIPP liners were beneficial because they allowed rehabilitation of pipelines in environmentally challenging areas, additional costs were associated with specialized liner modifications, and pull-in methods caused further issues. Ultimately, however, the CIPP liners were successful in rehabilitating the system.

In Catonsville, MD, Baltimore County used CIPP liners to rehabilitate 39,000 LF as part of a project involving a major interceptor and relief sewer. The concrete tile Interceptor Sewer ranged in diameter from 21- to 54-inches, while the relief sewer was an RCP with diameters ranging from 48- to 72-inches. The County performed an extensive visual inspection and evaluation for several renewal options before settling on CIPP for its ability to be installed trenchlessly and for the fact that it simplified access issues associated with the location of the pipeline along a river through major park lands. The County had several environmental issues to work around including the proximity to the Patapsco River, heavily vegetated areas with forest stands, wildlife habits, a resident bald eagle, and 8 defined wetland areas. All of the environmental concerns made permitting a significant challenge in itself, and one of the lessons learned by the County was the criticality of communication between all involved agencies as early on in the project as possible. Access issues were resolved through the construction of temporary wood-plank roadways that could be easily installed and removed without harm to the surrounding environments. Weather conditions were also a factor, and an on-site wet out facility had to be enclosed in a heated tent to prevent premature curing of the liner after impregnation. The County also noted the important role groundwater plays in CIPP liner installations because high groundwater levels can lead to leaking of lateral connections or joints, proper curing of the resin may not be achieved. Figure 4-22 below shows the installation process in a CIPP Liner project.


**Figure 4-22.** Inversion Equipment Setup, Dispersion of Resin after Impregnation, and Inflated Liner Passing through Manhole (images courtesy of Baltimore County)

The City of Colchester, IL turned to CIPP liners after pipe bursting was more time intensive and difficult than anticipated. There were two primary concerns identified with the use of CIPP liners in this project. The first was that the poor condition of the host pipe would not support installation of the CIPP liner, and the second was that the reduction in cross-sectional area would reduce hydraulic capacity which was already a concern. A hydraulic analysis, however, indicated that although the cross-section was reduced, the significant improvement to the friction coefficient could double the hydraulic capacity of the pipeline. 65 LF of cast iron pipe was successfully rehabilitated beneath a main arterial street, and the utility stressed the advantages they found with maintaining flexibility throughout the project and keeping all options on the table since ultimately project site conditions are often associated with unknown factors that dictate the direction of the project.

**Fold and Form Pipe (FFP) Liner Technologies**

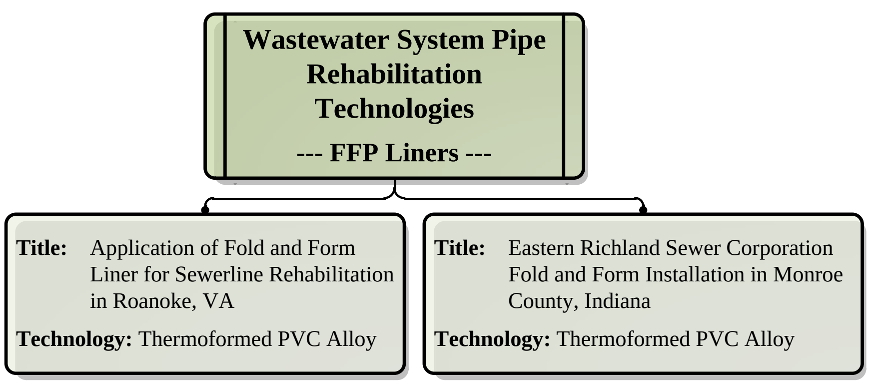


**Figure 4-23.** Wastewater System Pipe Rehabilitation Technologies – FFP Liner Technologies

One full case study and one abbreviated case study were developed for FFP liner technologies as shown above in Figure 4-23. Both utilized Thermoformed PVC liners to rehabilitate multiple runs of pipeline, and both had issues with minor defects in the liner wall that were identified during post-installation inspections.

The Western Virginia Water Authority in Roanoke, VA has used FFP liner technology extensively to rehabilitate sewerlines in their service area. In 2008 a thermoformed PVC liner was used to rehabilitate 6, 273 LF of 8-inch concrete and clay pipe. The project required the reinstatement of 42 laterals as well as the removal of 2 protruding laterals. The project was initiated to solve issues with high rates of I/I due to root intrusion. An important lesson learned was the criticality of temperature in steam curing. If the steam does not reach the temperature specified for curing, 180° in this case, the liner may not be able to cure completely, increasing the risk for liner failure. Inadequate heating caused small pinholes to form on the liner as it stretched that showed up on the CCTV camera screen as small black dots. As a result, the liner had to be removed and re-installed. In a different project, the Authority had a contractor line over a 'stump' root that was not cut all the way out, so once the lining was in place, there was no way to remove it without removal of the liner. The velocity of the water through the pipeline was not such that the protrusion caused any performance issues, but the experience highlighted the need for improved QA/QC during liner installations. The primary benefits of FFP liners for the Authority was the reduced construction footprint and disruption to the public, increased productivity compared to dig and replace methods, and reduced project costs compared to dig and replace. Since laterals can be reinstated robotically, the installation is completely trenchless in most cases.

In much the same manner, Monroe County, Indiana, used a thermoformed PVC liner to rehabilitate about 550 LF of 12-inch, 3,894 LF of 10-inch, and 30,183 LF of 8-inch VCP sewer pipe. They noted the importance of having a good contractor to work with, and the only challenge was in repair of minor liner defects located during the post-installation CCTV inspection. These repairs were taken care of by the contractor without any issues.

## Grout-in-Place Pipe (GIPP) Liner Technologies

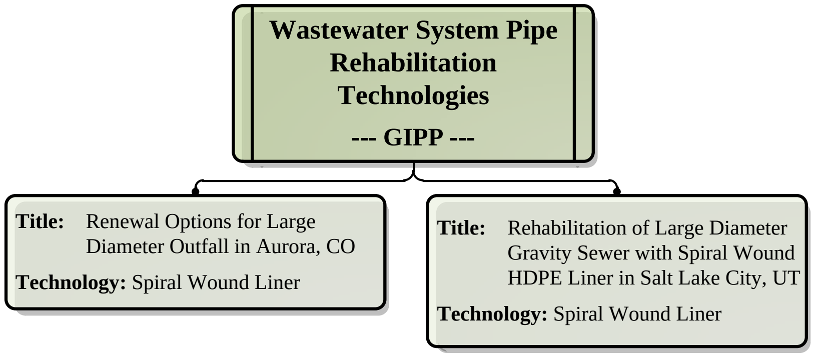


**Figure 4-24.** Wastewater System Pipe Rehabilitation Technologies – GIPP Liner Technologies

Two full case studies were developed for GIPP Liners as shown in Figure 4-24 below. Both were for Spiral Wound Liners.

In Salt Lake City, UT, 3,375 LF of 66-inch RCP close to the wastewater treatment plant was in need of rehabilitation due to severe deterioration caused by hydrogen sulfide attack. The City chose machine wound spiral wound liner as the solutions. The location of the trunk sewer in the downstream reaches of the system, beneath a railroad, and beneath an interstate made it a critical asset because failure would impact the ability of all upstream wastewater flows coming to the treatment plant as well as railroad and interstate traffic. The location also meant that the pipeline could not be taken out of service. Additional challenges were associated with a large radius bend just before the treatment plant, businesses that would be cut off from direct access during some parts of the construction activities, and cold temperatures which can prevent adequate weld seams from being achieved. The temperature issue was resolved by pre-heating the liner material in an enclosed tent prior to installation. Another issue identified in the design stages was the presences of high groundwater pressures that were too great for liner installation. The City first thought to pump out the groundwater and discharge it back through the sewer, but this increased the TSS in the sewage, violating permits for discharge into the wastewater treatment plant.

A second challenge came when the bends could not be negotiated with the spiral wound liner unless shorter segments were wound and joined, so CIPP liners were deemed to be more cost effective in those areas.

A steep slope in the alignment caused problems when higher than normal velocities broke the pipe loose from its restraint one night, pulling the pipe material from the spool down the manhole and into the pipeline. An 18-inch ABS pipe was installed to bypass night flows after that incident. The steep slope also caused difficulties in keeping the wound segments in place long enough to be welded together. The spool holds material for lining up to 200 LF of pipe at a time, so each of the individual segments have to be hand-welded together with a PE joint strip. Initially, a packer system was used to isolate the joint for welding, but the packer system was too difficult to keep in place on the slope. The contractor was able to perform welding at night during low-flow conditions to solve this issue. The importance of achieving a good weld seam was highlighted later in the project when failure of a joint seam allowed grout to leak into the liner. The segment had to be removed and re-grouted, increasing construction costs.

The last important challenge was associated with grouting of the annular space. Initially, the contractor floated the pipe, but maintaining a constant slope down the entire alignment proved to be difficult and tedious. If a constant slope is not maintained there will be bows in the profile of the pipe alignment. The contractor decided to grout in short segments with 3 grout lifts per segment to ensure an even distribution of grout within the annular space. The primary benefits to the City associated with spiral wound liners is their structural capabilities, high chemical resistance, and ability to be installed trenchlessly with no bypass pumping requirements unless specific project situations require it. The limitation of the liner included the difficulties associated with achieving well-bonded weld seams.

Aurora Water also considered spiral wound liners in their large diameter outfall rehabilitation project, citing its advantages to be its completely trenchless installation. The drawback, however, was the increased costs an d difficulties associated with grouting of the annular space.

**Sliplining**

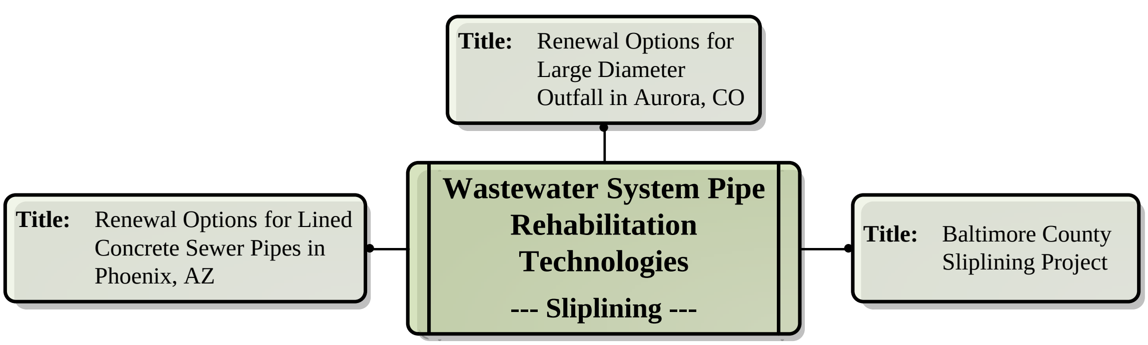


**Figure 4-25. Wastewater System Pipe Rehabilitation Technologies – Sliplining Technologies**

Three total case studies were associated with sliplining as shown in Figure 4-25 below. One case study was developed for sliplining, but another two case studies included details of its consideration for use in general rehabilitation programs.

Baltimore County plans to use sliplining to rehabilitate approximately 4,000 LF of 54-inch pipe, but the case study developed focuses on a smaller project that included the sliplining of 100 LF of 54-inch pipe with a 50-inch pipe. One challenge that was encountered was due to a preliminary decision to fore-go inspection of the host pipe. During insertion, “kinks” in the host pipe caused the new pipe to get stuck, and it had to be removed so that the host pipe could be prepared for insertion. Extensive cleaning was the primary solution, and the removal of the liner pipe and cleaning extended the project schedule by two weeks. The advantages of sliplining for Baltimore County are that it is relatively economical and does not require specialized equipment or labor. The primary disadvantage is the loss in cross-sectional area. This simple case study highlighted the importance of host pipe inspection before rehabilitation, and the County also noted that the difficulty and planning requirements for sliplining increase as the host pipe and liner pipe get closer to the same diameter.

Sliplining was one of the first considerations for rehabilitation of the large diameter stormwater outfall in Aurora, CO. The first thought was to install a smaller diameter CMP liner inside the existing CMP pipe which would reduce the diameter of the 120-inch pipe to 102-inches and 96-inch diameter pipe to 84-inches. Ultimately, sliplining was not selected as the most appropriate method because of the extra costs associated with grouting of the annular space as well as requirements for excavations to facilitate pull-in of the new pipe liner. In much the same way, sliplining is one of the options for Phoenix, AZ when they need to renew their PVC-lined sewer pipes. The primary limitations associated with sliplining are the decreased diameter and requirements for excavation. Defects that exist in the pipeline such as crown indentations must be repaired before sliplining can be performed. Aurora investigated the use of CCFRPM pipe and Spirolite plastic pipe for sliplining, but costs were prohibitive in both cases.

### 4.4.6 Wastewater System Pipe Replacement Technologies

#### In-Line Pipe Replacement Technologies

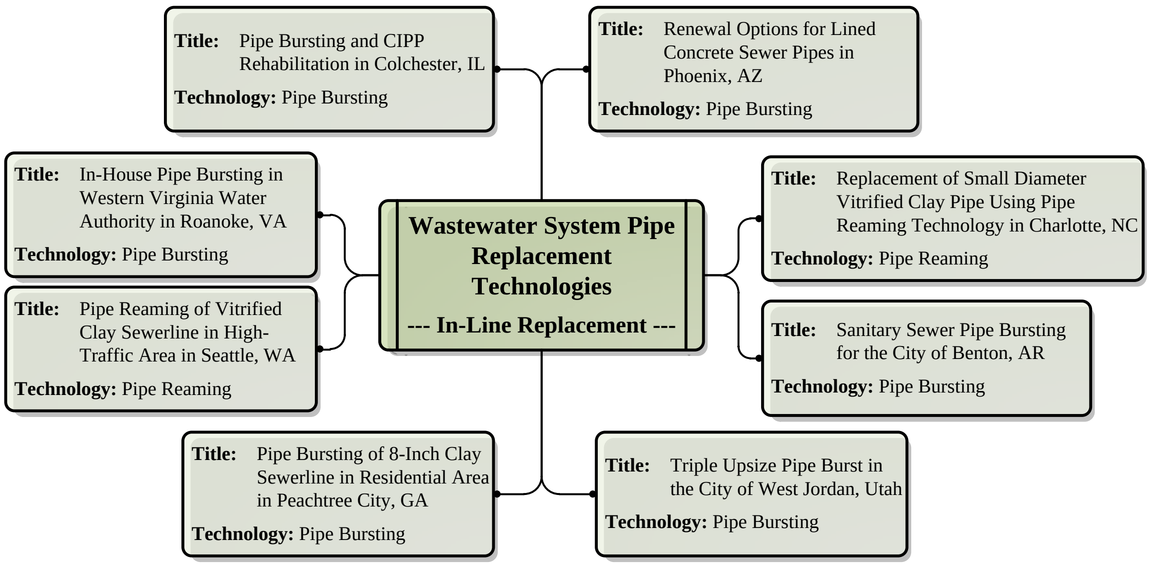


**Figure 4-26.** Wastewater System Pipe Replacement Technologies - In-Line Replacement Technologies

Eight full case studies were developed for In-Line Replacement technologies as shown below in Figure 4-26. This showed the popularity of pipe bursting, as all of the case studies were for bursting except for two which were developed for pipe reaming. The only discussion for open trench was inside case studies where utilities used it as a measure for the success of the project or to complete parts of the project where the other technologies could not be applied.

**Pipe Bursting**

The City of West Jordan, UT used pipe bursting to replace an undersized 10-inch concrete sewer pipe with an 18-inch HDPE pipe. The project installed approximately 4,000 LF of new pipe using static bursting techniques. Originally, the City had planned to use traditional open cut methods, but the location of the pipe in a tight utility corridor as well as in close proximity to underground utilities and overhead power lines made pipe bursting a more appropriate option. The soils were primarily silty gravels and clay which were not necessarily bad, but softer, more cohesive soils would be better for the degree of upsizing to be performed and to minimize the risk of disturbing surrounding utilities. The construction was performed in winter, so where bentonite lubricant would typically be used, it could not be used in the harsh winter weather. The installation process was mostly smooth, except for one segment where open trench was required and there was some difficulty in bracing existing utilities while maintaining a stable trench wall.

The City of Benton, Arkansas, also used a combination of open trench and pipe bursting to replace 22,000 LF failing sewerline. Pipe bursting was used to replace 16,000 LF of 6- and 8-inch host pipe with 8- and 10-inch pipe, respectively. A total of 50 bursts were required at an average length of 300 LF and with the longest run being 500 LF at 12-feet below the ground surface. Figure 4-27 below shows the launch pit and bursting head coming through the host pipe in this project.

**Figure 4-27. Launch Pit and Bursting Head in Benton, AR Pipe Bursting Project (images courtesy of the City of Benton) (TT Technologies, Inc., 2011)**

The City of Peachtree City in Georgia used pipe bursting in the summer of 2011 to replace 1,200 LF of deteriorated 8-inch clay pipe with 8-inch HDPE pipe. The defects existing in the line included root intrusion blockages, longitudinal and circumferential fractures, circumferential cracks, and offset joints. One of the benefits of pipe bursting for Peachtree City was the ability to keep excavations small. A total of 11 excavations were necessary, and at the end of the project only 220 square yards of asphalt required replacement. A limitation is the number of pits needed, one for each lateral connection or appurtenance that required reconnection. A second limitation was the requirement for temporary bypass during installation.

The pull-in was performed continuously, so the entire string of HDPE pipe was fused and laid out behind the insertion pit. The total operation took approximately 3 weeks to complete, and the temporary bypass was provided only for the segment under construction. Only one significant challenge was met in bursting which was an unexpected buried outside drop encased in concrete that was not on the plans. This led to changes in contractor submittal requirements in future projects since it was the responsibility of the contractor to make sure the location of all existing underground utilities or obstructions is known.

WVWA in Roanoke, VA developed an in-house pipe bursting program due to the success the utility had in the past with pipe bursting operations. The utility uses pipe bursting as its primary means of replacement for pipelines that are 8- to 12-inches in diameter, but it notes that it is important to recognize that there are still some situations in which pipe bursting is not the best option. The utility purchased the pneumatic bursting equipment from a local contractor that was no longer interested in pipe bursting, and WVWA had its crew members trained in proper installation techniques. While bursting can be used to upsize pipes in some cases, WVWA uses their in-house crews only for size on size replacements. WVWA has found pipe bursting to be inappropriate for use where excessive roots are present, laterals are too flat, bedding soils are too hard, or where repair clamps have been used to seal leaks along the alignment. Flat laterals create issues because often times pipe bursting will change the grade of the sewer enough to affect flat laterals, while dense bedding soils can prevent even dispersion of the bursted host pipe particles, leading to significant changes in the new pipe alignment and grade. The most common challenges encountered are deep sewers and cold temperatures. Deep sewers increase the size requirements for excavation pits which is not always economical or possible in some locations, and cold temperatures reduce the flexibility of the new pipe, especially where materials such as HDPE are used.

Colchester, IL had an unexpected experience with the pneumatic pipe bursting of four cast iron and clay sewer pipes that crossed beneath Illinois Highway 136. The City expected that capacity issues were due to poor conditions of the pipelines due to SSOs in the area, and bursting was chosen as the best replacement method due to the location of the pipe beneath a major highway and because there was uncertainty in the capability of the host pipes to support rehabilitation methods such as CIPP or sliplining. While bursting was ultimately successful, the attempts on the cast iron segments were far more time and labor intensive than expected and in one 36-foot long segment, the pipe was actually being pushed, rather than burst. This segment was replaced by pushing and cutting the host pipe out at the end manhole in 3-4 foot increments. After this experience, the City investigated other options for the remaining pipelines, and ultimately, CIPP was selected for the rehabilitation of the last segment.

**Pipe Reaming**

Seattle Public Utilities used pipe reaming to replace 1,700 LF of sewerline that was originally installed in 1923. 450 LF of the pipe was 24-inch VCP, while the remaining 1,300 LF was 18-inch VCP. T The pipeline was located between 8 and 30 feet beneath 9th Avenue which is a very busy street within one of the fastest growing neighborhoods of Seattle. The sewerline was particularly susceptible to surcharging and surface flooding during major rain events which was problematic because of its location in the high-traffic Mercer Corridor, commonly called the "Mercer Mess". The sewerline had very flat slopes ranging from 0.05% - 0.27% and flowed away from Lake Union into a 72-inch brick-lined tunnel. The location was the primary challenge in the project, though there were a couple of issues during installation.

A total of 5 excavation pits were originally planned, but during the first pull in, the maximum pulling force of the rig was reached 200 feet into the 320 foot stretch. This required an extra access pit to remove the reaming head and make adjustments that would help reduce pulling forces. A second additional pit was excavated just before an intersection as a precaution because if the pulling force was exceeded beneath the intersection, excavation would be extremely expensive and cause major traffic disruptions. The rest of the drilling went smoothly except for one unexpected obstruction which was never identified, and connection to the 72-inch brick interceptor tunnel was expanded from 18-inches to 30-inches to facilitate connection of the new pipeline using concrete coring equipment, concrete fill, and timber lagging. The primary benefits to Seattle with regards to pipe reaming was the reduced likelihood for ground heaving compared to pipe bursting, especially where unconsolidated soils were present. It also posed less risk for damage to nearby utilities and reduced the number of required insertion /removal pits compared to pipe bursting. The primary disadvantage experienced was the requirement for a separation plant to remove material from the drilling fluid, increasing project costs compared to pipe bursting where the old pipe material is pushed into the surrounding soil tunnel.

The Charlotte Mecklenburg Utility Department in Charlotte, NC also used pipe reaming, but in this case it was used to replace 400 LF of 6-inch VCP with 8-inch HDPE pipe. While sewer main lines are typically installed beneath the roadways in residential areas, the mainline in this case was buried across the backyards of many of the homeowners. Work would need to be completed within a corridor approximately 15-feet wide in order to stay within utility easement CMUD owns around each of its sewerlines. The space limitations played a role in the available renewal options because only a narrow corridor would be available for construction activities. The renewal options were also affected by the shallow depths of the pipeline.

In addition, one of the backyards had an unstable concrete pad that had been poured on top of the sewer alignment, so the new pipeline would need to be installed beneath it without harming the pad. While replacement of the pipeline would cause inconveniences to the homeowners as the construction was in progress, several of the homeowners had many overflow issues that sometimes caused sewage backups into their property. In general, the homeowners were more than willing to work with the utility to fix these issues.

The primary benefits of pipe reaming were that it was able to reduce sags in the pipelines, decreased vibrations and ground movement compared to pipe bursting, and reduced the construction footprint and excavated areas. The reduced vibration and construction footprint were significant benefits because of the proximity of the construction work to residences as well as space limitations in the backyards. The primary limitation to consider in pipe reaming is that because it installs the new pipe along the same centerline as the host pipe, if upsizing is performed, calculations are required to make certain that the invert elevations work with the rest of the project and connections.

### Off-Line Pipe Replacement Technologies

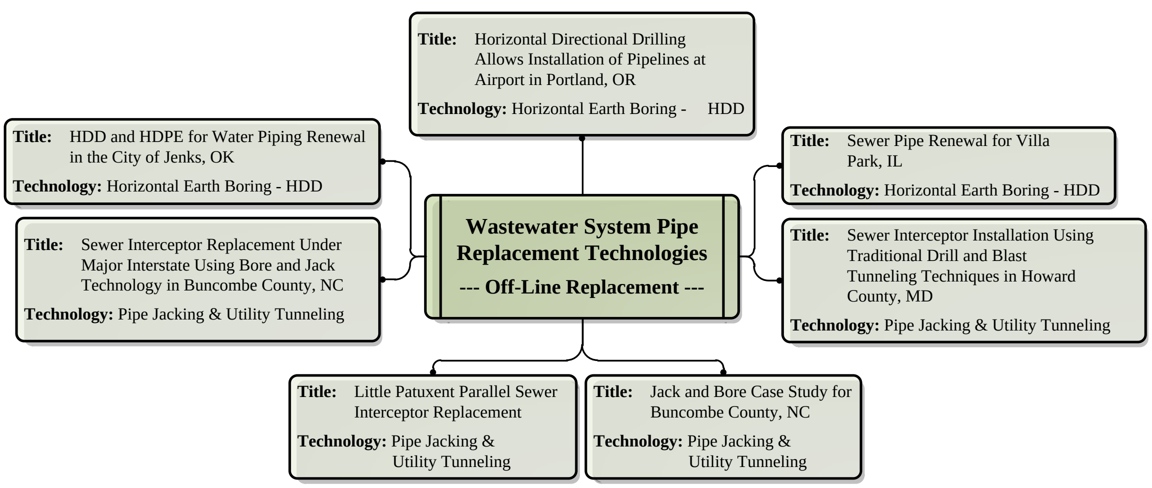


**Figure 4-28.** Wastewater System Pipe Replacement Technologies – Off-Line Replacement Technologies

Seven full case studies were developed for Off-Line Replacement technologies as shown below in Figure 4-28. There was a fairly even split of case studies available for HDD and Pipe Jacking & Utility Tunneling. The only discussion for open trench was inside case studies where utilities used it as a measure for the success of the project or to complete parts of the project where the other technologies could not be applied.

**Pipe Jacking & Utility Tunneling**

Buncombe County, NC used auger boring machines (ABMs) to complete a pipe jacking project with numerous challenges. The technology was used to install 296 LF of ductile iron pipe encased in 54-inch high strength steel pipe beneath a major interstate. The original pipe was an 18-inch clay pipe installed during the initial construction of the interstate. This installation was part of a much larger replacement project that used bore and jack in other locations as well, and the challenges associated with all installations are considered within the case study. One of the first challenges was associated with the soils in the area which were mostly compressible soft blue clay. To facilitate the construction of the interstate (during the late 1960's), rock was blasted from roadway cuts nearby and used to cover the blue clay soils for added stability. With regards to the current project, the bore and jack operation was planned to go through the area where the remnants of blasted rock met the original layers of blue clay. The loose fill rock created some difficulty during bore operations. The other main challenges in the project were installations beneath a steam generated power plant spur track and above ground conduit raceway for electrical and fuel supply lines. The current alignment of the pipeline ran beneath the power plant coal stockpiles, where machinery often dislodged manhole covers, allowing coal to fall into the sewer and cause blockages.

For the difficult soils beneath the interstate, the ABM was fitted with a hybrid cutting head. Part of the way into the installation of the casing pipe, however, the utility had to switch to a rock boring machine. The elevation of the new pipeline was such that it ran along the interface of the clay-rock fill material, but because the new sewerline had to connect with the existing, there was no way to adjust the elevation and avoid rocky material. One limitation of boring is that once operations begin, they cannot be reversed. When the boring head was switched out, the failed bore tunnel had to be abandoned and the encasement pipe filled with concrete to prevent issues with collapse since it was beneath an interstate where settlement would cause major problems. The new alignment was started just a few feet from the failed bore alignment, and the steel encasement pipe was lowered in and installed one segment at a time, with each subsequent segment being butt welded to the previous one. Installation of the carrier pipe took about a week, and once it was in place, the carrier pipe was pulled into place. Spacers are used around the carrier pipe to keep it on alignment, and care was taken during pull-in to ensure that the carrier pipe did not rotate so that all of the spacers would stay correctly positioned. The annular space between the carrier pipe and encasement pipe was filled with lightweight cellular concrete to keep the carrier pipe in alignment and to provide additional structural strength for the encasement pipe. Figure 4-29 below shows the boring machine at the receiving pit and the carrier pipe as it is pulled into place within the encasement pipe.


**Figure 4-29.** Auger Boring Machine at Receiving Pit and Installation of Carrier Pipe in Encasement Pipe (images courtesy of the Metropolitan Sewerage District of Buncombe County, NC)

The primary benefits of the auger boring machine was the ability to install pipelines beneath surface obstructions like interstates or railroad tracks, and they can also be used where excessively deep cuts would result in longer pipe runs with much flatter grades. Limitations include the increased costs associated with specialized equipment such as rock bores and the impact that soils and surrounding ground medium characteristics can have on the boring operations. Where multiple soil types are encountered, the bore tends to be pushed off of alignment.

Traditional tunneling techniques were used by Baltimore County to install a 355-foot long 42-inch FRP pipe within an 8-foot wide, 8.5-foot tall horseshoe tunnel. Traditional tunneling included drill and blast operations with hand removal of spoils in 6-foot increments. The accuracy of the drilling is very important for effective tunnel blasting. The design drill pattern changes based on the position of the blasting along the alignment, and the drill head is positioned according to the design drill pattern displayed on the rock face by lasers. The drill pattern specifies the angle, depth, spacing, and location of the drill holes so as to achieve the most effective breaking of the rock. Once the holes are drilled, the explosives are loaded by a certified blast technician, and detonation is achieved with either instantaneous or delay exploders in a sequence specifically designed for the current project and position along the alignment. Once the blast sequence has been fired, any un-detonated explosives, as well as dust and gasses need to be allowed to dissipate before workers can be allowed to re-enter the tunnel. A rock shovel is then used to move broken rock and excess earth to the mucking buckets which are transported to the tunnel entrance via locomotive along tracks and lifted out of the tunnel with a crane.

Traditional tunneling techniques were used because the site location had multiple access issues and was on a very steep, rocky river embankment. The existing pipeline had been installed in the river to avoid the earthwork related to open trench installation, but excessive inflow and infiltration as well as capacity issues led to the installation of a new, parallel pipe to help handle the flows. The primary advantages of traditional tunneling were the different options for tunneling (mechanical or hand) and the fact that it could be installed in most subsurface conditions. Both of these provide Howard County with flexibility to handle the construction of the tunnel where conditions were uncertain. The primary disadvantages were the slow pace of hand mining, safety concerns, high installation costs, and requirements for liner plates and a carrier pipe. Figure 4-30 below shows the tunnel during preparation for the next blasting.

**Figure 4-30.** Traditional Drill and Blast Utility Tunneling (images courtesy of Howard County Public Utilities)

**Horizontal Earth Boring**

**<u>HDD</u>**

Two separate installations were completed by the Port of Portland using HDD to upgrade the Portland International Airport (PDX) deiczing system. The first first segment was an installation at the Columbia River Outfall and included 1,100 feet of 30-inch high density polyethylene (HDPE) pipe. The second location required that 3,800 feet of 24-inch and 3,800 feet of 6-inch fusible polyvinyl chloride (PVC) pipe be installed within the same bore hole. The primary drivers for these installations were regulatory after low flow rates in the Columbia Slough made it difficult to meet permit requirements set by the Oregon Department of Environmental Quality. To control the buoyancy of the pipe string and simplify insertion, the 30" HDPE pipeline was filled with water. Figure 4-31 shows the Barge on the Columbia River and Pull-In of 30-inch HDPE Pipe at the outfall location.

**Figure 4-31.** Barge on Columbia River (left) and Pull-In of 30" HDPE Pipe at Columbia River Outfall (right) (Kinnan Engineering, Inc., 2009)

A whole different set of challenges had to be faced at the HDD installation beneath the active airfield. First, there were two lengths of 3,800 linear feet of pipeline that would need to be fused into continuous segments for pull-in, the 6-inch fusible PVC pipe for concentrated flows and the 24-inch fusible PVC pipe for diluted flows. The long length made it necessary to use land outside of the airfield space across a perimeter road and fence. However, airport security and access requirements made it necessary to keep the road in service and not disturb the fence, so the pipe string would need to pass beneath both obstacles. A temporary set of corrugated plastic culverts were put in beneath both obstacles, one for each pipe, to allow the pipes to cross without disturbing the road or fence. Figure 4-32 shows the two pipes crossing through the culverts as well as the overall pipe lay-down area.

Past the perimeter road and fence was green space which contained wetlands and other environmentally sensitive areas. The alignment had to be adjusted to maneuver around all wetlands and sensitive areas, and while it was possible to avoid all wetlands, another solution would be required to work around the sensitive areas. The pipe had to be carefully placed on rollers and arced to a safe distance at least 50 feet away from the sensitive areas. Fusible PVC is a relatively inflexible material, increasing the length of the arcs to ensure that the maximum bending radius of the pipeline was not exceeded. In general, the HDD technology had significant benefits to the Port because of its reduced costs compared to open trench methods, the minimal excavation and trenching depths requirements, reduced disruption to the surroundings, and the ability to complete work without any disruption to the primary functions of the airport. The primary limitation was the extensive space required for pipe lay-down, especially at the airfield where there was limited space and security issues where outside property was used.

**Figure 4-32.** Duel Pipe String Passing Through Culverts (left) (Kinnan Engineering, Inc., 2010), Pipe Lay-Down Area (right) (Jack R. Ostlund, 2011)

In Villa Park, IL, HDD was used in conjunction with CIPP Liner installations to rehabilitate several segments of sewer main ranging in diameter from 8- to 18-inches. The driver for system rehabilitation was to reduce the quantity of I/I entering the system. The project was challenging due to its location in an urban/suburban area where impacts to several surface obstructions, traffic, and business operations had to be strongly considered. Because it was hard for the City to estimate levels of I/I before system rehabilitation, the effectiveness of I/I removal was marked by the 15% and 30% reductions in total inflow for a 1-year and 30-year storm event respectively. An advantage for the City was eliminating the need to excavate within the city where several surface obstructions existed. Figure 4-33 below shows the stream beneath which HDD allowed the installation of the new sewer main.

**Figure 4-33.** HDD Crossing of Stream in Villa Park, IL

## 4.5 Wastewater System Pipeline Renewal Technology Usage – Synthesis of Current Practices from State of the Art Literature and State of the Art Practice Reviews

### 4.5.1 Purpose and Scope of Synthesis

In the above sections, the state of the industry was defined in terms of the technology practices commonly cited in literature and the technology practices based on case studies written to capture actual utility experience rather than vendor-driven claims. The experiences described in the previous sections are synthesized below to provide an overall view of the State of the Industry for Wastewater System Pipe Renewal Technology availability and use.

### 4.5.2 Pipe Materials

Traditionally, the materials used in gravity wastewater systems include VCP, RCP, Lined RCP, PVC, HDPE, Ductile Iron, Cast Iron, Asbestos Cement, and Brick. (Dr. Ray Sterling, May 2009). Gravity sewers in cities such as Boston and Philadelphia tend to have older systems which have many large diameter brick, oddly shaped sewers that present unique challenges in renewal. RCP is an especially popular material, but issues with deterioration of the concrete material led to an initiative within utilities to line the interior of the pipeline, at least partially, with a protective coating. Especially in the case of rehabilitation, there is an increasing amount of plastic pipe being used. This was clear in literature and practice, mostly due to the availability of pipe materials available for rehabilitation technologies. FFP Liners and most modified sliplining technologies use thermoformed pipe materials such as PVC and HDPE. Large diameter pipes continue to be materials that have been proven to be structurally sound over time such as cast iron and concrete.

Ductile Iron, Cast Iron, PVC, HDPE, PCCP, Steel, fiber reinforced plastic, asbestos cement, and RCP are the materials found in force main systems, with the majority up to 36-inch diameter pipe being ductile iron and above 36-inches being PCCP. (Dr. Ray Sterling, May 2009).

### 4.5.3 Drivers for Renewal

The Government Accounting Standards Board (GASB) Statement Number 34 was released in June 1999 and required all utilities to report the value of all assets on a balance sheet. The value could be calculated using a standard calculation for infrastructure depreciation expenses based on historical acquisition costs or through implementation of an effective asset management system which required proof that the utility was maintaining assets at least well enough to meet minimum standards or spending enough on maintenance to prevent deterioration. The enforcement of GASB 34 forced several wastewater utilities to start accounting for what they had in their system, a significant advancement, since many utilities had no idea what condition their pipelines were in. Perhaps even more so than the regulations forcing utilities to be held accountable for their assets, EPA has issued consent decrees to utilities with excessive SSOs or CSOs in their system, giving them a certain window in which to reduce their overflows, with checkpoints along the way. State DEQs also issue mandates to utilities where, for example, for violations of point source pollution, an example of which was in Portland when discharge from an outfall into a low-flow slough of the Columbia River violated NPDES permit restrictions set for BOD levels. (Port of Portland, 2009) Regulatory action for overflow control and mandatory accounting for assets have become important drivers for wastewater pipe renewal, and many utilities have set goals for the minimum percent of their pipelines that need to be renewed each year to stay on track.

Driven mostly by the EPA issued consent decrees, many utilities base their renewal decisions on how they can achieve the greatest reduction in I/I into their systems. Condition assessment techniques and flow monitoring are often used to identify areas within the wastewater system that are large contributors to I/I, and the pipelines in these areas become candidates for renewal. Nashville Metro Department of Water and Sewer Services has been a leader in I/I reduction strategies and actively uses renewal technologies such as CIPP liners to achieve their reduction goals (G.E. Kurz G. B., 2009).

A number of typical issues encountered in wastewater systems also drive the implementation of pipeline renewal technologies. Many of the cases from literature dealt with the renewal of pipelines that had a long history of leaks or breaks, or they were renewed as part of much larger projects aimed at renewing an entire portion of the service area. According to the May 2009 EPA State of Technology Review Report for *Rehabilitation of Wastewater Collection and Water Distribution Systems*, the following defects are most commonly affecting the integrity of gravity sewers: Joint leaks, misalignments and separations, cracks, internal corrosion, grease build-up, root intrusion, excessive pipe deflection, lateral connections/leaks, and grade/alignment issues. This was mostly reinforced by literature and practice since one of these factors was noted as the underlying cause for renewal. The reduction of fats, oils, and grease (FOG) build-up has been a large focus recently, and education has been the key to success. This carries over to other types of renewal projects, as utilities have learned over time to communicate with citizens more effectively. Citizens that are educated about the signs of a deficient sewerline in their area can help utilities identify problematic regions of their service area, and for that reason, records of customer complaints, odor complaints for example, are often kept track of in terms of the type of complaint and their location.

### 4.5.4 Trends by Technology Categories

A general trend in technology usage was seen through literature and in practice, and these observations are discussed below.

**Repair Technologies**

For pipe joint and leak seals, many of the reports stated that the most popular form of repair was chemical grouting (Robert S. Amick, December 2000). However, examples of actual chemical grout packer uses were not easy to find. It was easier to find examples of joint repair by mechanical sleeve or re-welding of joint strips. Most of the examples of repair technology uses from literature were repairs made to pipelines before rehabilitation could take place, for example, (Kozman, August 2002), (Vivian Housen, March 2004) (Miriam Siegfried, March 2004) all required repair before rehabilitation could be completed. In practice, most utilities that were asked about their repair practices responded that it was the responsibility of their maintenance crews. This meant that other than the records indicating that the repair was completed, there was no further information on the projects.

Pipe point repairs were the most common type of repair found in technology use examples from literature. These were also the most common form of repairs listed by utilities when asked about their pipe repair practices. More specifically, utilities tended toward the installation of pipe material or welding strips because the methods were easy and inexpensive. The City of Phoenix and Buncombe County, NC are two examples for this. Phoenix used welded in place PVC material, while Buncombe County used CIPP short liners. Like with pipe joint seals, a common use for point repair is to use it to prepare the host pipe for renewal. It is also used to seal defects in liners after installation (Kozman, August 2002) . The WVWA case study also documents the use of point repair following renewal when they used it to seal the pinholes in their newly installed FFP Liners. Another type of point repair mentioned was fiber reinforced pipe wrap, but is primarily used for force mains where used in sewer applications. This technology is more common for waterlines.

Pipe coatings are used to prepare pipe for renewal, as was demonstrated by Norristown, PA, when a cementitious swath was required to fix severe corrosion, pitting, etc. with the pipe invert before it could be rehabilitated with SIPP Liner. (Erez N. Allouche, June 2009) Extension of the coating in a pipeline in Aurora was used for the same reason, as documented in the case study for SIPP Liners, to cover areas of severe corrosion. A common practice among utilities is to line their pipes, especially concrete, with some type of protective interior lining to protect it from corrosion. Most utilities choose a cement mortar.

**Rehabilitation Technologies**

One of the main benefits of choosing rehabilitation is that several of the technologies can be installed trenchlessly or with minimal trenching requirements. Manholes are used to provide access into the pipeline whenever possible. While some technologies, particularly those that install plastic pipes, can use robots to reinstate laterals, some forms of rehabilitation such as sliplining with metal pipe, require laterals to be reinstated by hand. Where there are multiple connections or appurtenances that require replacement or excavation for reinstatement, it is more cost effective at some point for the utility to just excavate the entire pipeline rather than rehabilitate it.

CIPP liners are the most commonly used technology for wastewater pipeline rehabilitation today. With the expiration of the Insituform patent, many contractors and technology providers have developed their own CIPP liner systems, but not all are created equal. It is important to perform materials testing and be sure that the liner being installed is using high quality materials. Compromising on lower grades of felt or lower grades of resin can significantly decrease the lifespan of the product. (Gerhard P. Muenchmeyer, January 2007) While there are three different types of hoses available for CIPP (felt, woven hose, and reinforced hose) only examples of felt tube were found. In one case in California, a woven hose liner was considered for the rehabilitation of a force main, but there was hesitation because no good examples of its use existed in the United States. (Vivian Housen, March 2004) CIPP liners have been on the market for about 40 years, and as such, utilities have not gotten very comfortable with the use of the liners in their wastewater systems. There are also a plethora of available contractors which tends to reduce overall project costs in a competitive bidding process.

Spiral wound liners seem to be the recent trend for GIPP Liners, with many examples of their installation available in literature (Bruce J. Corwin, 2010) (Mark M. Behe, 2009), as well as in practice. Many of the larger utilities such as WSSC and those in the San Francisco Bay Area have used spiral wound liners, though there are no good sources that exemplify use of the product in small utilities. The other somewhat popular GIPP Liner is panel-lining which was used in Fort Wayne, but there is still not a great deal of documentation for actual applications. Information is available through reports such as the EPA State of Technology reports or the *New Pipes for Old* report by Jason

Consultants, Inc (Jason Consultants International, Inc., 2000), but these only provide the technical information, not examples of use.

The other common practice is cementitious SIPP Liners. While there is extensive research underway on the applications of high build polymer based linings, there have been no great examples of successful implementation in America. Many utilities use Cement Mortar Lining for structural rehabilitation, as well as shotcrete with welded steel reinforcements. This seemed to be a common practice for the large diameter brick tunnel renewal projects, and was usually at least considered for use if not chosen.

Sliplining, modified sliplining, and FFP Liners are used, but not heavily compared to CIPP Liners. The literature available for examples of CIPP use dwarfed that available for any other type of rehabilitation, especially modified sliplining and FFP liners. There were many utilities that use sliplining regularly to provide a completely new pipe without destroying the host pipe, but the main hesitation is the decrease in diameter and therefore reduction in capacity (usually). Continuous sliplining requires long lay-down areas for pipe fusion which can also make it a less attractive option.

**Replacement Technologies**

Open trench construction is still the most common method for pipeline installation and replacement, but it is primarily documented when other, more innovative products are used in conjunction with open cut. In-Line Pipe Replacement for water system pipelines is dominated by pipe bursting, with the total length of pipe being replaced with pipe bursting technologies growing by about 20% each year according to the ASCE 2006 Pipe Bursting Manual. One of the disadvantages of pipe bursting is that prior to beginning the burst, any sags or significant defects have to be repaired to prevent the cutting head from getting stuck or from getting significantly off line and grade during pull-in. Small sags can be bursted through, but it is likely that a sag will develop at that location in the future. (Hashemi, December 2008) Hashemi also notes that compared to open trench, a 40% reduction in costs is achieved on average.

Pipe reaming is another technology gaining in popularity. According to the City of Charlotte who has had a couple of successful replacements with pipe reaming technology, one of the important factors preventing them from using the technology more often is a lack of contractors in the area. When the bidding environment is not competitive, the costs of the technology become much higher. Pipe reaming has specific advantages over pipe bursting, however, including its ability to correct slight sags in the pipeline more-so than pipe bursting as well as reduced vibrations and therefore less risk to surrounding utilities or above ground structures. Both of these advantages were verified by utilities that used the technology.

The off-line pipe replacement market is dominated by horizontal directional drilling, Microtunneling and open trench construction. Other forms of off-line replacement such as pilot tube microtunneling (Boschert, 2007) and pipe ramming (Tadesse Meskele, March 2011) are not well documented but have been used with some success in the United States. HDD methods are very common in both literature and in practice, primarily in situations where above ground obstructions need to be avoided. Microtunneling with a Microtunneling machine is typically used for installations between 12- and 120-inches in diameter where increased accuracy is desired because the machines have a guidance system that is remote-controlled from the surface to provide accurate grade and alignment control (Ray Sterling J. S., July 2010). Auger boring is typical in projects where an encasement pipe is required such as under railroads and major interstates. The controlling agencies (railroad companies, state DOTs, etc.) have certain requirements for installations of pipelines beneath their infrastructure, and this drives the technology selection for pipe renewal in those locations. The smallest difference between information available in literature and practice is for replacement in general. Pipe bursting and HDD are very well documented in literature and very common in practice as well.

### 4.5.5 Conclusion

While the technologies available for renewal of wastewater system pipelines continue to advance, the most commonly used technologies today include CIPP Liners, pipe bursting, and horizontal earth boring with technologies such as HDD. There are innovative solutions available, but there is a great deal of hesitation on the part of utilities to use these technologies without their having been proven in the United States. CIPP Liners for pressure systems, though right now somewhat limited in diameter, have the potential to advance force main rehabilitation significantly, and SIPP Linings, particularly polymer-based, also have a great deal of potential to advance the renewal strategies of wastewater system pipelines.

The State of the Art Literature and State of the Art Practice Reviews above were based on examples of technology applications from literature and on examples of technology use identified through contact with utilities, respectfully. In general, the primary difference in what was found in literature versus practice was the literature sources focused on providing examples of innovative technology uses and showcases of projects that push the limits of technology claims. The literature seems to provide adequate information on all of the most commonly used technologies, but examples of use for proven technologies such as modified sliplining did not seem to be as common in conference proceedings and journals. Most utilities were open about their tendencies to stick to practices with which they were comfortable and confident in. Until new technologies have been proven, the risk, especially in large diameter gravity and force mains, associated with failure is too high to warrant their application.

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# CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The water and wastewater system pipelines are no doubt in need of attention, and the intent of this thesis is to provide readers with an overview of major technologies available to the industry as well as an understanding of what technologies are being used and why. The State of the Art Literature Review provides examples of how technologies are used based on literature which differed between water and wastewater systems. The literature available for water systems tended to capture innovative technology applications, pilot projects, and other experiences geared toward spreading the word about advancements in technology. Literature on wastewater, however, focuses more on installations of traditionally used technologies such as CIPP Liners or pipe bursting that pushed the current limits of the technology claims. Wastewater systems have a greater diversity of well-established technologies available for use, and literature tends towards examples of how technologies are adapted to problems rather than to provide information on innovative or proprietary technologies.

One technology that is emerging for use that could significantly advance both water and wastewater system renewal is woven hose and reinforced fiber CIPP Liners. While they have been available on the market for a number of years, they have not caught on in the United States, so utilities cannot find good examples of installations by which they can judge the applicability of the technology in their own situation. One significant limiting factor for water system pipe renewal in the United States is the requirements for NSF 61 approval. The evaluation of the process is far out of the scope of this thesis, but the approval process as it stands now can take many years to go through, slowing the integration of new technologies into the market for water system renewal. There are plenty of opportunities for future research in both water and wastewater technologies, most notably in standardized post-construction information collection standards which would better allow utilities to evaluate how technologies are working in their systems over time. Currently, the common practice is to perform CCTV inspections to verify the success of the installation and then move forward to the next project without much documentation of the experience. This is particularly true of repair technology applications which made it very hard to collect data from utilities on their pipe repair practice. Once a technology is well-integrated into a system renewal program, the documentation of its use tends to decrease.

## 5.1. Pipeline Renewal Project QA/QC Practices

The critical role of good QA/QC practices in successfully implementing a pipeline renewal project was consistently discussed both in literature and practice. There are considerations to be made in every phase of the project, from design to post-construction inspections. The QA/QC practices for drinking water and wastewater renewal projects are summarized in more detail below. These practices are a synthesis of information from both literature sources and utility provided data and interviews.

### 5.2. Material Qualification

Material qualification is an important part of drinking water pipe QA/QC because the material must be able to withstand the operating conditions and loadings in the specific project. While established technologies typically rely on developed industry standards such as those published by ASTM, technologies without established standards must meet the specifications written by the owner of the technology. Typical material testing includes creep testing for long-term tensile, compressive, and/or flexural creep-rupture properties or a minimum cell classification that defines minimum physical properties of a thermoplastic material. Chemical resistance testing is also performed, but this is more important for sanitary sewers than for waterlines because of the corrosive gasses present within sewer pipes. The primary material consideration for drinking water pipelines is the National Sanitary Foundation (NSF) Standard 61 for Drinking Water System Components certification which verifies that the material will not release any contaminants into the drinking water that could adversely impact the health of customers.

### 5.3. Design Phase Considerations

There are steps in each phase of a project that need to be taken to ensure that the quality of the product to be installed as well as the product itself is maintained. During the design phase, a condition assessment of the pipeline should be performed so that the exact scope of work to be performed can be defined. Many renewal technologies require localized repairs of existing host pipe deficiency for optimal performance of the installed technology. A common example of this is repair of pipe sags before installation of a thermoformed liner or before replacement with pipe bursting. In both cases, the sag will still be present in the renewed pipeline, though pipe bursting does have slight corrective abilities.

Contract documents and specifications are also critical components of the design phase for successful pipeline renewal projects. These documents are used to precisely define the work to be carried out by the contractor, how the work is to be carried out, and the steps to take when unexpected obstructions or events occur. It is imperative that specifications do not contain ambiguities, especially with respect to construction orders and conflict resolutions, as unclear language can cause confusion on the part of the contractor and lead to mistakes which more than often increase project costs and lengthen the project schedule. The correctness and completeness of other documents such as condition assessment results and geotechnical investigations should also be verified, and the utility/contractor need to make sure they are aware of all required permits and that the permitting applications are submitted on-time.

### 5.4.Project Bidding Phase Considerations

In the bidding phase, it is important for the utility to make sure that the contractor is qualified to complete the work as it is bid. It is good practice to check contractor licensing, experience, and training claims as well as to perform a security screening and check references for past work. In some cases where the project is large or contains notable challenges, utilities can set certain prequalification standards for contractors to meet before they qualify to participate in the project bidding process. This often requires the utility to accept contractors from outside of their local area to meet all qualification standards. Another standard procedure to encourage a high quality installation is a pre-bid meeting and initial site visits to clear up any confusion and answer any questions about the project. The pre-bid meeting and site visit can help contractors make more accurate bids and eliminate the necessity to make risky assumptions on bid items.

### 5.5. Pre-Construction Phase Considerations

Once the project has been awarded, the utility, contractor, and any other involved parties must work together and maintain close communication to keep the project on track and get construction activities underway. This includes coordination between all agencies to complete such items as obtaining all permit approvals, setting and approving a construction sequence, and approving temporary bypass systems, sediment control, and traffic control plans. Before construction activities begin it is a good idea to hire a professional to take pictures or video documenting the existing site conditions, especially where there are above ground structures or heavy landscaping. This can help resolve any post-construction issues that might come up with site restoration and be beneficial in avoiding law suits. Also before construction begins, the public should be made aware of any impacts the project will have on their day to day lives such as traffic or water service disruptions. The degree of public notification will be dependent on the size and scope of the project. If only a small area is impacted, brochures, door hangers, or even door to door visits may be the most appropriate, whereas large projects may require outreach through radio broadcast or television notifications.

### 5.6. Construction and Post-Construction Phase Considerations

During construction, many utilities require a qualified inspector to be on-site at all times due to the significant impact that the installation quality has on the success of the project. The quality of the materials to be used during installation must also be verified to ensure that the product being installed is of the quality set in the specifications. The QA/QC procedures for construction differ based on the technologies and products involved in the project. The post-construction QA/QC procedures also vary by technology but mostly include a set of performance tests to verify that the installed product is performing to a level that is consistent with requirements defined in the contract and bid documents.

## 5.7. Recommendations for Future Work

There are a few recommendations based on observations from literature and practice that would help drive the pipeline renewal technology industry forward. These are discussed below with regards to solutions for existing issues that hinder technology advancements.

### 5.7.1. Recommendations for Waterline Renewal

The greatest need for water pipeline renewal technologies is the further development and refinement of existing innovative technologies and integration of the technologies into practice. The most promising technologies at this time are high-build polymer-based SIPP Linings and CIPP Liners for pressure pipelines. The challenges hindering the effective integration of technologies into practice include:

- **NSF 61 Approval.** All materials used in drinking water pipe renewal require NSF 61 approval for use in potable water applications. The process is tedious and takes a great deal of time to maneuver. It would be beneficial to look into more efficient ways to approve renewal technologies for use in potable water applications, and along the same lines, improved methods for disinfection of waterlines after renewal to facilitate efficient return to service.
- **Innovative Product Installations.** Pilot projects are very important because they allow innovative technologies to be installed in 'real-world' situations rather than in ideal laboratory situations, allowing technology developers work out kinks in their products. The issue is that utilities do not often have adequate budgets to risk installation of a technology that is not guaranteed to work. A cost-share between the utility and technology developer could be a potential solution to easing these issues.
- **Technology Applicability to Pressurized Systems.** One of the primary reasons for gaps between technologies available for sewer systems and those available for water systems is that water pipelines are typically under internal pressure. Pipeline renewal began with the sanitary and stormwater systems, so most of the technologies available were designed for use in gravity pipelines. Materials behave very differently under pressure, limiting the applicability of technologies to pressurized systems. There would be substantial benefit in retrofitting existing technologies to be able to handle the stresses of a pressurized system.

- **Service Reinstatement Methods.** There is a great need for advancements in methods for reinstatement of service connections following renewal. A commonly cited reason for choosing open trench replacement over rehabilitation is that with the number of excavations required for service connection reinstatements, it is more cost effective to dig up the entire pipeline. There have been advancements in recent years that allow services in some pipe types to be reinstated robotically, but for the most part, excavations are required at all connections, valves, and appurtenances. Water pipelines do not typically have redundancy, and the time a line can be taken out of service is severely limited. Bypass systems increase project costs substantially, but it is unacceptable to leave customers without clean water for an extended period of time.

### 5.7.2. Recommendations for Wastewater Pipeline Renewal

The greatest need for wastewater pipeline renewal technologies is the refinement of existing, well-developed technologies and integration of the technologies into practice. The best example of this is CIPP Liners, especially for rehabilitation of force mains and sewer laterals. The challenges hindering the effective integration of technologies into practice include:

- **Innovative Product Installations.** Just as with water pipeline renewal technologies, pilot projects play an important role in product development and refinement. The discussion above related to the need for pilot projects to enhance existing and integrate new water pipeline technologies is also relevant for wastewater pipelines.
- **Technology Applicability to Pressurized Systems.** Sewer force mains are still relatively young as a whole, but there are currently very few ways to renew them without excavation. There is a significant need for research into repair and rehabilitation technologies, especially trenchless technologies that could solve force main issues without excavation. There are no lateral connections on sewer force mains, so the primary concerns are harsh water chemistry and increased stresses associated with pressurized systems.
- **Sewer Laterals.** There has been a significant movement for renewal of sewer laterals because of studies that show that a majority of I/I that enters into the system comes from faulty connections. New CIPP Liner and grouting technologies have been developed to address leaking laterals, but there is still room for growth and research into how to improve the installation procedures and general effectiveness of these technologies.

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# APPENDICES

# Appendix A – List of Case Studies

| Water System Pipe Renewal Case Studies | Technology | EPA Region |
|---|---|---|
| Large Diameter Waterline Repair with Spray-Applied Polyurea Lining in Aurora, CO | Pipe Coating | 8 |
| Repair of Prestressed Concrete Cylinder Pipes in Washington, D.C. with Carbon Fiber Reinforced Composite (CFRC) Pipe Wrap | Joint & Leak Seal - Joint Parging<br>Pipe Coating - Mortar<br>Point Repair | 3 |
| Cleaning and Cement Mortar Lining (C&CML) for Unlined Cast Iron Pipes in Seattle, WA | Pipe Coating - Cementitious | 10 |
| 54-inch Water Main Rehabilitation Using Multiple Renewal Methods in Brookline and Boston, MA | Pipe Coating | 1 |
| Installation of CIPP Liner in Small Diameter Water Main in Central New York City, NY | CIPP - Woven Hose Liner | 2 |
| Installation of Tight Fit HDPE Liner in 12-inch Cast Iron Water Main in Alberta, CA | Modified Sliplining - Radial Reduction | |
| Rehabilitation of Residential Sewerline With Fully Structural Woven Hose Liner Outside of Los Angeles, CA | CIPP - Woven Hose Liner | 9 |
| Expand in Place PVC Lining Applied to Small Diameter Water Main in Washington, D.C. Area | Modified Sliplining - Expand in Place PVC | 3 |
| Sliplining with FPVC in the City of Helena, MT | Sliplining | 8 |
| 54-inch Water Main Rehabilitation Using Multiple Renewal Methods in Brookline and Boston, MA | Sliplining<br>SIPP - Cementitous | 1 |
| Gloucester Street Water Main Rehabilitation | Sliplining | Int. |
| Albuquerque, NM | GIPP | 6 |
| Highland, Indiana | FFP | 5 |
| The City of Billings, Montana: Double-Sized Pipe Bursting | In-Line Replace:<br>Pipe Bursting | 8 |
| The City of South Salt Lake: 18-inch Pipe Burst Using FPVC | In-Line Replace:<br>Pipe Bursting | 8 |
| Horizontal Directional Drilling in Standing Rock Sioux Tribe Territory in ND | Off-Line Replace: HDD | 8 |
| Static Pipe Bursting in New Town, ND | In-Line Replace:<br>Pipe Bursting | 8 |
| Record Pipe Bursting: The Town of Taos, New Mexico | In-Line Replace:<br>Pipe Bursting | 6 |
| FPVC Water Main for St. John's Water Company, Johns Island, South Carolina | Off-Line Replace: Open Trench | 4 |
| HDPE Water Transmission Main for the Navajo Nation, Counselor, New Mexico | Off-Line Replace: Open Trench | 6 |
| Portland Heights Pump Main Renewal | Off-Line Replace:<br>Open Trench | 10 |
| HDD Installation of FPVC Water Piping for the City of Green Bay, WI | Off-Line Replace:<br>HDD | 5 |

| Wastewater System Pipe Renewal Case Studies | Technology | EPA Region |
|---|---|---|
| Application of Non-Mechanical PVC Liner Patches in PVC-Lined Concrete Pipes in Phoenix, AZ | Point Repair | 9 |
| Application of CIPP Liner Patches for Repair of Wastewater Pipelines in Buncombe County, NC | Point Repair | 4 |
| Renewal Options for Lined Concrete Sewer Pipes in Phoenix, AZ | Point Repair<br>Pipe Coatings | 9 |
| Renewal Options for Large Diameter Stormwater Outfall in Aurora, CO | Point Repair | 8 |
| CIPP Sewer Pipe Renewal for Villa Park, IL | CIPP - Felt Tube | 5 |
| CIPP Sewer Piping Renewal for Hendorson Water Utility, Henderson, KY | CIPP - Felt Tube | 4 |
| Application of CIPP in Deteriorated 24-inch VCP and Brick Sewers in Columbus, OH | CIPP - Felt Tube | 5 |
| Large Diameter CIPP Interceptor and Relief Sewer Rehabilitation in Baltimore County, MD | CIPP - Felt Tube | 3 |
| Rehabilitation of Large Diameter Gravity Sewer with Spiral Wound HDPE Liner in Salt Lake City, UT | GIPP - Spiral Wound | 8 |
| Application of Fold and Form Liner for Sewerline Rehabilitation in Roanoke, VA | FFP - Thermoformed | 3 |
| Baltimore County Sliplining Project | Sliplining | 3 |
| Pipe Bursting and CIPP Rehabilitation in Colchester, IL | CIPP - Felt Tube | 5 |
| Renewal Options for Lined Concrete Sewer Pipes in Phoenix, AZ | CIPP - Felt Tube<br>Sliplining | 9 |
| Renewal Options for Large Diameter Outfall in Aurora, CO | CIPP - Felt Tube<br>GIPP - Spiral Wound<br>Sliplining | 8 |
| Eastern Richland Sewer Corporation Fold and Form Installation in Monroe County, Indiana | FFP - Thermoformed | 5 |
| Triple Upsize Pipe Burst in the City of West Jordan, Utah | In-Line Replace:<br>Pipe Bursting | 8 |
| Sanitary Sewer Pipe Bursting for the City of Benton, AR | In-Line Replace:<br>Pipe Bursting | 6 |
| Replacement of Small Diameter Vitrified Clay Pipe Using Pipe Reaming Technology in Charlotte, NC | In-Line Replace:<br>Pipe Reaming | 4 |
| Sewer Interceptor Installation Using Traditional Drill and Blast Tunneling Techniques in Howard County, MD | Off-Line Replace:<br>Pipe Jacking & Utility Tunneling | 3 |
| Sewer Interceptor Replacement Under Major Interstate Using Bore and Jack Technology in Buncombe County, NC | Off-Line Replace:<br>Pipe Jacking & Utility Tunneling | 4 |
| Pipe Bursting of 8-Inch Clay Sewerline in Residential Area in Peachtree City, GA | In-Line Replace:<br>Pipe Bursting | 4 |
| Pipe Reaming of Vitrified Clay Sewerline in High-Traffic Area in Seattle, WA | In-Line Replace:<br>Pipe Reaming | 10 |
| HDD and HDPE for Water Piping Renewal in the City of Jenks, OK | Off-Line Replace:<br>HDD | 6 |
| In-House Pipe Bursting | In-Line Replace:<br>Pipe Bursting | 3 |
| Jack and Bore Case Study for Buncombe County, NC | Off-Line Replace:<br>Pipe Jacking & Utility Tunneling | 4 |
| Little Patuxent Parallel Sewer Interceptor | Off-Line Replace:<br>Pipe Jacking & Utility Tunneling | 3 |
| Pipe Bursting and CIPP Rehabilitation in Colchester, IL | In-Line Replace:<br>Pipe Bursting | 5 |
| Horizontal Directional Drilling Allows Installation of Pipelines at Airport in Portland, OR | Off-Line Replace:<br>HDD | 10 |
| Renewal Options for Lined Concrete Sewer Pipes in Phoenix, AZ | In-Line Replace:<br>Pipe Bursting | 9 |
| Sewer Pipe Renewal for Villa Park, IL | Off-Line Replace:<br>HDD | 5 |
| Upsizing a 10-inch Clay Sewer Pipe to a 20-inch HDPE Pipe in Edmond, OK | In-Line Replace: Pipe Reaming | 6 |

## Appendix B – Example RE Technology Guiding Questions

RENEWAL ENGINEERING (RE) WASTEWATER SYSTEM
DATA MINING--QUESTIONNAIRE

Note: The following questionnaire will be used to facilitate data mining in the effort of producing case studies on RE Management Practices and on specific RE Technologies.

1. **Background Info (same as CA)**

   (Information from maps, plans, database information as available)

   i. System size (# and length of pipeline, # of people served)
   ii. Materials of pipelines in system.
   iii. Age (installation/manufacturing).
   iv. Locations of replaced pipelines.
   v. GIS database information available
   vi. Is your system combined wastewater/water or separate?
   vii. Does your utility purchase water and distribute it or is it responsible for collection, treatment, etc.
   viii. Annual budget for Renewal Engineering
   ix. Number of customers.
   x. Industrial, wholesale customer summary.

2. **RE Management Practices and Prioritization**

   (From responsible person(s), in-house manuals and procedures, etc.)

   i. What is the basis for selecting renewal of pipelines?
   ii. What is the motivation or reasoning behind the implementation of this renewal project? (Regulatory requirements i.e. CSOs, I/I reductions, etc.)
   iii. How are sewer laterals and other appurtenances on private property handled? (some cities require inspection with transfer of property ownership, some include laterals in rehabilitation projects while some make them the exclusive responsibility of the property owner)
   iv. How is the knowledge from your field personnel captured and used for renewal prioritization?

i. Is there an interview process used to "data mine" their knowledge? And if so, is this documented where we can access it?
ii. What is the most valuable information available through the field personnel that is not available through the use of technologies?

v. GIS data for the location of important renewal case studies?

vi. Is there a Master Plan?
i. What are the details of the Master Plan for system renewal?
ii. What was the basis for formulating the Master Plan? (i.e. renew oldest pipes first, renew most critical pipes first, prioritize based upon structural renewal, overflow prevention, infiltration control, etc.)

vii. Are there any tools (i.e. software) that are used to assist in prioritization of system renewal?

viii. O&M strategies
i. Do these changes vary asset-to-asset, or is there a long term plan set for how to handle O&M for the system collectively?
ii. What is included as part of O&M?

ix. What is the strategy for performing QA/QC throughout the course of a project?

x. Are there long-term asset management and life-cycle cost analyses included in the system renewal planning?
i. Does the utility take a macro-(aggregation) or micro-(individual asset) valuation perspective?
ii. How are such analyses achieved? (CMMS, cost allocation, etc.)
iii. What are defined as the trends and drivers for life cycle costing?

xi. Who claims responsibility for the inspection and renewal of septic tank systems?

xii. What steps are taken to integrate new employees into their workforce?
i. Is the training hands on/field training, paper/computer modules, or a combination of the two?

ii. Are there training manuals and materials we may have access to?

**Renewal Engineering Technologies**

Note: For each RE technology used can you provide the following information.

1. Name of Technology and Provider (please include cathodic protection as well as repair, rehab, replacement)
2. Specific Pipe Information (i.e. Age, length, size, soil type, etc. of pipes that were renewed)? Do you have standard coded CA data on the host pipe?
3. Please identify each case in which the technology was used so that the case studies can reflect the full spectrum of different experiences. (successful/normal installations, failed installations and/or experiences that pushed the limits of the technology's capabilities)
4. What standards or codes must be met before the utility will consider use of the product for their system? (pressure rating, structural rating, certifications, etc.)
5. What extraneous requirements are necessary for the implementation of the renewal technology? (pit sizes, construction staging requirements, temporary by-pass system, etc.)
6. How is proper installation verified?
7. GIS files relaying spatial location of prominent renewal case studies.
8. Performance Data
    i. Information on what data was collected and the accuracy of data collection.
    ii. Information on problems encountered during any phase of the project which affected performance. (i.e. design or manufacturing errors or problems pre-, during, or post- construction)
    iii. Can you provide standard coded data on the "as-built" condition of the RE technology?

iv. Do you have follow-up inspection data on the condition of previously installed RE technologies? How often are follow up inspections performed and on what basis do you decide to perform them?

v. Have you encountered RE technology imperfections and/or post-construction failures?

vi. How do you monitor long term performance of the asset? What parameters are included in this analysis and how are they collected?

9. Triple Bottom Line Cost Analysis

(note: we are looking for both parameters included in the analysis and any analysis that resulted in quantifiable costs)

i. Direct Costs to Utility – What were the costs associated with:
   a. Repair/return to service
   b. Service outage mitigation
   c. Utility emergency response
   d. Public safety
   e. Administrative and legal associated with damage settlements
   f. Increased costs associated with treatment of extraneous flows that enter system

ii. Direct Costs to Customer
   a. Property damage (including business restoration)
   b. Service outage (including mitigation or substitutes for service)
   c. Access impairment/travel delay
   d. Health costs

iii. Costs to Community
   a. Emotional strain & welfare
   b. Environmental pollution, erosion, sedimentation
   c. Habitat destruction or damage

d. Compromised Aesthetic quality of community (economic, tourists)

10. Direct Quantifiable Costs
    i. Design Costs
        a. What costs were considered ‘design costs’?
        b. How were they quantified?
    ii. Construction Costs
        a. What were costs included in ‘construction costs’?
        b. How are they quantified?
    iii. Personnel
        a. Number of personnel assigned to project
        b. Number of hours logged to project
        c. Equipment/expense costs for personnel (trucks, gas, etc.)
    iv. Other
11. Indirect Costs
    i. Traffic stoppage costs or other ‘inconvenience’ costs
    ii. Reduced life of RE technology (i.e. imperfections prevent design compliance)
    iii. Permits required - can you provide copies?
    iv. Other
12. Unforeseen events affecting cost of project
13. Additional cost structure information break downs – any information available

**14. <u>Lessons Learned</u>**

i. What are the key points learned using this renewal engineering technology (i.e. technology worked only in certain conditions etc.)?
ii. What mistakes were made? How can these be resolved for future?
iii. How have implementing previous lessons learned improved results? What documentation is available to validate this?

iv. What do they feel are their strengths and weaknesses as a utility regarding renewal engineering? Where have the most valuable lessons been learned to develop strengths or identify weaknesses?

v. Based on the testing the utility have done, what is your biggest need that you have not been able to fill due to technology or budget limitations?

**15. Contact Information (name, email, telephone, fax, other)**

i. Contact Information for Wastewater Renewal Systems:

ii. Other important points of contact:

**16. Appendix of Useful Documents**

i. Performance:

a. Product Approval documentation
b. Contractor Pre-Qualification documentation
c. Test Reports
d. Specifications
e. Information from manufacturer's QA/QC reports
f. Information from Field Inspector reports
g. Information from post-construction physical testing reports

ii. Costs:

a. Work Orders
b. Contract Documents
c. Change Orders
d. Permits that were required - costs for permit and how time intensive the process was

iii. Other Useful Standardized Documentation

a. Training manuals and/or guides
b. Specifications
c. Design Manuals
d. Construction documents
e. Material selection and approval documents
f. Standard details

g. System layout outline
h. Maintenance management reports for renewed assets including procedures upon report of problem
i. Pilot installation reports
j. Publications helpful in renewal decisions

## Additional Material Needed From Utilities – Defining BMP Case Histories and Technology Case Studies

**Best Management Case Histories:** These should include a review of the structure of the utility and how it makes its renewal engineering decisions. With this in mind, we need to collect anything that they have on:

- Background of the utility size and structure (is there a separate contact for each division like stormwater, water and wastewater or are they combined?)
- Ownership of the assets as well as the wastewater the assets carry and the treatment plants
- The process of data analysis, parameters and thought process that go into choosing which pipes to renew
- What their criteria is to decide whether to repair, rehabilitate, or replace
- How they select the product to be used for the project – is it the utility that decides, does their consultant decide, etc.
- Understanding the components of their bid process
- Project management strategies (design phase through post-construction restoration)
- How is project progress tracked, and how are the records stored at project close?
- How they integrate new employees seamlessly into their workforce

**Technology Case Histories:** In general these will paint a picture of what product was used, in what situations it was used in and whether the product was able to achieve the goals originally set for the project. With this in mind, we need to collect anything available regarding:

- Multiple uses of the same technology: we will be able to state very quickly how frequently the product is used within the utility, but due to time limitations it is not feasible to create a detailed case history for each and every use. We want to therefore concentrate on capturing what a typical product installation would look like, any difficult project experiences or failures, any successful product uses that stand out, and any projects that pushed the limits of what the product claimed to be able to do (this could have a positive or negative outcome)

- A full, detailed description of site specific parameters (soil type, traffic loading, location, etc.). This will allow utilities to be able to find case histories for products used in similar conditions to their own and will allow us to be able to identify any major trends relating site specific parameters to successes or problems.
- What technology was used and what qualified it as the best choice for the particular project. (size restrictions, pressure requirements, etc.)
- What were the initial expectations of the product? Documentation of how the product did or did not meet these expectations.
- The components and explanation of project specific product design – anything that made tailoring the product to the project needs a simple, ordinary or challenging process
- Any extraneous requirements associated with the use of the product such as installation pits required, construction staging area, materials storage requirements, etc.
- Difficulties encountered during the construction phase. This could be due to manufacturing errors, damage during transportation, temperature conditions, etc.
- Once the product has been installed, how were lateral connections re-established? Were there any difficulties with the process?
- What tests were performed post-installation to ensure that the product was properly installed, the level of service and the expected performance was being achieved?
- Cost. This includes direct, indirect, quantifiable, abstract, assumptions, estimations….everything. Once we have all of the information on cost issues, it should be clearer what the best way to portray cost within the case histories will be.
- Quick summary of their satisfaction with the product.

## Appendix C – Example Technology Data Sheet

| **Technology/Method** | **Fold-and-Form /Thermoformed** |
|---|---|
| I. Technology Background | |
| Status | Conventional |
| Date of Introduction | 1994 |
| Utilization Rates | Over 4.5 million ft installed since 1994. Split fairly evenly between 4" to 16" and 18" to 30" pipeliner installations. As of 2008, PVC Alloy Pipeliner has been installed in 36 states, and 2 international countries, with over $20 million dollars worth of PVC Alloy Pipeliner contracts completed annually. Listed for use by at least 30 State DOT's. |
| Vendor Name(s) | **Ultraliner PVC Alloy Pipeliner™**<br>Ultraliner, Inc.<br>201 Snow Street / PO Drawer 3630<br>Oxford, AL 36203<br>Phone: +1 (256) 831-5515<br>Fax: +1 (256) 831-5575<br>Website: www.ultraliner.com<br>Email: info@ultraliner.com |
| Practitioner(s) | **Georgia Department of Transportation (GDOT) – District One**<br>**Ken Reed, District Bridge Maintenance Manager**<br>**2505 Athens Hwy SE**<br>**P.O. Box 1057**<br>**Gainesville, Georgia 30503-1057**<br><br>**City of Los Angeles, California**<br>**Keith Hanks**<br>**650 S. Spring St., Room 1000** |

| Technology/Method | Fold-and-Form /Thermoformed |
|---|---|
| | **Los Angeles, CA 90014**<br><br>**Phone +1 (213) 847-8770**<br><br><br>**Jacksonville Naval Air Station [1]**<br><br>**Bill Myer, the Navy's airfield facility manager for both NAS Jacksonville and the Outlying Field [OLF] of the White House**<br><br>**Phone +1 (904) 542-3176**<br><br>**Email bill.meyer@navy.mil** |
| Description of Main Features | Ultraliner PVC Alloy Pipeliner is a solid wall PVC pipe manufactured from virgin PVC homopolymer resin with no fillers, which is modified with special additives to improve ductility and toughness. The pipeliner is collapsed flat and coiled on a reel in continuous, jointless lengths. Small diameters, 12" and less, are folded in the field prior to insertion, while large diameters, 15" and above, are deflected to a smaller profile (approx. 50%) at the manufacturing facility. |
| Main Benefits Claimed | • Conforms to size transitions, tight bends, offset joints and other irregularities.<br>• Does not shift/shrink longitudinally or radially after installation (memory reset by heat and stretching to new dimensions); consistently achieves a tight fit.<br>• Able to withstand significant shallow impact loads.<br>• Reliable flanged and gasketed end seals in pressure applications and hydrophilic gasket end seals in gravity applications.<br>• The solid wall PVC alloy cuts and polishes smoothly and quickly without jagged edges at lateral reconnections.<br>• Very high abrasion resistance and ductility.<br>• PVC alloys are chemically compatible with any sewerage application where a traditional direct burial PVC pipe would be appropriate.<br>• Factory controlled consistency of design properties including modulus, wall thickness, and corrosion resistance enhances long-term asset manageability [2], [3].<br>• Low mobilization, shipping, and set-up costs make for exceptional competitiveness in rural, DOT, and smaller scale projects.<br>• Relatively small jobsite foot print. Most equipment can be parked away from the insertion access if necessary. |
| Main Limitations Cited | • Materials are NSF 61 approved, but system has yet to be listed for use in potable water lines; listing is planned to be pursued in the future.<br>• Limited long-term pressure test data to support independent use |

| Technology/Method | Fold-and-Form /Thermoformed |
|---|---|
| | as a fully structural liner in pressure applications; available data supplemented by 10 years of practical field application.<br>• Requires access at both ends of the pipe for installation.<br>• Requires excavation for a pressure seal at branch connections.<br>• All tight-fitting liners require additional technologies (grout packing, lateral lining, or other) to provide a seal at internal branch connections.<br>• Elevated temperatures lower the modulus of thermoplastics like PVC alloys, thus modulus adjustments should be considered within the structural equations when the application is significantly above routine wastewater flow temperatures.<br>• Construction network is small scale which limits available economies of scale and influences potential competitiveness on larger scale projects (particularly 30,000 lf +).<br>• Not currently available in most major metros. This is subject to change with coverage expansion. |
| Applicability (Underline those that apply) | Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Culverts, Industrial, Water Intake |
| II. Technology Parameters | |
| Service Application | Wastewater, storm water, raw water, industrial, power |
| Service Connections | Laterals remotely reinstated with robots. Down time 5 hours plus time to reinstate laterals. Sewer main flow typically disrupted for 3 to 4 hours. |
| Structural Rating Claimed | Fully structural, independent liner. Flexural modulus available as 145,000 psi (F1871) or 280,000 psi (F1504), and flexural strength as 4,100 psi (F1871) or 5,000 psi (F1504). Design is determined by industry standard equations with material properties adjusted for long-term performance under load. |
| Materials of Composition | Virgin PVC alloy compound (impact modified, no fillers, NSF approved) |
| Diameter Range, inches | 4” to 30” – F1504 only to 16” |
| Thickness Range, inches | 4” – DR 32.5, 6”, 8”, 9” – DR 32.5 to 35, 10”, 12”, 15”, 16” – DR 32.5 to 41, 18” – DR 35 to 50, 21”, 24”, 30” – generally designated by wall thickness up to .65” |
| Pressure Capacity, psi | Currently available for low pressure, under 80 psi (only available |

| Technology/Method | Fold-and-Form /Thermoformed |
|---|---|
| | up to 15" diameter pipe). Design methodologies are still being researched, with no available standards. Have completed one "experimental" 150 psi project. |
| Temperature Range, $^{o}$F | 100$^{o}$F (continuous) for F1871; 120$^{o}$F for F1504; intermittent and diluted flows at higher temps may be acceptable. Under sustained elevated temperatures, the design modulus needs to be adjusted for structural calculations. |
| Renewal Length, ft | Up to 600 ft typical; 1,000 ft. for 8" to 12" has been achieved, and up to 650 ft. for 21" and 24", up to 500' for 30" |
| Other Notes | Minimal to no loss of flow capacity expected; flow velocity increases can be significant. No noxious or toxic chemicals (NSF potable water and FDA food contact safe materials). Safe for use in environmentally sensitive applications. Has evidenced comparable I/I control to competitive alternatives in field applications. |
| III. Technology Design, Installation, and QA/QC Information | |
| Product Standards | ASTM F-1871 Standard Specification for Folded/Formed Poly (Vinyl Chloride) Pipe Type A for Existing Sewer and Conduit Rehabilitation<br><br>ASTM F-1504 Standard Specification for Folded Poly (Vinyl Chloride) (PVC) Pipe for Existing Sewer and Conduit Rehabilitation |
| Design Standards | Appendix within ASTM installation standard F1867 and F1947 is the same as that within ASTM F1216 for CIPP products. |
| Design Life Range | 100 year claimed [4],[5], but not field-demonstrated; long-term material data testing and creep strain analysis offered as evidence of claim. |
| Installation Standards | ASTM F1867<br><br>ASTM F1947 |
| Installation Methodology | The Ultraliner PVC Alloy pipeliner is pulled into the cleaned host pipe, usually through a manhole. Access is required at both ends. Once in place, the ends are plugged and the pipeliner expanded with steam and air pressure (thermoformed) to reset the PVC Alloy's "memory" to the new size and shape. Installation and processing of the liner takes 4 to 5 hours, excluding the time to reinstate laterals and |

| Technology/Method | Fold-and-Form /Thermoformed |
|---|---|
| | some street operations set-up and tear down time. |
| QA/QC | Design material properties are quality assured at the manufacturing facility per ASTM product standards (F1871 or F1504) using industry standard QA/QC protocols common to the manufacture of all PVC pipes. Specification compliance is confirmed prior to installation. Standard industry post-construction QA/QC tests are available for further verification. |
| IV. Operation and Maintenance Requirements | |
| O&M Needs | No special maintenance training is required. Any cleaning or de-rooting procedure routinely practiced by maintenance personnel within PVC pipes is safe for use within PVC Alloy pipeliners. The host pipe can easily be removed (hammer a rigid host pipe to shatter it) without damaging the pipeliner, if new connections or repairs need to be made in the future. Standard fittings, couplings, and saddles are readily adaptable for use with PVC Alloy Pipeliners. |
| Repair Requirements for Rehabilitated Sections | PVC Alloy pipeliners are capable of structurally lining and conforming to crushed sections of pipe and severe off-sets. Repair decisions are therefore generally driven by system performance and long-term O&M requirements rather than constructability limitations. |
| V. Costs | |
| Key Cost Factors | PVC Alloy Pipeliners have relatively low set-up, mobilization, and shipping & handling costs. Materials are shelf-stable (do not have to be temperature controlled) and can be affordably shipped one reel at a time or in bulk (thereby enabling payment for stored materials where appropriate).<br>• Extensive cleaning of the host pipe, above and beyond what is considered a routine pipe maintenance cleaning project, is required for all tight-fitting liners.<br>• On gravity pipes, no excavation is required, providing significant savings. Access can be achieved through a manhole ring on one end and at least a clean-out on the other end. Laterals are robotically reinstated internally.<br>• Pressure pipes frequently require excavation at the ends (and in the middle where maximum lengths have been exceeded), at valves and hydrants, and at connections. This can significantly impact cost-competitiveness against alternative technologies that can avoid excavation.<br>• De-watering is not required for quality assurance, as water exposure cannot alter design property compliance of a solid wall |

| Technology/Method | Fold-and-Form /Thermoformed |
|---|---|
| | PVC Alloy Pipeliner, but it may be utilized for risk control, as appropriate, since excessive groundwater can narrow the window of installability.<br>• The material cost is all inclusive (and includes manufacturing QA/QC) with no additional on-sight mixing of chemicals, nor “finishing” labor requirements prior to installation.<br>• End seals, when specified, are routinely included in the unit price for the pipeliner.<br>• Lateral reinstatements are generally a separate cost because the numbers of connections vary.<br>• PVC Alloy pipeliners tend to be more competitive on small scale (short lengths, small diameter) projects given low mobilization and set up costs compared to other trenchless rehab methodologies. |
| Case Study Costs | GDOT- seven deteriorated culverts, ranging in diameter from 15-inch to 30-inch and 40 to 80 ft in length were lined for a total cost of $43,288. This was 34% less than the bid price of $65,674 to dig-and-replace. Generally speaking, large scale (25,000’ +) 8” PVC Alloy pipeliner projects can receive bids in the $22 per ft range, whereas smaller scale 8” projects with significant mobilization requirements or especially challenging conditions can receive prices up into the $40’s per ft range. |
| VI. Data Sources | |
| References | **Ultraliner PVC Alloy Pipeliner™ brochure**<br>**Private correspondence with Grant Whittle, VP of Ultraliner.**<br>**[1] Whittle L. G. (2008). Takes Off at Naval Air Station in Jacksonville, Fla. Trenchless Technology Magazine, November, 2008.**<br>**[2] Whittle L. G., and W. Zhao (2009). The Need for and Benefits of a Minimum Wall Thickness Requirement for Pipeliners. No Dig International 2009, Toronto, Canada, March 29 – April 3. Paper Accepted.**<br>**[3] Zhao W., and L. G. Whittle (2009). An Asset Management Definition of Pipe Rehabilitation Success or Failure. ASCE Pipeline International 2009, San Diego, CA, Aug 16-19. Abstract Accept.**<br>**[4] Zhao W., and L. G. Whittle (2008). Long-term Performance life Prediction Using Critical Buckling Strain. NASTT No-dig 2008, Dallas, TX, April 27-May 2.**<br>**[5] Zhao W., and L. G. Whittle (2008). Plastic Pipeliner Long-term Design: How to Accommodate Creep? ASCE Pipeline International 2008, Atlanta, GA, July 22-27.** |

# Appendix D – Example Technology Profile

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WATERiD
WATER infrastructure DATABASE
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YOU ARE HERE Cured-in-Place Pipe Liners

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Cured-in-Place Pipe Liners

View Edit Workflow

By gwhittle@vt.edu - Posted on 18 June 2011

General Information

**Image:**

**Related Technology Profiles:**
Pipe Renewal Engineering
Pipe Rehabilitation
Search WATERiD for related Technology Profiles
Cured-in-Place-Pipe Lateral Liners
Sectional Cured-in-Place-Pipe Liners
CIPP Patch Repair
Pressure Rated Cured-in-Place Pipe Liners
Potable Water Approved Cured-in-Place Pipe Liners
Styrene-Free Cured-in-Place Pipe Liners
CIPP Liner: Felt, Polyester Resin
CIPP Liner: Glass Reinforced, UV Cured
CIPP Liner: Woven-Hose with Epoxy Resin and PE Coating
Cured-in-Place Pipe Liner Tube Materials
Cured-in-Place Pipe Liner Resins
Cured-in-Place Pipe Liner Resin Impregnation Method
Cured-in-Place Pipe Liner Insertion Method
Cured-in-Place Pipe Liner Curing Method
**Technology Class:**
RE: Rehabilitation: Cured-in-Place Pipe
RE: Rehabilitation: CIPP: Segmental
RE: Rehabilitation: CIPP: Lateral
RE: Rehabilitation: CIPP: Felt tube
RE: Rehabilitation: CIPP: Woven
RE: Rehabilitation: CIPP: Spiral Wound Layers
RE: Rehabilitation: CIPP: Fiber-reinforced tube
RE: Rehabilitation: CIPP: Fiber-reinforced tube: Carbon
RE: Rehabilitation: CIPP: Fiber-reinforced tube: Glass
RE: Rehabilitation: CIPP: Polyester
RE: Rehabilitation: CIPP: Vinyl ester
RE: Rehabilitation: CIPP: Epoxy
RE: Rehabilitation: CIPP: Ambient cured
RE: Rehabilitation: CIPP: Hot water cured
RE: Rehabilitation: CIPP: Steam cured
RE: Rehabilitation: CIPP: UV cured
RE: Rehabilitation: CIPP: Hand Lay-up
RE: Rehabilitation: CIPP: Inversion
RE: Rehabilitation: CIPP: Pulled-in-place

**Description:**

Cured-in-Place Pipe (CIPP) liners are used to trenchlessly seal and or structurally renew existing pipes. The basic CIPP liner product is a tube, impregnated with a liquid thermoset resin, inserted into a pipeline, typically through a manhole, and cured. CIPP liners have been commercially used since around 1971. Efforts to take water pipe coating resins and use them to also coat sewer pipes did not work, because the resins would not consistently adhere to the greasy sewer walls, no matter how much cleaning was performed. CIPP was developed as essentially a modified coating system wherein the resins were delivered in a carrying tube (often described as a "sock") that could hold the desired "coating" in place until the resin had time to cure. Design was advanced to justify the use of this "modified coating system" as a "pipe inside a pipe."

The major classes of CIPP liners are described in terms of the tube construction, insertion method, the resins used, and the cure method. The tubes can be manufactured from felt or fiber-reinforced materials, and are either woven, unwoven, or spirally wrapped. CIPP liners are either inverted, pulled-in-place, or hand laid to insert them inside the host pipe. All are radially expanded or otherwise conformed tightly against the host pipe. Various resins are utilized including epoxy, polyester, silicate, and vinylester resins; the most commonly used resins are styrene-based. By far, the super-majority (likely 90%+) of CIPP liners are currently (2011) installed utilizing styrenated polyester resins. The resins are either ambient cured, thermally cured (utilizing either hot water or steam), or UV cured. Structural capabilities and field performance histories vary significantly across technology variants. Tube design, tube construction, resin selection, and field manufacturing are all critical to the appropriate application of this technology class.

**Media Files providing Technology Description:**
Structural CIPP, InsituMain Data Sheet
InsituMain Data Sheet page
Semi-structural CIPP Liner, Process Phoenix Data Sheet
Process Phoenix Data Sheet page

**Application / Construction Description:**

There are too many variants of the CIPP liner construction process to adequately describe herein; more detailed descriptions are provided in the more specific Technology Profiles for each class of CIPP liner technology and within each Product profile. In general terms, the resin impregnated tube is inserted into the host pipe; insertion is possible through existing access chambers such as manholes, or from one pipe end to the next. In non-pressure applications, manholes can be used to join CIPP liner sections. In pressure applications, various methods are used to join sections. Branch connections are generally internally reinstated robotically in non-pressure applications; some technologies are capable of internal robotic reinstatements in pressure applications as well. Construction method and personnel expertise are critical, because CIPP liners are inherently "field manufactured;" that is design compliance regarding modulus, strength, wall thickness, leak tightness, and corrosion resistance are significantly influenced by the construction process and are not fully established or capable of being confirmed until post-construction.

**Problems Addressed or Identified:**
leaks: exfiltration
leaks: infiltration
pipe: break
pipe: corrosion
pipe: crack
pipe: fracture
root intrusion
sewer overflows

**Utility Department:**
Design
Construction
Qualification
Operations & Maintenance
Renewal

**Keywords:**
cured-in-place pipe, sock liner, modified coating system, NOT cast-in-place pipe, CIPP, insitu form, pipeliner, pipe liner, renewal liner, rehabilitation liner, pipe rehabilitation, Process Phoenix, Phoenix, semi-structural, structural, PRS, Rohrsnaierung, GmbH, PRS Rohrsnaierung GmbH

**Are you willing to provide more detailed information about this submission?:**
Yes

Cost Information

**Material or Equipment Costs:**

Material and equipment costs vary greatly across different sub-classes of CIPP liners; see sub-class Technology Profiles and Product Profiles for more reliable cost information. As compared to direct burial pipe materials, CIPP liner material costs are relatively high, but these increased material costs are generally off-set by reduced equipment-time, labor-time, and social costs. Reinforced materials generally cost more than non-reinforced. Styrenated polyester resins, are claimed to represent 90% of CIPP liner use and are among the lowest cost materials, but their cost varies with resin grade and catalyst admixture. The CIPP installation standards do not provide governance of resin grade. Higher grades of resins frequently cure more reliably under a variety of field conditions, but unless specific grades of allowable resin are specified, competition on cost may drive the selection of lower grade resins.

**Construction Costs:**
The relatively fast installation time of CIPP liners greatly reduces labor costs as compared to dig and replace; this cost advantage is relative to the local labor wages. CIPP requires highly skilled labor at significantly higher wages than typical exhume and replace construction workers. Mobilization and set-up costs can be a high percentage of the construction costs of a CIPP project. As such, the higher the volume of CIPP lining available in the area, as well as on a specific project, the lower the per unit cost can become. Longer lengths of individual line segments on a project will also lower the per unit cost. Thus, CIPP liners become more cost-competitive as total project size and line segment length increase. Ambient and thermally cured CIPP liners must be refrigerated during shipment; depending upon the shipping distance, refrigeration can add US$2 or more per linear foot to the cost of a CIPP liner project. Refrigeration costs are greatly influenced by local energy costs. The closer the wet-out facility to the project, the lower the refrigeration costs. UV cured liners must be packaged to protect against UV exposure; with proper packaging UV cured liners have significantly longer shelf lives than thermally cured liners, providing inventory control and project management advantages. For ambient and thermally cured technologies, CIPP liner installation is significantly influenced by site temperature. Exceptionally hot climates will require increased energy costs for liner refrigeration to prevent pre-mature catalysis of ambient or thermally cured liners. Exceptionally cold climates will require increased energy costs for longer heating cycles in order for thermally cured liners to achieve complete catalysis. As the diameters and length of tubes get larger, the weight of the tube and the mass of regulated materials will affect shipping cost and feasibility, prospectively reaching a cross-over point where on-site wet-out facilities become more cost-effective. The tube design and catalyst admixture for larger diameter CIPP also requires greater expertise with less margin for error. Due to substantially higher material, labor, and equipment costs per line segment, the construction risk costs are much higher for longer length and larger diameter installations. There is a large cost difference between a trenchless project and an exhume and replace project; a failed CIPP project can turn into an exhume and replace project. A contractor performing higher risk projects needs to have the financial ability to absorb the risk. CIPP contractors need to adequately prorate the cost of their risk into the pricing of their projects. However, a single line failure under a major highway can represent as much as 7 years of profits for a small-scale CIPP contractor, making proper risk allocation challenging. As diameters and flow volumes become greater, by-pass pumping costs can also greatly influence total construction costs, and can influence competitiveness against alternative technologies which can avoid by-pass pumping costs. By-pass pumping costs, logistics costs, and increased equipment requirements, can significantly increase the relative cost of larger diameter CIPP installations.

**Social Costs:**
CIPP liners have a relatively short installation time. For smaller diameter gravity pipes, generally no digging is required at all. For larger diameters, generally only the manhole ring and cone must be removed. For pressure pipe applications, more digging is required. The construction site footprint is relatively small, with the CIPP liner compactly contained near the manhole or other access ends (no long string of pipe required.) For water pipes, the establishment of service by-pass lines limits service disruption, but the sanitation requirements post-installation, require extensive periods of by-passing and site disruption. The impact of nuisance odors (particularly with styrenated resins) should be considered and perhaps controlled.

**Safety, Environmental, and Health Impacts:**
NSF drinking water approved CIPP liner systems are available. When hot water is used to cure CIPP liners, the release of high volumes of hot water can cause thermal pollution in the environment and can lead to fish and amphibian kills; proper handling and disposal of hot wastewater is essential. Most CIPP liners used in non-potable applications (>90%) contain styrene. Styrene and other chemicals from the resins can contaminate the wastewater or condensation water from a CIPP liner installation. The release of contaminated waters into the environment is not recommended, although it should be noted that styrene does not bio-accumulate and rapidly degrades in the environment with no known long-term environmental impacts. With wastewater pipes, release into the wastewater stream should take into consideration the distance from the treatment facility. Contaminated CIPP wastewater is believed to have an impact on the biological treatment process, particularly if the styrene has not had sufficient time to degrade or volatilize out of the wastewater stream. Styrene has a strong, noxious odor, and has been known to cause reactions with asthmatics. Care must be taken to properly inform the public of risks and to ensure that sewer traps are functioning properly to prevent CIPP fumes from entering buildings during installation; where CIPP fumes have entered buildings, occupants have had to be evacuated. As of June 10, 2011, the U.S. Department of Health and Human Services in its 12th Report on Carcinogens (RoC) has listed styrene as a substance that is "reasonably anticipated to be a human carcinogen." This listing is highly controversial, and despite the strong odor, the styrene exposure levels during a CIPP liner installation are negligible and widely believed to cause no human cancer risk. Construction risk management practices can be provided by CIPP contractors regarding how such risks are appropriately managed.

**Life-cycle Costs:**
CIPP liners can be designed to provide a full structural renewal for 50 to 100 years or more. Limited information is available regarding the statistical confidence limit for "as-built" compliance with the design. The field manufactured CIPP technology is expected to periodically have imperfections and variations as influenced by varying site conditions and by the related essential variations in construction decisions (pressures, temperatures, times, resin admixture, etc.). Even where all design properties exceed specification requirements, the inherent variability of CIPP liners, from one line segment to the next, may limit the ability to control life-cycle costs through predictive modelling. To control life-cycle costs, baseline condition assessment data reported for CIPP liners "as-built" for each line segment is essential for monitoring change over time.

**Cost Documentation:**
Search WATERiD for related Cost Information
QA/QC versus Low Bid: What Should Dictate the Future of the Trenchless Industry?
Rehabilitation of Deteriorated Sewers by the County Sanitation Districts of Los Angeles County
Cost Case Study (Indianapolis, IN; CIPP lining): Merrill Street Combined Sewer Rehabilitation Project
Cost Case Study (Mount Prospect, IL): 2008 Sewer Rehabilitation Cured-in-Place Pipe
Cost Case Study (Elmendorf AFB, AK): Reconstruction of Existing Water Main Using Cured-in-Place Pipe Lining Method
Cost Case Study (Las Vegas, NV; CIPP): Capacity Addition/Manhole and Pipe Rehabilitation - Package 1
Cost Case Study (Barstow, NV; CIPP): Sewer Rehabilitation Project No.1
Cost Case Study (Aurora, CO; CIPP): 2009 CIPP Rehabilitation
Cost Case Study (Rockville, MD; CIPP): Construction of Sanitary Sewer System Rehabilitation
Cost Case Study (Orange County, FL; internal point repair, CIPP): Gravity Main and Manhole Lining
Cost Case Study (Spokane, WA; CIPP): Cure in Place Pipe 2009 Sanitary Sewer Rehabilitation
Cost Case Study (Indianapolis, IN): Small Diameter Sewer Rehabilitation, Phase I

## Application: Summary

**Benefits Claimed:**
30+ years performance history
Widely available
Widely specified
Control of Infiltration
Control of Root Intrusion
Structural renewal
Significantly reduces Social Costs
**Limitations Cited:**
Risk of "as-built" design non-compliance is relatively high
Design compliance cannot be confirmed until post-construction
Remediation options for non-compliant CIPP liners is frequently limited
**Performance Considerations:**
Inherent variability from line segment to line segment will limit the efficacy of long-term performance modelling for CIPP liners. Without special CIPP tube construction, lining through bends and diameter restrictions will generally leave prospectively flow obstructing wrinkles.

## Commercial Info

**Is this Profile for a "Technology" or a "Product"?:**
Technology

## Availability

**Technology Suppliers:**
Search WATERiD for related Technology Suppliers
Applied Felts
Chevalier
CIPP, Inc.
Inland Waters
Inliner
Insituform
LMK
MasterLiner
National Liner
Perma-Liner
Reline America
Saertex
**Technology Practitioners:**
Search WATERiD for related Technology Practitioners
PRS Rohrsnaierung GmbH
**Technology End-Users:**
Search WATERiD for related Technology End-Users
Atlanta
Houston
Los Angeles
Nashville
WSSC
**Case Studies:**
Search WATERiD for related Case Studies
Technology Case Study for CIPP for Small Diameter Water Main in New York City
Montana Demonstration Project: Innovative Culvert Rehabilitation Using Trenchless Technologies Final Report
Technology Case Study for Los Angeles Department of Water & Power (LADWP) Woven Hose Liner
Nashville Project shows Long-Term Effectiveness of Sewer Rehabilitation for Infiltration Reduction
Rehabilitation of Deteriorated Sewers by the County Sanitation Districts of Los Angeles County
Rehabilitation Options for Lined Concrete Sewer Pipes in Phoenix, AZ
**Date of First Introduction:**
1971
**Status:**
Conventional
**Total Usage:**
65000

## Host Pipe Info.

**Host Pipe Materials:**
ABS
Aluminum
Asbestos Cement
Brick
Clay
Clay: Tile
Clay: Vitrified
Concrete
Concrete: Reinforced
Fiberglass
Glass
Iron: Cast
Iron: Ductile
Lead
Metal: Corrugated
Orangeburg
PCCP
Polymer-Mortar Pipe
Steel
Steel: Galvanized
**Host Pipe Geometry:**
Arched
Box
Egg
Ellipse
Ellipse: Horizontal
Ellipse: Vertical
Horseshoe
Oval
Round
Semi-Elliptical
Thumbnail
**Host Pipe Defects:**
CIPP liners are used to structurally renew pipes, stop leaks, stop erosion of soil through infiltration, eliminate exfiltration, structurally stabilize the pipe-soil system, and stop root intrusion through failing pipe joints. Cracks, breaks, fractures, and missing pipe sections can all be renewed. The generally applied, ASTM F1216 design calculations require a circular or oval design, and are valid for use with up to 10% ovality. When a host pipe has a severely crushed section, collapsed section, or a section with a reversal of curvature, a point repair is generally necessary prior to lining with CIPP. The ring stability of a CIPP liner is effectively lost with a reversal of curvature. CIPP will not correct line and grade issues. When lining through off-sets, bends and other diameter restrictions, the point of pressure concentration will result in resin displacement and prospectively have a thinner wall and a lower modulus (because of a resulting lower resin to felt ratio) at the diameter restriction. Active infiltration can wash away or emulsify the resin, affecting the wall thickness and modulus of the liner. Active infiltration can also have a localized impact on curing of the material. CIPP is effective for localized infiltration control; that is CIPP can stop leaks within the lined section. However, without a global infiltration control plan, infiltration will still enter from leaking manholes or lateral pipes, and the volume of infiltration making it to the treatment plant may not be altered without a comprehensive watershed approach to sealing the entire system.
**Cross-section Reduction:**
-< 5%
**Bends:**
90
**Size Transition:**
size transition through a larger size
size transition through a smaller size
**Pressure or Non-Pressure:**
Non-Pressure
Pressure

Extended Pipe Info

**How many diameter ranges are required to describe the available lengths, thicknesses, etc. of this entry?:**
5
**Minimum Diameter 1:**
75.00mm
**Maximum Diameter 1:**
199.00
**Minimum Diameter 2:**
200.00
**Maximum Diameter 2:**
499.00
**Minimum Length 2:**
0.20
**Maximum Length 2:**
750.00
**Minimum Thickness 2:**
2.80
**Minimum Diameter 3:**
500.00mm
**Maximum Diameter 3:**
2700.00mm
**Impact on Flow:**
Restore
Minor Gain (up to 30%)
**Destructive or Non-Destructive:**
Non-Destructive

Site Condition Info

**Service Disruption:**
Disruptive: Less than 8 hours
**Community Disruption:**
Disruptive: Less than 8 hours
**Required Access:**
Internal
One Pipe End
**Trench or Trenchless:**
Trenchless
**Considerations pertaining to Type of Pipe Cover:**
With pull-in-place liners, flowing sand can infiltrate between the CIPP liner and the host pipe, prior to radial expansion if pre-installation measures aren't taken. With inversion CIPP liners, a jet-vac can remove flowing sand from immediately in front of the inversion head to avoid trapping mounds of sand between the CIPP liner and the host pipe.

Application

**Technology Use:**
Renewal Engineering
**Design Considerations :**
The historical ASTM F1216 design methodology has been proven to be conservative with approximately 30 years of practical application with non-reinforced CIPP liners. Box culverts and other designs requiring a "beam load" should not be completed using the ASTM F1216 design method. Recent changes to the ASTM F1216 design equations have reduced their inherent conservatism. The development of new, higher modulus materials may also affect the conservatism behind the assumptions in the design. In particular, reinforced materials and other higher modulus materials may have different cross-over points regarding the controlling failure mechanisms that govern design equation selection. In particular, the ASTM F1216 design equations completely ignore the influence of local imperfections, under the assumption that the influence of global imperfections will overwhelm and control structural stability. As the relative thickness of the CIPP liner becomes increasingly thinner, however, there is a cross-over point where macro local imperfections will begin to control long-term structural buckling; this is currently not considered in the design, and too much may be expected of the safety factor of 2. Research is needed to determine how the recent changes in the structural equations, which permit thinner liner design, will affect the currently ignored variable of local imperfections. Furthermore, CIPP liner design should take into consideration not only theoretical structural performance, but also likelihood of "as-built" compliance with the design. The design of CIPP liners should include adequate controls in the design phase to limit "as-built" variability during construction; consistency is essential to long-term performance prediction and Asset Management. Design non-compliance with a field manufactured liner is not merely a construction failure, it can also be indicative of inadequate design-phase constructability controls. Particularly, in regards to field constructed technologies, the industry needs to determine confidence limits for "as-built" design compliance, under various challenging field conditions (cold or hot weather, high active infiltration, diameter restrictions, etc.) in order to guide responsible "performance-based" technology selection. With the inherent variability of field manufactured technologies, there is an increased need for historical performance-based design augmenting the theoretical equations to ensure constructability. This should be an engineering design responsibility, and not merely a contractor liability.
**Design Standards, Specifications, and Guidance Documents:**
Search WATERiD for related Design Information
ASTM F1216
ASTM F1743
**Maximum Design Life Claim:**
100
**Manufacturing Considerations:**
The components of a CIPP liner are factory manufactured, but the finished product is field manufactured. The field manufacturing process prevents design compliance verification until post-construction. CIPP liners have Raw Material based Product Standards (ASTM D5813) and Installation Standards (ASTM F1216, F1743, F2019). The various Installation Standards provide some guidance regarding raw material selection for manufacturing, but many are extremely broad (i.e. polyester, vinyl ester, epoxy, or silicate resins), and do not specify appropriate resin grades amongst the allowable resin types. For example, there are many grades of polyester resin, but many of the grades which would be applicable for factory manufacturing of a shower stall, may not provide reliable design properties under the varying conditions of CIPP field manufacturing. Resin properties determined in a lab, are not reliable indicators of post-construction properties in a CIPP liner. Additionally, the catalyst mixture for the resin must be adjusted for the expected site conditions; catalysts with broad capabilities have been developed by resin manufacturers to handle "most" conditions, however, catalyst expertise is recommended particularly with the thicker walls of larger diameter CIPP liners. Regardless of the quality of the catalyst design, if the catalyst is not evenly blended with the resin, the resin will not cure properly during field manufacturing. A recommended appropriate practice is for CIPP system suppliers to use a different color for their catalyst than for their raw resin, so that the elimination of "marbling" becomes a visible indicator of adequate blending. The color of the blended resin can also be used as an indicator of proper tube impregnation. Complete saturation is essential for the "as-built" CIPP liner to meet target strengths and achieve non-porosity. If the tube is not properly and completely impregnated, then the corrosion resistance of the "as-built" CIPP liner can also be impacted. Various proprietary methods are used to control both complete resin impregnation, resin to felt ratio, and liner thickness. The resin must also be selected for appropriate bonding to the matrix of the tube materials. The design of the tube materials is also critical. Different tube materials can hold different volumes of resin, and their ability to hold the resin can be impacted as the tube radially expands. Depending upon the warp and weave, or the stretching or compression of the fabric matrix, the resin can squeeze out of the carrier tube during expansion; the "as-built" resin-to-felt ratio is critical in achieving the targeted flexural modulus, corrosion resistance and non-porosity of the "as-built" CIPP liner. With limited product standards to govern resin grade, catalyst mixture, tube compatibility, and specific manufacturing and installation practice, unless a contractor purchases a well-engineered, branded CIPP system from a supplier, then the contractor will be responsible for self-selection of the design and manufacturing of their own CIPP systems, and would benefit from having such engineering expertise in-house.
**Factory or Field Manufactured :**
field
**Product/Manufacturing Standards, Specifications, and Guidance Documents:**
Search WATERiD for related Product/Manufacturing Information
ASTM D5813 - Standard Specification for Cured-In-Place Thermosetting Resin Sewer Piping Systems
**Construction Considerations:**
The equipment set-up and curing methods, including temperature and pressure cycles, must be appropriately matched to the specific CIPP system used. The exact same CIPP liner system produced from the same batch and lot and sent to two different construction crews in different climates, using different equipment, and with different field supervisors, can routinely result in significant material property differences in an "as-built" CIPP liner.
**Construction Standards, Specifications, and Guidance Documents:**
Search WATERiD for related Construction Information
ASTM F1216 -Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
ASTM F1743 -Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe
ASTM F2019 - Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Pulled-in-Place Installation of Glass Reinforced Plastic (GRP) Cured-in-Place Thermosetting Resin Pipe

**QA/QC Considerations:**
ASTM D5813 is widely espoused as the means of controlling CIPP liner design properties. ASTM D5813 is a stringent standard for raw materials qualification and product manufacture, but it is not a quality assurance standard for the "as-built" product. Cured-in-Place-Pipe liners do not have ASTM standards or any other means that assure product design property compliance prior to construction. There is also no standard means of verifying the "as-built" design property compliance down the entire length of each installed Cured-in-Place-Pipe liner. QA/QC must extend beyond materials qualification and provide quality assurance for the commissioning of each new pipe liner asset. QA/QC sampling and testing is intended for both qualification purposes and for baseline data establishment for use with long-term performance prediction and operations and maintenance purposes. Merely exceeding specification requirements is not sufficient for long-term O&M. A reliable baseline must be identified from which change over time can be measured. High rates of undocumented variance (even when exceeding the specification requirements) from line segment to line segment will preclude predictive maintenance in the future. To avoid undermining life-cycle asset management goals, QA/QC sampling rates should be sufficient to not only verify manufacturer claims and design property compliance at an acceptable confidence limit, but to also determine actual baseline property data within an acceptable confidence limit. If every line segment is known to have considerable design property variations, then for post-construction QA/QC verification purposes every line segment "should" be treated as an independent batch/lot for sampling purposes. Unfortunately, down hole samples are not necessarily representative of the performance limiting variations which can occur at local imperfections (localized resin wash-out, incomplete curing, excessive resin migration at discontinuities, etc.) down the length of a CIPP liner. For QA/QC data to have validity in performance prediction over time, it must be representative of the expected controlling performance limitations on each line segment. As a result, field manufactured technologies prospectively require higher rates of post-construction sampling and testing.
**QA/QC Standards, Specifications, and Guidance Documents:**
Search WATERiD for related QA/QC Information
NASSCO CIPP Inspector Training Course
Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains
**Required Rate of "as-built" post-construction QA/QC sampling:**
1.00samples/batch
**QA/QC Confidence Rate:**
unknown
**Maintenance Considerations:**
Maintenance personnel must be trained to know what jetter pressures and what cleaning equipment can be safely used inside of CIPP without damaging it. Training is also advised regarding making new connections and point repairs on a pipe that has been lined with CIPP. As significant differences exist between CIPP liner segment installations, performance prediction is more dependent upon line by line analysis, and requires detailed baseline data so that change over time can be appropriately measured.
**Operations and Maintenance, Standards, Specifications, and Guidance Documents:**
Search WATERiD for related O&M Information

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**Water type:**
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**Technology Type:**
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